MONITORING THE ABUNDANCE OF LAKE TROUT (Salvelinus namaycush) WITH INDEX NETTING

by

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A thesis submitted in conformity with the requirements for the degree of Master of Science Graduate Department of Zoology University of Toronto

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The catch-per-unit-effort (CUE) from index netting is commonly used as an index of abundance. Catchability, a proportionality parameter, relates the index of abundance (CUE) to the actual abundance of the population. Catchability was measured for a spring littoral index netting method used by the Ontario Ministry of Natural Resources to estimate the density of lake trout populations province-wide. The catchability of this method was modeled as a function of population density and lake size. Across lakes, catchability was found to decrease with density and increase with lake surface area. In one lake the catchability of lake trout in bottom-set gillnets was observed to be two-times higher in the spring compared to summer due to seasonal shifts in lake trout foraging and spatial distribution. Consequently, among-lake variation in catchability may be more pronounced in the summer due to differences in trophic structure making the interpretation of CUE more difficult.
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# TABLE OF CONTENTS

List of Tables vii

List of Figures viii

General Introduction 1

Chapter One: The habitat requirements of lake trout, *Salvelinus namaycush*, and implications for spatial distribution 3

Chapter Two: Measuring lake trout gillnet catchability

  Abstract 12

  2.1. Introduction 13

  2.2. Materials and Methods

    2.2.1. Model development 15

    2.2.2. Estimates of lake trout density 15

    2.2.3. Spring Littoral Index Netting 17

  2.3. Results

    2.3.1. CUE versus lake trout density 22

    2.3.2. Model improvement 22

    2.3.3. Parameter estimation 22

    2.3.4. Candidate variables not included in the catchability model 23

  2.4. Discussion

    2.4.1. Density-dependent catchability 31

    2.4.2. Lake size effect on catchability 32

    2.4.3. Conclusions 33

Chapter Three: Seasonal variation in lake trout gillnet catchability

  Abstract 35

  3.1. Introduction 36
3.2. Materials and Methods

3.2.1. Depth-stratified netting 39
3.2.2. Catch data analysis 40
3.2.3. Light and temperature profiles 41
3.2.4. Tracking studies 41
3.2.5. Analysis of tracking data 42
3.2.6. Diet composition 44
3.2.7. Bottom orientation 44

3.3. Results

3.3.1. Seasonal differences in CUE 47
3.3.2. Gear visibility 47
3.3.3. Movement 48

3.4. Discussion 62

General Conclusions 67
References 69
Appendix A: Spring Littoral Index Netting 74
LIST OF TABLES

Table 2.1: Mark recapture estimates of adult lake trout density (D) and 95% confidence limits (D_upper, D_low) in 5 Ontario Lakes. 18

Table 2.2: Lake trout density estimated from harvest data for 8 Ontario Lakes. Annual harvest and density refers to the segment of the population larger than the modal size of harvested fish (i.e. critical size). 19

Table 2.3: Spring Littoral Index Netting (SLIN) projects included in analysis. Data collected by the Ontario Ministry of Natural Resources. The number of net sets is represented by n. P and NP represent lake trout populations that are piscivorous and non-piscivorous, respectively. 20

Table 2.4: Results of SLIN projects for all lake trout caught (CUE_all) and for lake trout larger than the critical size (CUE). The number of net sets is represented by n, the standard error of CUE_all is represented by SE, and L represents the mean length of lake trout larger than the critical size caught. 21

Table 2.5: Summary of regression analyses. 25

Table 2.6: Parameters of the catchability model estimated from the log-log regression of CUE versus D and A. 26

Table 3.1: Transmissivity in the South Arm of Lake Opeongo in the spring and summer and results of a student's t-test 50

Table 3.2: Results of repeated-measures ANOVA testing for a seasonal change in lake trout swimming speed 51

Table 3.3: Results of repeated-measures ANOVA testing for a seasonal change in the short-term range of movement of adult lake trout 52

Table 3.4: Results of bottom-orientation study 53
LIST OF FIGURES

Figure 1.1: The vertical temperature gradient in Lake Opeongo, ON during the Spring and Summer, 2001. 5

Figure 1.2: The vertical oxygen gradient in Lake Opeongo, ON during the Spring and Summer, 2001. 7

Figure 2.1: The relationship between CUE and lake trout density (D) in 13 Ontario lakes. Dotted lines represent 95% confidence bands. \((\log_{10}\text{CUE} = -0.248 + 0.363\log_{10}D; r^2 = 0.29, F_{1,11} = 4.49, p = 0.058, n = 13; S\text{E}_{\text{est}} = 0.30)\) 27

Figure 2.2: A partial residual plot of the residuals from the log-log regression of CUE versus density (D) and lake size, measured as surface area (ha). 28

Figure 2.3: The relationship between CUE and lake trout density (D) for lakes 100-1000 ha. (open circles); 1000-10000 ha. (solid circles) and >10000 ha. (open squares). The predicted relationship is shown for 100 ha (-----), 1000 ha (- - -), and 10000 ha (__) lakes. \((\log_{10}\text{CUE} = -1.29 + 0.33\log_{10}A + 0.53\log_{10}; R^2 = 0.60, F_{2,10} = 7.58, p = 0.0099, n = 13; S\text{E}_{\text{est}} = 0.23)\). 29

Figure 2.4: The predicted relationship between CUE and lake trout density (D) for lakes 100 ha (-----), 1000 ha (- - -), and 10000 ha (__) in surface area. 30

Figure 2.5: The area potentially covered by 91.2 m gillnets (shown in gray) set at the shoreline of 100 ha and 1000 ha lakes (Scale 1 : 40000). 34

Figure 3.1: The South Arm of Lake Opeongo north of Englehart Island. Gridlines show 250 m² quadrats. Shading is progressively darker for deeper strata: 2-10 m, 10-20 m, 20-30 m, and 30+ m. 46

Figure 3.2: Distribution of catches (±SE) across depth strata in the spring and summer. Area of stratum is expressed as a proportion of the total surface area of the South Arm of Lake Opeongo, and was used to weight the CUE of each stratum in the stratified estimate of CUE. 54

Figure 3.3: Stratified estimate of the mean CUE (±SE) for Spring and Summer 55

Figure 3.4: Light levels (lux) associated with spring and summer gillnet samples conducted on Lake Opeongo. 56

Figure 3.5: Mean swimming speed (±SE) of tagged lake trout during the spring and summer. Data were square-root transformed 57

Figure 3.6: Maps generated from ARCVIEW of the locations recorded during the Spring (left) and Summer (right) for tracked fish 2335, A; 3579, B; 610, C; and 2236, D. Symbols correspond to distinct sampling periods conducted on different days 58

Figure 3.7: Mean short-term range of movement (±SE) during the spring and summer for tagged lake trout. 60
Figure 3.8: The proportions of cisco, A; warm water fishes, B; unidentified fishes, C; terrestrial insects, D; and aquatic insects, E; in the stomachs of adult lake trout (>450mm fork length) in the spring (I) (n=243) and summer (II) (n=348).
General Introduction

Lake trout (*Salvelinus namaycush*) are cold water fish indigenous to northern North America. They are widely distributed throughout Canada and northeastern United States, with the greatest number of lake trout populations occurring in Ontario (Scott and Crossman 1998). In addition to being a very popular game fish, lake trout are also subjected to harvesting pressure from commercial and subsistence fishing, making management of the resource imperative.

Fisheries management evaluates the impact of stresses on fish resources and aims to quantify the amount of the existing resource in order to maintain populations at a sustainable level (e.g. Lester and Dunlop 2000; Lester et al. 2001). In view of this goal, the Ontario Ministry of Natural Resources (OMNR) implemented Spring Littoral Index Netting (SLIN) as a method for assessing the status of lake trout populations in Ontario. SLIN is a low impact method that uses the catch from randomly placed gillnets in the littoral zone during the spring as an index of abundance. This method is intended as a tool for broad scale assessment of the lake trout resource in 2200 lakes across Ontario and has been widely adopted since the early 1990's. Yet, it remains to be shown how lake trout catches from SLIN are related to the actual lake-wide density of the population. This thesis describes the relationship between lake trout density and SLIN catch rates using data from a sample of lakes that were surveyed by the OMNR. In addition, it addresses the question of whether a summer sampling program might be more efficient than the proposed spring program.

Chapter One reviews the habitat requirements of lake trout and the factors governing the spatial distribution and movement of lake trout relative to gear used in index netting. Chapter Two aims to measure the catchability of the SLIN method, where catchability (q) is a proportionality parameter relating an index of abundance (CUE) to the actual lake-wide...
density. To measure catchability, I examine SLIN projects conducted on a subset of lakes where estimates of adult lake trout density have been obtained by other methods.

The date of thermal stratification imposes a short time window on a spring sampling period and constrains the number of lakes that can be sampled each year. The OMNR has recently proposed shifting to a summer index netting survey to allow more time for sampling. Chapter Three evaluates the impact of a seasonal change in the index-netting program. Depth-stratified netting was conducted on Lake Opeongo during the spring and summer 2000 and differences in CUE are used to make inferences about seasonal variation in lake trout gillnet catchability.
Chapter One

The habitat requirements of lake trout, *Salvelinus namaycush*, and implications for spatial distribution

1.1. INTRODUCTION

This thesis evaluates the use of index-netting surveys to obtain an index of adult lake trout abundance. The catch-per-unit-effort (CUE) of index-netting surveys is commonly used as an index of abundance. CUE is related to the density of the population (D) by a proportionality parameter termed catchability (q) (CUE = qD). Catchability is a function of the probability that a fish encounters the gear, the probability that the fish contacts the gear once encountered, and the probability that the gear retains the fish given that the fish has encountered and contacted the gear (Hamley 1975; Anderson 1998). The catchability of passive gear, for example gillnets, is largely determined by the behaviour of the target organism and its spatial distribution relative to the gear (Hubert 1996). Here, I examine the habitat requirements of lake trout (*Salvelinus namaycush*) as reported in the literature. An interaction of biotic and abiotic factors influences the spatial distribution and movement of lake trout, and so will also impact gillnet catchability.

1.2. ABIOTIC FACTORS

1.2.1. Temperature

Temperature is considered to be the most important factor influencing the distribution and movement of lake trout (Martin and Olver 1980). Lake trout prefer cold water, between 6-13°C, and are generally thought to be closely associated with the lake bottom (Martin and Olver 1980). An organism will ultimately gravitate towards and adjust its behaviour to remain near a temperature, defined by Fry (1947) as the final thermal preferendum (*in Christie and Regier 1988*). Laboratory studies indicate the final thermal preferendum of adult and juvenile lake trout falls within the range of 10.8 - 12.7°C (reviewed by Christie and
Lakes in the southern range of lake trout distribution become thermally stratified as the water warms in the late spring or early summer. The thermocline acts as a barrier to lake trout distribution during the summer months because temperatures above the thermocline are much higher than the temperature preferendum of lake trout (Martin and Olver 1980). Consequently, lake trout change their depth distribution between seasons and tend to aggregate in the colder deeper parts of a lake after thermal stratification (Scott and Crossman 1998; Martin and Olver 1980; Galligan 1962). Lake Opeongo, ON thermally stratifies in late spring and provides an example of the shift in the vertical temperature gradient between spring and summer (Figure 1.1).

Magnuson et al. (1979) reported that the temperature range at which an organism experiences optimal conditions for growth and metabolism is within ±2°C of their final temperature preferendum observed in the wild (reviewed by Christie and Regier 1988). Christie and Regier (1988) credit O'Connor et al. (1981) with the finding that lake trout experience optimal growth between 10-12°C, which corresponds well with the final thermal preferendum. The mean midsummer temperature distribution of adult lake trout in the field was found to be 9.5±1.1°C (95% C.I.) (reviewed by Evans et al. 1991). Therefore, on average, adult lake trout are able to occur within the temperature range required for optimal growth and metabolism even during the midsummer by altering their depth distribution.

The probability of a lake trout encountering passive gear depends not only on its spatial distribution, but also on its swimming speed (Gerritsen and Strickler 1977; Giguère et al. 1982). Gibson and Fry (1954) reported that in the lab lake trout reach maximum activity levels, measured as the highest steady swimming rate, between 15-17°C. Therefore, changes in the thermal distribution of lake trout will impact their swimming speed.
Figure 1.1: The vertical temperature gradient in Lake Opeongo, ON during the Spring and Summer, 2000.
1.2.2. Oxygen

Like temperature, there is also a seasonal shift in the vertical oxygen gradient in lakes. Oxygen concentrations generally decrease in the hypolimnion between the spring and summer due to the decomposition of accumulated organic matter on the lake bottom (Figure 1.2). Though oxygen is rarely limiting in Ontario lakes, oxygen can pose a problem for lake trout in small, shallow lakes or in lakes that are highly developed.

In general, lake trout become oxygen limited at concentrations of about 6-4 mg/L. The oxygen concentration at which lake trout begin to show an avoidance response, termed the upper response threshold, is estimated to be $5.8 \pm 0.5$ mg/L based on the distribution of adult lake trout in the wild (reviewed by Evans et al. 1991).

Sellers et al. (1998) reported that the concentration of dissolved oxygen was more important than temperature in explaining the distribution of lake trout in three small Canadian Shield lakes. The thermal habitat selected by lake trout was higher than expected and quite variable in these lakes, whereas 75-90% of the fish remained in waters with oxygen concentrations in excess of 6 mg/L. Sellers et al. (1998) concluded that lake trout could tolerate warmer waters provided there is sufficient dissolved oxygen.
Figure 1.2: The vertical oxygen gradient in Lake Opeongo, ON in the Spring and Summer, 2000.
1.3. **BIOTIC FACTORS**

1.3.1. **Lake trout movement and home range**

Lake trout have been described as “nomadic” and have been reported to travel extensively in large lakes especially in spring and fall, presumably in search of prey (Martin and Olver 1980). In theory, encounter probabilities are directly related to the distance traveled by a fish during the sampling period (Rudstam et al. 1984). Home range is defined as the “area over which an animal normally travels” (Gerking 1953). The probability of encounter is expected to increase with the home range of an individual, assuming home range is indicative of the short-term range of movement.

In the laboratory, the swimming speed of fish has been found to increase with body size (Bainbridge 1957). A comparison of freshwater fish species revealed home range size increases allometrically with body size (Minns 1995). Moreover, the exponent relating home range and body length was similar to the consumption exponent in fish growth equations, presumably because energy consumed for growth and metabolism is gathered within the home range (Minns 1995). Thus, the home range and short-term range of movement of lake trout may vary in response to consumption rates, and in turn, factors affecting consumption rates may impact the probability of lake trout encountering gillnets.

1.3.2. **Predator-prey interactions**

Planktivorous populations of lake trout in Algonquin Park, ON were found to have higher activity costs, associated with foraging, compared to their piscivorous counterparts (Pazzia 2000). In addition to prey type, prey availability is also expected to influence the feeding activity of lake trout. Borgström (1992) attributed an inverse relationship between gillnet catchability and the density of brown trout (*Salmo trutta*) to negative effects of density on food availability. Borgström (1992) concluded that as prey density decreased in response to a larger predator population, the swimming speed of predators decreased as a
result of lower energy return rates. Others have modeled the speed of a predator as a hump-shaped response to increases in prey densities (Johansson and Leonardsson 1997). Seasonal and lake-to-lake differences in prey type and availability are expected to impact encounter probabilities, though the effects on the foraging behaviour and speed of lake trout remain unclear.

Further, studies conducted by Sellers et al. (1998) and Galligan (1962) found that the spatial distribution of lake trout could be better explained by prey distribution than by temperature. The thermal habitats used by lake trout in both studies suggested lake trout are capable of utilizing a broader thermal range than previously thought. Galligan (1962) observed adult lake trout entering the warmer, shallower waters of Cayuga Lake to feed on highly abundant prey fish inshore. Sellers et al. (1998) hypothesized that lake trout in small lakes were observed to use waters warmer than those reported for large lakes because the presence of species that prey on or compete with lake trout limit their distribution in large lakes. McRae and Jackson (2001) reported a reduction in the abundance of littoral zone fish in lakes with smallmouth bass (Micropterus dolomieu). The presence of smallmouth bass, or other littoral zone predators, in a lake is expected to reduce the amount of prey available to lake trout in the shallow zone, thereby altering lake trout foraging activity and habitat use. Consequently, the availability of lake trout to passive gear set in the littoral zone may be influenced by the community structure of a lake.

1.3.3. Intra-specific interactions

Juvenile lake trout remain spatially segregated from adult conspecifics, presumably to avoid cannibalism (Evans et al. 1991). The mean midsummer depth distribution of juvenile lake trout in the wild was $38.8 \pm 11.5\text{m (95\%CI)}$ compared to $23.2 \pm 4.9\text{m}$ for adults (reviewed by Evans et al. 1991). Despite exhibiting the same temperature and oxygen preferences as adults in the laboratory, in the wild, juvenile lake trout are restricted to water
ranging between 3 - 7 °C and containing only 2-6 mg/L of oxygen during midsummer (Evans et al. 1991). In the presence of adults, juveniles sacrifice growth potential by occupying sub-optimal habitat with respect to temperature and oxygen to minimize predation by adults (Evans et al. 1991).

Low oxygen levels have been shown to limit the metabolic rate of lake trout (Gibson and Fry 1954). The swimming speed of a juvenile, and thus the rate of encounter with passive gear, will be limited if ambient oxygen levels are low enough to limit activity, causing juveniles to be underrepresented in gillnet catches.

The spatial segregation of juveniles and adult lake trout will have implications for gillnet catchability. A study performed by Casselman (1987) on Wildcat Lake, ON found that gillnets set at depths greater than 30 m caught only juvenile lake trout (< 24 cm). In contrast, only lake trout greater than 24 cm were found between 10 - 20 m in the midsummer (Casselman 1987 in Evans et al. 1991). The probability of encountering a lake trout of a given size is a function of the sampling depth. Adult lake trout will dominate catches when sampling shallower depths, whereas gear set deeper will be more likely to encounter small, juvenile lake trout.

The degree of spatial segregation between juveniles and adult lake trout may vary with lake differences in water clarity. During daytime sampling, Davis et al. (1997) found that the highest relative density of juvenile lake trout occurred at depths of 15-25 m. In contrast, at night the greatest density of juveniles was observed at depths as shallow as 5-10 m. This suggests that under low light conditions, when visibility is reduced, juvenile lake trout are able to utilize shallower waters despite the presence of adults. The depth distribution of juveniles relative to the adult distribution may depend on the light extinction in a lake.
1.4. CONCLUSIONS

The spatial distribution of lake trout is governed by a number of interacting abiotic and biotic factors. Vertical gradients of temperature and oxygen change seasonally and play an important role in the depth distribution of lake trout across seasons. Though, physiological requirements such as oxygen and temperature demands will determine the areas within a lake that are suitable lake trout habitat, biotic factors must also be considered. The movement and spatial distribution of lake trout, as observed in the wild, appear to be largely determined by ecological factors such as predator-prey interactions and intra-specific competition and therefore these will impact gillnet catchability. Seasonal changes in lake trout movement and spatial distribution are expected to introduce a seasonality component to gillnet catchability.
Chapter Two

Measuring lake trout gillnet catchability

ABSTRACT

Spring Littoral Index Netting (SLIN) has been implemented as a standard method for assessing the status of lake trout populations in Ontario lakes. SLIN uses the catch-per-unit-effort (CUE) of randomly placed gillnets as an index of lake trout abundance. CUE is related to the density (D) of a fish stock by the proportionality parameter, catchability (q) (CUE = q*D). In recognition that catchability may vary across lakes, the relationship between index netting CUE and density was analyzed for 13 lakes to validate SLIN as an index of abundance. Catchability was found to increase with lake surface area and decrease with lake trout density. Therefore, catchability (q) has been modeled as a function of both density (D) and surface area (A): q = 0.51*D^{-0.47}*A^{0.33}. This model provides a tool for interpreting index netting CUE data, taking into account among-lake variation in SLIN catchability.
2.1. INTRODUCTION

The Ontario Ministry of Natural Resources (OMNR) implemented Spring Littoral Index Netting (SLIN) in the early 1990’s as a standard method for assessing the abundance of lake trout in Ontario lakes (Lester et al., 1991). SLIN employs short duration sets (90 minutes) of small mesh gillnet (38, 51. 64 mm) randomly placed in the littoral zone of lakes during the spring prior to thermal stratification (See Appendix A for details). Because lake trout are usually entangled, not wedged, by this gear, the method avoids unnecessary killing of fish and thus reduces the impact of sampling. Furthermore, since gear effectively samples a broad size range of lake trout (roughly 250 - 900 mm), all lake trout lakes can be sampled effectively by the same method in spite of large variation in the growth characteristics of lake trout populations.

Although SLIN has been widely adopted in Ontario, it remains to be shown that lake trout catch rates are related to lake trout abundance. Here, the relationship between index netting CUE and density is examined using data from a subset of lakes where lake trout density has been estimated by other methods. The goal of this Chapter is to identify factors affecting the relationship between CUE and lake trout density and to measure the catchability of the SLIN index netting method.

Catchability (q) is a proportionality parameter that relates an index of fish abundance to the actual lake-wide density (D). SLIN uses the mean catch-per-unit-effort (CUE) of lake trout as an index of abundance. Therefore, by definition, CUE should relate to lake trout density (D) as:

\[ \text{CUE} = q \times D \]

(1)

If catchability is constant across lakes, then CUE will be directly proportional to the lake-wide density of lake trout and a simple regression through the origin will provide an estimate of index netting catchability. However, it is necessary to recognize that catchability may vary among lakes and that a linear relationship between CUE and density may not hold.
It must be acknowledged that catchability may vary with fish density. Paloheimo and Dickie (1964) first hypothesized that the catchability of commercial fisheries is density-dependent due to abundance related changes in the geographic range of a fish stock. Thereafter, the catchability of commercial and sport fisheries has been found to vary inversely with fish stock abundance (Peterman and Steer 1981; Winters and Wheeler 1985; Crecco and Overholtz 1990; Swain and Sinclair 1994; Shuter et al. 1998; Rose and Kulka 1999). Commercial and sport fishermen employ non-random search behaviour and allocate effort to maximize catch rates. Therefore, fishing effort is targeted at areas with high local densities and previous fishing success (Paloheimo and Dickie 1964; Hilborn 1985; Gillis et al. 1993). Large reductions in fish abundance can occur without substantially affecting the density of fish in the preferred habitat because of abundance related changes in habitat selection (reviewed by MacCall 1990). Since commercial fishing effort is concentrated on the preferred habitat of target species catch rates remain high despite global reductions in fish density.

The catchability of index netting is not expected to be density-dependent because net sets are spatially randomized. However, SLIN only allocates netting effort to the littoral zone, the preferred habitat of lake trout in the spring. In addition, index-fishing surveys are subject to gear saturation (Hansen et al. 1998), in which gear efficiency decreases due to the presence of fish already captured in the net (Hamley 1975). Gear saturation has been found to result in density-dependent catchability in experimental gillnet catches (Henderson et al. 1983; Minns and Hurley 1988). Therefore, it is necessary to consider that the catchability of lake trout in the SLIN survey may be density-dependent.

Next, catchability may vary among lakes in response to lake-specific factors affecting the probability of encountering and contacting index netting gear. The possible influence of lake-specific variables, including lake trout size, water clarity, lake trophic structure and lake surface area, on the relationship between CUE and density were explored.
2.2. METHODS

2.2.1. Model development

To account for possible density-dependence in SLIN catchability, catchability (q) is modeled as a function of the lake-wide density of lake trout (D):

\[ q = aD^b; \]

where \( a \) and \( b \) are parameters to be estimated. Substituting this model of \( q \) into Equation 1, and isolating for CUE yields:

\[ CUE = aD^{(1+b)} \]

Linearizing this function yields:

\[ \log_{10}CUE = \log_{10}a + (1+b)\log_{10}D \]

These parameters must be estimated to measure catchability and develop a model to predict lake trout density from CUE data of SLIN surveys. To do this, CUE data from SLIN surveys on 13 lakes with known lake trout densities were analyzed.

2.2.2. Estimates of lake trout density

Hereafter, stock abundance is expressed in terms of density, the number of individuals in a population relative to the surface area of the lake. Estimates of lake trout density were available for 13 lakes where SLIN surveys have been conducted by the OMNR. In some cases, a density estimate for a lake was not available for the same year SLIN was conducted but was obtained within several years of the SLIN surveys. This can be done for lake trout populations since there is little inter-annual variation in lake trout abundance and exploitation rates (Shuter et al. 1998).

Density estimates came from two sources: mark-recapture studies and harvest data. Mark-recapture studies supplied estimates of lake trout abundance in 5 lakes (Table 2.1). These studies applied tags to lake trout captured on the spawning shoals during the fall. Tagged fish were later recaptured either by anglers during the next fishing season or by
netting on spawning shoals during the next fall. The proportion of individuals recaptured relative to the total catch is used to estimate abundance according to the adjusted Peterson method described in Ricker (1975, p.78). Since these studies estimate the abundance of the mature portion of the population, they must be compared with SLIN catches of mature fish to estimate the catchability of SLIN. The reported length at first maturity was therefore used as a critical (i.e. minimum) length when calculating SLIN CUE for each lake.

The remaining 8 estimates of lake trout density were obtained from harvest data (Table 2.2). The density of lake trout can also be estimated from harvest data (Table 2.2). Given an estimate of the annual harvest (H, #/ha) and the fishing mortality rate (F, yr⁻¹), average lake trout density (D, #/ha) can be calculated as (Ricker 1975, p.13):

\[ D = \frac{H}{F} \]  

Creel surveys conducted by the OMNR supplied estimates of annual harvest on these lakes (Table 2.2). Fishing mortality rate was calculated as:

\[ F = Z - M \]

where Z (yr⁻¹), total mortality rate, was estimated from catch-at-age data (Robson and Chapman 1961) and M (yr⁻¹), natural mortality rate, was calculated using Shuter et al.'s (1998) adaptation of Pauly's (1980) empirical formula which is based on von Bertalanffy growth parameters and an annual average water temperature of 6°C:

\[ M = 2.054 \cdot \exp(0.655 \cdot T - 0.933) \]  

Harvest and mortality estimates were obtained for the segment of the population that was fully recruited into the fishery by using the modal size of fish in the harvest as a critical length (see Table 2.2). The same critical length was therefore used when comparing SLIN catch rates to lake trout density in order to estimate the catchability of SLIN. Density estimates obtained from harvest data for Dickey and Flack Lakes were taken from Shuter et
al. (1998). The critical length for these density estimates was the observed length at 50% vulnerability, supplied by Shuter et al. (1998).

2.2.3. Spring littoral index netting

The Ontario Ministry of Natural Resources (OMNR) conducted SLIN surveys on the 13 lakes for which lake trout density estimates were obtained (Table 2.3). For each survey, the CUE (#/set) was calculated for lake trout larger than the critical size for which density estimates were calculated (Table 2.4). For lakes surveyed in several years, the mean CUE was then calculated. In addition, the mean length of lake trout larger than the critical size for each lake was computed. This resulted in a data set of 13 lakes with estimates of lake trout density, SLIN CUE, and SLIN mean length for lake trout that exceeded a critical length. Regression analysis was then done to describe the relationship between SLIN CUE and lake trout density.
Table 2.1: Mark recapture estimates of adult lake trout density (D) and 95% confidence limits ($D_{low}$, $D_{upper}$) in 5 Ontario Lakes.

<table>
<thead>
<tr>
<th>Lake</th>
<th>Surface area (ha)</th>
<th>Critical size (mm)</th>
<th>Year</th>
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<th>$D_{low}$ (#/ha)</th>
<th>$D_{upper}$ (#/ha)</th>
<th>D (#/ha)</th>
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Table 2.2: Lake trout density estimated from harvest data for 8 Ontario Lakes. Annual harvest and density refer to the segment of the population larger than the modal size of harvested fish (i.e. critical size).

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<th>Lake</th>
<th>Surface area (ha)</th>
<th>Critical size (mm)</th>
<th>Critical size source</th>
<th>Harvest source</th>
<th>Z (yr⁻¹)</th>
<th>M (yr⁻¹)</th>
<th>F (yr⁻¹)</th>
<th>D (#/ha)</th>
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<td>347*</td>
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<td>L-c50, Shuter et al.</td>
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<td>0.66</td>
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<td>310</td>
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<td>0.94</td>
<td>0.22</td>
<td>0.72</td>
</tr>
</tbody>
</table>

* from Shuter et al. 1998;
** Z estimated using the ML method outlined in Lester et al. (1991)
Table 2.3: Spring Littoral Index Netting (SLIN) projects included in analysis. Data collected by the Ontario Ministry of Natural Resources. The number of net sets is represented by $n$, $P$ and $NP$ represent lake trout populations that are piscivorous and non-piscivorous, respectively.

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<th>Longitude</th>
<th>Year</th>
<th>Start date</th>
<th>End date</th>
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<th>Secchi base (m)</th>
<th>Prey</th>
<th>$n$</th>
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Table 2.4: Results of SLiN projects for all lake trout caught (CUE_all) and for lake trout larger than the critical size (CUE). The number of net sets is represented by \( n \), the standard error of CUE_all is represented by SE, and \( L \) represents the mean length of lake trout larger than the critical size caught.

<table>
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<th>Lake</th>
<th>Year</th>
<th>( n )</th>
<th>CUE_all (#/set)</th>
<th>SE</th>
<th>Critical size (#/set)</th>
<th>Proportion &gt; critical size</th>
<th>CUE (#/set)</th>
<th>D (#/ha)</th>
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<td></td>
<td>1994</td>
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<td>1.11</td>
<td>0.22</td>
<td>354</td>
<td>0.86</td>
<td>0.95</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>mean</td>
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<td></td>
<td></td>
<td>1.05</td>
<td></td>
<td>10.05</td>
<td>428</td>
<td></td>
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<tr>
<td>Timberwolf</td>
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<td>0.12</td>
<td>480</td>
<td>0.29</td>
<td>0.22</td>
<td>0.69</td>
<td>527</td>
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<tr>
<td>Twelvemile</td>
<td>1995</td>
<td>83</td>
<td>0.27</td>
<td>0.07</td>
<td>435</td>
<td>0.55</td>
<td>0.15</td>
<td>0.37</td>
<td>554</td>
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</table>
2.3. RESULTS

2.3.1. CUE versus lake trout density

Lake trout CUE was found to increase non-linearly with lake trout density (D) (Figure 2.1). A log-log regression analysis \( r^2 = 0.29, F_{1,11} = 4.49, p = 0.058, n = 13; \) SEest = 0.30; Figure 2.1) of the relationship between CUE (range: 0.15 - 2.88 #/set) and lake trout density (D, range: 0.29 - 11.10 #/ha) generated the following equation:

\[
\log_{10} \text{CUE} = -0.248 + 0.363 \log_{10} D;
\]

The fitted equation explains only 29% of the variation. Partial residual plots examined whether the model could be improved by incorporating additional regressor variables hypothesized to affect catchability.

2.3.2. Model improvement

A partial residual plot indicated a strong positive trend between the logarithm of lake surface area (A, (ha)) and the residuals of the log-log regression of CUE versus D (Figure 2.2) indicating that the model can be improved by incorporating lake size (A) (Montgomery and Peck 1992). Therefore, catchability may be modeled more accurately as:

\[
q = a^*D^b^*A^c;
\]

where (a), (b), and (c) are parameters to be estimated.

2.3.3. Parameter estimation

A log-log regression \( R^2 = 0.60, F_{2,10} = 7.58, p = 0.0099, n = 13; \) SEest = 0.23; Figure 2.3) of CUE versus lake trout density (D) and lake size (A, range: 167-11907 ha) yields:

\[
\log_{10} \text{CUE} = -1.29 + 0.33 \log_{10} A + 0.53 \log_{10} D
\]

The model explains 60% of the variation and both variables contribute significantly to the model. A two-tailed student's t-test indicated that the regression coefficient for A was significantly different than 0 \( (t_{0.05(2,11)} = 2.8, p = 0.019) \) indicating a significant effect of lake
size on catchability. The regression coefficient for \( D (1 + b) \) was significantly < 1 \( (t_{0.05(1)} = -3.22, p = 0.008) \), and therefore, parameter \( b \) is significantly < 0. The regressor variables, density \( (D) \) and surface area \( (A) \) are not statistically independent since density \( (D) \) is the number of fish per unit of surface area \( (N/A) \). However, the equation obtained from the log-log regression of CUE versus lake trout abundance \( (N) \) and surface area \( (A) \) is the same as expected if the \( N/A \). A regression coefficients are rearranged to get the \( N, A \) regression coefficients (see Table 2.5 for a summary of regression analyses).

Substituting the parameters \( (a, b, \text{and } c) \) estimated from the log-log regression of CUE versus lake trout density \( (D) \) and lake size \( (A) \) (Table 2.6) into the basic CUE model (Equation 1) yields the following equation for estimating catchability \( (q) \):

\[
q = 0.051 D^{0.47} A^{0.33}
\]

Having measured catchability, substituting \( q \) into Equation 1 provides a model predicting the relationship between the index of abundance obtained from SLIN and the actual lake-wide density for lakes varying in size and density (Figure 2.4).

2.3.4. Candidate variables not included in the catchability model

Other variables considered to impact SLIN catchability were the mean length of lake trout caught in gillnets (mm) (Table 2.4), prey base (piscivorous or non-piscivorous), and secchi depth (m) (Table 2.3). The average swimming speed of a fish, and hence the distance traveled during the sampling period, is expected to vary allometrically with body length (Bainbridge 1957; Henderson and Wong 1991; Rudstam et al. 1984). Therefore, the probability of encountering randomly placed gillnets was expected to increase with body size (mean fork lengths 390 – 602 mm). Lake trout in non-piscivorous populations have higher foraging activity costs compared to piscivorous populations (Pazzia 2000) and so encounter rates were expected to be higher in non-piscivorous populations. Once gear is encountered, the probability that a fish will contact the gear is a function of water clarity so variation in
water clarity should affect index-netting catchability. However, the lakes in the current analysis did not range widely in secchi depth (10 of the 13 lakes ranged between 5 – 7 m), severely limiting an analysis of the effects of water clarity on contact probabilities. Partial residual plots indicated that there were no trends between any of these variables and the residuals of the log-log regression of CUE against D, and so were not included in the model.
Table 2.5: Summary of regression analyses.

<table>
<thead>
<tr>
<th>Regression</th>
<th>Fitted equation</th>
<th>$R^2$</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUE vs. D</td>
<td>( \log_{10} \text{CUE} = -0.248 + 0.363 \log_{10} \text{D} )</td>
<td>0.29</td>
<td>4.49</td>
<td>1.11</td>
<td>0.06</td>
<td>0.30</td>
</tr>
<tr>
<td>CUE vs. D, A</td>
<td>( \log_{10} \text{CUE} = -1.29 + 0.53 \log_{10} \text{D} + 0.33 \log_{10} \text{A} )</td>
<td>0.60</td>
<td>7.58</td>
<td>2.10</td>
<td>0.01</td>
<td>0.23</td>
</tr>
<tr>
<td>CUE vs. N, A</td>
<td>( \log_{10} \text{CUE} = -1.29 + 0.53 \log_{10} \text{N} - 0.20 \log_{10} \text{A} )</td>
<td>0.60</td>
<td>7.58</td>
<td>2.10</td>
<td>0.01</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Table 2.6: Parameters of the catchability model estimated from the log-log regression of CUE versus D and A.

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameters</th>
<th>Estimate</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>q = a<em>A^b</em>D^c</td>
<td>a</td>
<td>0.51</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>-0.47</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>0.33</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Figure 2.1: The relationship between CUE and lake trout density (D) in 13 Ontario lakes. Dotted lines represent 95% confidence bands.

\[ \log_{10}\text{CUE} = -0.248 + 0.363\log_{10}D; \quad r^2 = 0.29, \quad F_{1, 11} = 4.49, \quad p = 0.058, \quad n = 13; \quad SE_{\text{est}} = 0.30 \]
Figure 2.2: A partial residual plot of the residuals from the log-log regression of CUE versus density (D) and lake size, measured as surface area (ha).
Figure 2.3: The relationship between CUE and lake trout density (D) for lakes 100-1000 ha, (open circles); 1000-10000 ha, (solid circles) and >10000 ha, (open squares). The predicted relationship is shown for 100 ha (---), 1000 ha (--), and 10000 ha (—) lakes. (Bernard, BER; Dickey, DK; Flack, FL; Joseph, JO; Koshlong, KO; Louisa, LO; Muskoka, MUS; Opeongo, OP; Rosseau, RO; Smoke, SM; Squeers, SQ; Timberwolf, TIM; Twelvemile, TW.)

\[ \log_{10}\text{CUE} = -1.29 + 0.33 \log_{10} A + 0.53 \log_{10} D; \quad R^2 = 0.60, \quad F_{2,10} = 7.58, \quad p = 0.0099, \quad n = 13; \quad \text{SE}_{\text{est}} = 0.23 \]
Figure 2.4: The predicted relationship between CUE and lake trout density (D) for lakes 100 ha (---), 1000 ha (- - -), and 10000 ha (- - - -) in surface area.
2.4. DISCUSSION

2.4.1. Density-dependent catchability

CUE was found to increase with lake trout density validating SLIN as a method for obtaining an index of lake trout abundance. However, the relationship between CUE and density was non-linear indicating that the catchability of this method is density-dependent (Figure 2.4).

The negative exponent relating q to D (Equation 11) indicates that SLIN catchability increases as the lake-wide density decreases. It is unlikely that this effect is due to gear saturation since the maximum catch included in the analysis was an average of 2.88 lake trout in a 91.2 m gillnet set for 90 minutes. Since the netting effort is restricted to the littoral zone, and this is the preferred habitat of lake trout in the spring, the inverse relationship between density and catchability may be due to abundance related shifts in the spatial distribution of lake trout. As density in the preferred habitat increases, individuals begin to fill less preferred habitat in response to increased competition in the preferred habitat (reviewed in MacCall 1990). Bleeding of fish into the less preferred habitat results in the expansion of the geographic range of the population making one unit of effort less efficient because the area sampled by the gear is now smaller relative to area occupied by the total population (Palcheimo and Dickie, 1964). In the current study, if lower density lakes had a greater proportion of the population in the littoral zone, then sampling of the littoral zone would be more efficient in low-density lakes because it would sample a larger proportion of the population.

A density-dependent SLIN catchability coefficient is similar to the catchability of commercial and sport fisheries. Catchability was found to vary inversely with the abundance of Atlantic cod (Gadus morhua) (Swain and Sinclair 1994; Rose and Kulka 1999), Atlantic herring (Clupea harengus harengus) (Winters and Wheeler 1985), and haddock (Melanogrammus aeglefinus) (Crecco and Overholtz 1990) in commercial fisheries.
Similarly, angling catchability was found to vary inversely and non-linearly with stock abundance for Pacific salmon (*Oncorhynchus tshawytscha*) (Peterman and Steer 1981) and lake trout (Shuter et al. 1998). A reduction in the geographic range of the declining stock, coupled with the non-random search behaviour of commercial and sport fishermen, accounted for the observed density-dependent catchability. In SLIN, gillnets are set randomly throughout the littoral zone but restricting sampling to the littoral zone results in the catchability being affected by density-dependent changes in the spatial distribution of lake trout.

### 2.4.2. Lake size effect on catchability

The significant relationship between lake size and catchability implies that at a given lake-wide density, catchability is higher in large lakes relative to small lakes. Index netting might be more efficient in the littoral zone of large lakes if a greater proportion of the population occupies the littoral zone. Fish may bleed more readily into the offshore areas in small lakes since the littoral zone and offshore areas are closer together. Consequently, one unit of netting effort in the littoral zone of a large lake would be more efficient than in a small lake as it would sample a larger proportion of the lake trout population. Further, catchability may be greater in large lakes because netting effort is entirely confined to the preferred habitat in large lakes, whereas 91m nets span a larger proportion of the entire surface area of small lakes reducing the efficiency of the gear (Figure 2.5). Alternatively, catchability may covary with lake size because lake trout from large lakes reach greater sizes than those from small lakes (Shuter et al. 1998) enabling fish in these populations to swim greater distances during a net set, and increasing the probability of encountering gear (Bainbridge 1957; Henderson and Wong 1991; Rudstam et al. 1984).
2.4.3. Conclusions

This study is the first step towards understanding the relationship between the catches of lake trout in gillnets and the actual population density in lakes across Ontario. CUE was found to increase with increases in lake trout density validating SLIN as a method for obtaining an index of lake trout abundance. However, the relationship between CUE and density was non-linear indicating that the catchability of this method varies inversely with density. SLIN nets are set randomly throughout the littoral zone but limiting netting effort to the preferred habitat of lake trout in the spring makes the catch from this method susceptible to abundance related changes in the spatial distribution of the population. Consequently, the density of lake trout in the littoral zone may vary little across lakes despite differences in the lake-wide abundance of lake trout.

At a given density, lake trout catches are expected to approximately double with each ten-fold increase in lake size (Figure 2.4). For example, the index of abundance obtained from SLIN is predicted to be 0.8 and 1.8 fish/set for two lakes with surface areas of 500 and 5000 ha, respectively, though both have a lake trout density of 4 fish/ha. Gear would be more efficient in the littoral zone of large lakes than in small lakes if lake trout are more localized to the preferred habitat in large lakes. The littoral zone and offshore areas are closer together in small lakes and so fish may bleed into nearby habitats more readily.

The Ontario Ministry of Natural Resources has recently initiated lake-wide index netting surveys of lake trout populations. Winter and Wheeler (1985) recommend sampling the entire distributional range of a fish population in order to eliminate the effects of density-dependent habitat selection on catch rates. Lake-wide index netting will provide knowledge on the spatial distribution of lake trout in response to population abundance and thus will improve interpretation of the logistically simpler littoral surveys.
Figure 2.5: The area potentially covered by 91.2 m gillnets (shown in gray) set at the shoreline of 100 ha and 1000 ha lakes (Scale 1 : 40000).
Chapter Three

Seasonal variation in lake trout gillnet catchability

ABSTRACT

Traditionally, lake trout index-netting has been conducted during the spring. The spring sampling window is limited by the date of thermal stratification, whereas a summer index of abundance would allow time for more extensive sampling. A depth-stratified gillnetting survey was conducted on Lake Opeongo, ON during the spring and summer in 2000. The stratified estimate of the mean catch-per-unit-effort (CUE) was used to infer an effect of season on lake trout gillnet catchability. Spring catchability was found to be greater than summer catchability by a factor of 2. Seasonal differences in lake trout movement and gear visibility were not responsible for the observed difference in gillnet catchability. The reduction in catchability is most likely due to a decrease in the probability of encountering bottom-set gillnets resulting from changes in the bottom orientation of lake trout in response to changes in feeding: adult lake trout in Lake Opeongo were observed to switch from a diet of littoral organisms in the spring to a diet dominated by a pelagic prey fish in the summer. Because seasonal differences in catchability in Lake Opeongo are largely due to predator-prey interactions, this change may not be consistent for index netting conducted on other lakes differing in trophic structure.
3.1. INTRODUCTION

The Ontario Ministry of Natural Resources (OMNR) has recommended Spring Littoral Index Netting (SLIN) as a method for assessing the status of lake trout (*Salvelinus namaycush*) populations in Ontario lakes (Lester et al. 1991). SLIN uses the mean catch from bottom-set gillnets in the littoral zone during the spring as an index of lake trout abundance. The mean catch per unit of effort (CUE) is related to the density of the population (D) by the proportionality parameter, catchability (q) (CUE = q*D).

One problem with a spring index of lake trout abundance is that it offers a very short period of time when surveys can be conducted. The protocol requests conducting several days of sampling after ice-out and before surface temperatures reach 13°C. On most lakes this results in a sampling window of only a few weeks each year. This short window constrains the number of net sets that can be conducted on a lake and limits the number of lakes which can be sampled in a year. Currently, the OMNR is considering implementing a summer index-netting program as an alternative to the traditional spring protocol. The date of thermal stratification imposes a short sampling window on a spring index program. Changing to a summer protocol would allow more time for sampling and would increase the number of lakes that can be surveyed in a year.

This chapter evaluates the effect of changing the standard index netting protocol from a spring to a summer sampling period. Specifically, this Chapter aims to measure the seasonal differences in lake trout gillnet catchability. Depth-stratified gillnet sampling was conducted on Lake Opeongo, ON during both spring and summer, and differences in adult lake trout CUE were examined. Depth-stratified netting was used to account for seasonal changes in lake trout spatial distribution. Lake trout are cold water fish, preferring 10-12°C, and consequently, must modify their depth distribution when the thermocline forms in late spring. As a result, the density in the warmer, shallower strata is expected to decrease while the density in the colder, deeper strata should increase. However, the overall stratified
CUE is expected to remain the same assuming the change in the benthic density of adult lake trout is negligible and that catchability is constant between seasons.

Catchability depends on the probability that a fish encounters the gear \((P_E)\), the probability of contact after encounter \((P_C)\), and the probability that the gear retains the fish given that it has both encountered and contacted the gear \((P_R)\) (Hamley 1975; Anderson 1998). Therefore, the expected CUE is:

\[
CUE = P_E \cdot P_C \cdot P_R \cdot D
\]

where \(D\) is lake trout density \((#/ha)\). Seasonal variation in any of these probabilities will result in a change in CUE unrelated to density.

\(P_E\) is expected to increase proportional to the area sampled by the gear.

\[
P_E = bA_s \cdot P_B
\]

where \((b)\) is a proportionality constant, \(A_s\) is the surface area sampled by the gear \((m^2)\) and \(P_B\) is the probability that a fish within the area sampled \((A_s)\) is within the height of the bottom-set gillnet and therefore vulnerable to the gear. Unlike active gear, passive capture techniques do not enclose a specified geometric space and as a result it is difficult to measure the area sampled. Instead, the effective area sampled by passive gear depends on the movement of the target organism (Hayes et al. 1996). For active gear, the area sampled is calculated as the length of the gear, multiplied by the distance covered by the gear. The distance covered by the gear is a function of the duration of the sampling period and the speed of the gear. For passive gear, I assign the speed of the target organism to the gear velocity. Thus the area swept by one unit of passive gear can be modeled as:

\[
A_s = l \cdot v \cdot d
\]

where \(l\) is the length of the gear \((m)\), \(v\) is the velocity of an average adult lake trout toward the gear \((m/min)\), and \(d\) is the duration of the sample \((min)\). Substituting Equation 3 into Equation 2 yields this model for \(P_E\):
Accordingly, seasonal variation in lake trout movement (v), or position above lake bottom (P_b) will affect the rate of encounter.

For passive gear, the probability of encounter is expected to increase with the average swimming speed of the organism (Gerritsen and Strickler 1977, Giguère et al. 1982) and the distance traveled by the organism during the sampling period (Rudstam et al. 1984). Both swimming speed and the directional consistency of successive displacements will affect the distance traveled by an organism, and therefore, the probability of encountering randomly placed gillnets. For example, if the successive displacements of an individual are consistent in direction, the net displacement will be greater than an individual swimming in various directions. In this Chapter, I measure both the swimming speed and the short-term range of movement of adult lake trout from tracking studies conducted during the spring and summer. Tracking studies were also used to test for a seasonal difference in P_b since the catching height of the gear and the vertical range of a fish will limit encounter probabilities.

Seasonal changes in the depth distribution of lake trout implies the daytime habitat of lake trout is darker during the summer. Consequently, the gear may be less visible and fish may be less able to avoid capture. In terms of the model presented here, this factor is accounted for by a change in P_c, the probability that a fish contacts the gear once encountered. It is hypothesized that seasonal changes in the depth of capture, possibly coupled with seasonal differences in light attenuation affect gear visibility and in turn, impact P_c.

The probability of retention (P_R) is a function of the gear and so is not expected to change because the same gear is used in each season. Therefore, any change in CUE with season will suggest a seasonal change in the probabilities of encounter and contact.
3.2. MATERIALS AND METHODS

3.2.1. Depth-stratified netting

To determine whether catchability changes seasonally within a lake, depth-stratified gillnet sampling was conducted in the South Arm of Lake Opeongo, ON (45°42'N, 78°22'W) during the spring and summer, 2000. Lake Opeongo is a large (5860ha), oligotrophic lake situated at the south east corner of Algonquin Park, Ontario and is comprised of three main basins, the South, North and East Arms. The area of the South Arm north of Englehart Island was divided into 250m² quadrats (Figure 3.1). Each quadrat was assigned to a depth stratum based on the depth at the centre of the quadrat. Four depth strata were created; 2-10m, 10-20m, 20-30m, and 30m+. Twenty sites were chosen randomly with replacement from each stratum. Depth strata were sampled equally in both seasons to account for seasonal differences in lake trout spatial distribution. Three blue-silver, monofilament gillnets with mesh sizes of 38mm, 51mm, and 64mm were utilized an equal number of times, in accordance with the SL1N protocol. Each gillnet comprised of 6 panels (length=15.2m, height=2.4m) totaling 91.2m in length. All netting was performed during the daytime between 08:00 and 17:00. Spring netting occurred between May 4 and May 27, 2000, prior to thermal stratification. Summer netting was conducted between July 14 and August 18, 2000, well after the thermocline was developed. Gillnets were set for 90 minutes on bottom and oriented perpendicular to the depth contour except at some of the 30+ m sites where orientation was not controlled. All fish caught were identified to species and total and fork lengths were measured. Fish were released promptly, but during the summer, some fish were noticeably stressed by the capture and were held in a tank filled with cold lake water (<14°C) pumped up from below the thermocline before being returned to the lake.
3.2.2. Catch data analysis

The mean catch-per-unit-effort for each depth stratum (CUE<sub>h</sub>) was calculated for spring and summer sampling. For each season, the stratified estimate of CUE was calculated as:

\[ \text{CUE} = \sum W_h \text{CUE}_h, \]

where \( W_h \) is the relative area of depth stratum \( h \) and \( \text{CUE}_h \) is the catch rate in depth stratum \( h \). The stratified CUE was used to make inference about lake trout catchability assuming the population density within the South Arm remained constant between spring and summer.

The most likely cause for violation of this assumption is the emigration of adult lake trout from the South Arm of Lake Opeongo into adjacent basins. Netting data conducted from early spring through to late spring (post-thermal stratification) on all three basins of Opeongo in 1995 validated this assumption. A decrease in the CUE of the South Arm concomitant with an increase in the CUE in the North or East Arms, which would indicate emigration of adult lake trout from the South Arm into other basins, was not observed. Further, tracking studies indicate that lake trout rarely migrate between the basins of Opeongo (Lori Flavelle, Department of Zoology, University of Waterloo, personal communication). Once the thermocline forms in late spring, lake trout are restricted within a basin by the high temperatures in the shallow narrows between basins.

Alternatively, this assumption would be invalid if angling significantly alters lake trout abundance between spring and summer. The exploitation rate in Lake Opeongo is estimated to be 18% on Opeongo (Shuter et al. 1998), and only a portion of that occurs between the spring and summer. Therefore, the assumption that the lake trout density within the South Arm remained constant between spring and summer is considered
reasonable and differences in CUE can be used to infer a seasonal effect on lake trout gillnet catchability.

3.2.3. Light and temperature profiles

To test for a seasonal difference in light attenuation, light profiles were taken several times throughout the spring and summer in the South Arm with a LI-COR photometer lowered at 0.5 m or 1m intervals. Light recordings at each depth were adjusted for changes in surface light intensity during profile measurements. In addition, four HOBO LI Intensity Meters were placed on a small, unvegetated island in the centre of the South Arm, where they collected surface light intensity readings at 15-minute intervals throughout the study. A Hydrolab multisensor probe was used to take temperature and oxygen profiles throughout the study. Oxygen profiles showed that concentrations were never limiting in Lake Opeongo, so this parameter is not discussed further.

3.2.4. Tracking studies

Sonic transmitters (Sonotronics, Tuscon, AZ, USA) were surgically implanted into adult lake trout (465 - 770mm FLEN) during the spring of 1999 and 2000. The weight of the transmitter was <2% of the body weight to minimize the impact of the tag on the physiology and swimming behaviour of the fish (Adams et al. 1998). Lake trout were caught by short-set gillnets and were anaesthetized in a clove oil solution until the fish lost their righting reflex (Summerfelt and Smith, 1990). Once anaesthetized, each fish was placed onto a V-shaped trough while the skin was kept moist and the gills were perfused with oxygenated water and anaesthetic solution via a water-recirculation pump (Summerfelt and Smith, 1990). Surgical instruments and transmitters were cleaned with ethanol before making an inch-long incision and inserting the transmitter between the skin and the abdominal wall of
the fish. The incision was sutured with stitches or surgical staples and the fish was allowed to recover in fresh lake water until the righting reflex was regained. The entire procedure, including recovery, took approximately 8 minutes.

To compare the movement of lake trout between spring and summer, six individuals were tracked in each season; four individuals were common to both seasons. Individuals were tracked during daylight hours between 07:30 and 17:30, conforming to the index netting protocol. Sampling days were divided into four periods: 07:30-09:30, 10:00-12:00, 12:30-14:30, and 15:00-17:00. These periods were designed to be similar in duration to an index-netting sampling period and were employed to provide information on the short-term range of movement and linear displacement rates of individuals during a typical net set. Individuals were tracked during only one sampling period per day to minimize day-specific effects (wind, weather, etc.) on the estimated overall seasonal activity of an individual.

During each sampling period the position of the fish was recorded at 5-8 minute intervals (25th and 75th percentiles) using the ground-zero method of tracking outlined by Nelson (1986). The ground-zero method involves positioning the boat directly above the tagged fish using a directional hydrophone (model DH-4 ©Sonotronics) connected to an ultrasonic receiver (model USR-5W ©Sonotronics). The position was recorded when the signal strength was strongest in the vertical direction or of equal strength in all horizontal directions (Nelson 1986). Individual fish were recognized by unique pulse codes associated with each transmitter.

3.2.5. Analysis of tracking data

To determine seasonal changes in lake trout movement, tracking data were used to calculate both the swimming speed (FLEN/min) and the short-term range of movement (ha) of tagged individuals. Multiple comparisons warranted a Bonferroni correction to maintain
an experimental-wide type-one error rate of 0.05. Thus seasonal differences in lake trout swimming speed and short-term range of movement were tested with a comparison-wise type-one error rate of $0.05/2 = 0.025$.

**Swimming speed**

To determine the linear displacement rate of lake trout, hereafter referred to as “swimming speed”, distances between observations were measured, divided by the time between observations, and expressed in forklengths/min. The distance between x-y coordinates was calculated using the formula from White and Garrott (1990):

\[
d_i = \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}
\]

where $x_i$ and $y_i$ denote position at time $i$. The mean swimming speed was calculated for each sampling period and used in statistical analysis.

To test for a seasonal effect on lake trout swimming speed, a repeated-measures ANOVA was performed. The three-factorial design included season and time of day as fixed effects and individual as a random effect. This test was chosen because individuals were subjected to four sampling periods in both seasons to detect seasonal effects on movement. Additionally, the power of the ANOVA is improved because all sources of inter-individual variation are excluded from the F test. (Sokal and Rohlff 1969). Swimming speed data were square-root transformed prior to analysis to make residuals homogeneous and normally distributed.

**Short-term range of movement**

Short-term range of movement (ha) was calculated to provide a two-dimensional measure of lake trout movement. To determine the short-term range of movement of individuals during the sampling period, a spider analysis was performed using the Animal Movement extension of ArcView 3.1 (ESRI Software, Redlands, CA). The spider analysis calculates the distance from all observed locations to a central point, determined as the arithmetic mean of the $(x, y)$ coordinates. The minimum and maximum distance of the
locations from this central point were then assigned as the primary and secondary radii of an ellipse whose area was used to represent the short-term range of movement.

The Minimum Convex Polygon (MCP) and the Jennrich-Turner models were also considered. The MCP method is sensitive to small sample sizes and is not appropriate for comparing data sets with unequal numbers of observations (White and Garrott, 1990). The Jennrich-Turner method is less sensitive to sample size but calculates an ellipse describing the area that an animal *normally* uses, with an associated probability (White and Garrott, 1990). These models are typically used for home range analysis and did not suit the objectives of this study, which was to estimate the *actual* area covered by the organism in the short-term. Further, the method chosen for this study minimized the effects of unequal numbers of observations on the area traversed during a sampling period.

A repeated-measures ANOVA was performed to test for a seasonal effect on the short-term range of movement, with season, sampling period, and individual as factors. Area data did not require a transformation, as residuals were normal and homogeneous.

### 3.2.6. Diet composition

A Creel Survey performed on Lake Opeongo during the spring and summer of 1999 provided stomach content data for adult lake trout caught by anglers. Stomach contents were used to infer seasonal differences in the foraging habitats of lake trout.

### 3.2.7. Bottom orientation

The distance of tagged individuals above the lake bottom, hereafter referred to as "bottom orientation" was determined during the summer tracking period. The pulse interval of the transmitter signal corresponds to the temperature of the transmitter and hence, the tagged organism. The depth of the organism during each observation was estimated from its temperature, as indicated by the pulse interval of the tag, and the depth associated with that
temperature determined from the average summer temperature profile of Lake Opeongo. The bottom orientation of the lake trout could then be calculated as the difference between the site depth, measured by a ©Garmin echo sounder, and the inferred depth of the fish. The resolution of the temperature data obtained from the pulse interval of the transmitters, as well as using the average summer temperature profile of Lake Opeongo limits this analysis. Below the thermocline (15 - 40 m), the slope of the line relating depth to temperature is very steep (Figure 1.1), indicating that even small deviations in temperature will produce large fluctuations in the estimate of depth. Therefore, depth information from the temperature of the transmitters are secondary to the depth distribution of lake trout inferred from diet composition data.

Bottom orientation data were available from daily fixes tracking, when an individual is located once per day, and from continuous tracking, when observations are taken continuously over a 1-2 hour period. The bottom orientation determined from daily fixes tracking suggest lake trout are closer to the lake bottom than do the measurements from continuous tracking. A transmitter implanted in a lake trout (fork length ≥ 45cm) was found to require 40-60 minutes to equilibrate following a 2°C and 5°C change in temperature (John Gunn, Ontario Ministry of Natural Resources, Sudbury, ON, unpublished data). Therefore, bottom orientation data from continuous tracking are presented since observations collected over a 1-2 hour period should provide a good average of the true bottom orientation of an individual.
Figure 3.1: The South Arm of Lake Opeongo north of Englehart Island. Gridlines show 250 m² quadrats. Shading is progressively darker for deeper strata: 2-10 m, 10-20 m, 20-30 m, and 30+ m.
3.3. RESULTS

3.3.1. Seasonal differences in CUE

Seasonal changes in the CUE at each depth stratum illustrate the changes in the spatial distribution of adult lake trout (Figure 3.2). In the spring, the highest catches of adult lake trout occur in the shallow stratum, 2-10m. During summer netting lake trout catches are greatest at 20-30m and least in the shallow stratum.

Overall, the stratified CUE in the spring was $1.13 \pm 0.28$ (SE) (adults/sample), approximately twice the stratified CUE in the summer, $0.57 \pm 0.12$ (SE) (adults/sample) (Figure 3.3). Assuming the change in adult lake trout density between seasons in the South Arm of Lake Opeongo is negligible, these results suggest spring catchability of adult lake trout in bottom-set gillnets is two times greater than summer catchability.

3.3.2. Gear visibility

Light profiles were compared to determine if seasonal differences in light attenuation exist. A two sample t-test indicated that transmissivity did not change between spring and summer ($t_6 = -1.18, p = 0.28$) (Table 3.1). Mean transmissivity, pooled across seasons, is 57.7% in the South Arm of Lake Opeongo. Since light attenuates similarly between seasons, spring and summer samples were conducted over the same light regime (Figure 3.4). Therefore, at a given depth, the probability of contact is not expected to change seasonally.

The probability of contact is expected to vary inversely with gear visibility and thus increase at reduced light intensity. On average, lake trout were caught at greater depths in the summer than in the spring; yet, reduced light intensity at the depth of capture did not result in greater catchability.
3.3.3. Movement

As Equation 4 outlines, both the horizontal movement and the bottom orientation of the target organism are expected to affect the probability of encountering passive gear. Therefore, both of these variables were estimated for spring and summer to determine whether the reduced catchability in the summer could be explained by seasonal changes in the movement of adult lake trout.

**Horizontal displacement**

The average swimming speed of individuals tracked (n = 4) was 13.0 FLEN/min (mean ± SE: 9.3 – 17.2 FLEN/min) in the spring and 19.1 FLEN/min (mean ± SE: 15.9 – 22.5 FLEN/min) in the summer. Lake trout did not exhibit a change in swimming speed in response to season (F₁,₃ = 2.51, comparison-wise p = 0.21, experimental-wise p = 0.42; Table 3.2; Figure 3.5). The small sample size limits the power of this analysis, however, there is not even a consistent trend in the direction of change in swimming speed with season across individuals.

The short-term range of movement of tagged individuals was consistently larger in the summer 10.0 ± 2.2 ha (mean ± SE) compared to spring 2.1 ± 1.1 ha (Figure 3.6, 3.7). However, the seasonal difference was non-significant after a Bonferroni correction (F₁,₃ = 11.74, comparison-wise p = 0.042, experimental-wise p = 0.084) (Table 3.3).

**Seasonal differences in diet composition and bottom orientation**

A chi-squared test indicated that the diet composition of adult lake trout differed significantly between spring and summer (X²₁ = 45.6, p < 0.0001) (Figure 3.8). One third of the spring diet is made up of terrestrial and aquatic insects associated with the littoral zone, but these food items make up only 6% of the summer diet. Instead, a pelagic prey species, the lake herring or cisco (Coregonus artedii), makes up more than half of the stomach contents of adult lake trout in the summer.
Moreover, bottom orientation data obtained during summer continuous tracking indicated that adult lake trout were above the catching surface of the nets (2.4m above lake bottom) in 80% of summer tracking observations (Table 3.4).
Table 3.1: Transmissivity in the South Arm of Lake Opeongo in the spring and summer and results of a student's t-test.

<table>
<thead>
<tr>
<th>Date</th>
<th>Transmissivity</th>
<th>Date</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/15/00</td>
<td>0.5254</td>
<td>06/14/00</td>
<td>0.5129</td>
</tr>
<tr>
<td>05/19/00</td>
<td>0.5603</td>
<td>07/10/00</td>
<td>0.6216</td>
</tr>
<tr>
<td>05/27/00</td>
<td>0.4812</td>
<td>07/19/00</td>
<td>0.5862</td>
</tr>
<tr>
<td>05/31/00</td>
<td>0.6228</td>
<td>07/25/00</td>
<td>0.7058</td>
</tr>
<tr>
<td>Mean</td>
<td>0.5474</td>
<td></td>
<td>0.6066</td>
</tr>
<tr>
<td>Variance</td>
<td>0.0036</td>
<td></td>
<td>0.0064</td>
</tr>
<tr>
<td>DF</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t_{stat}$</td>
<td>-1.184</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t_{critical}$ (0.05/2)</td>
<td>2.447</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p$</td>
<td>0.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled Mean Transmissivity</td>
<td>0.5770</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2: Results of repeated-measures ANOVA testing for a seasonal change in lake trout swimming speed.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season</td>
<td>1</td>
<td>4.82</td>
<td>4.82</td>
<td>F_{1,3} = 2.51</td>
<td>0.21</td>
</tr>
<tr>
<td>Time</td>
<td>3</td>
<td>0.47</td>
<td>0.16</td>
<td>F_{3,9} = 0.18</td>
<td>0.91</td>
</tr>
<tr>
<td>Fish</td>
<td>3</td>
<td>15.04</td>
<td>5.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season*Time</td>
<td>3</td>
<td>0.78</td>
<td>0.26</td>
<td>F_{3,9} = 0.26</td>
<td>0.85</td>
</tr>
<tr>
<td>Season*Fish</td>
<td>3</td>
<td>5.77</td>
<td>1.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time*Fish</td>
<td>9</td>
<td>7.87</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season<em>Time</em>Fish</td>
<td>9</td>
<td>8.97</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>43.73</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.3: Results of repeated-measures ANOVA testing for a seasonal change in the short-term range of movement of adult lake trout.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season</td>
<td>1</td>
<td>494.24</td>
<td>494.24</td>
<td>$F_{1,3} = 11.74$</td>
<td>0.042</td>
</tr>
<tr>
<td>Time</td>
<td>3</td>
<td>165.14</td>
<td>55.05</td>
<td>$F_{3,39} = 0.25$</td>
<td>0.859</td>
</tr>
<tr>
<td>Fish</td>
<td>3</td>
<td>159.24</td>
<td>53.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season*Time</td>
<td>3</td>
<td>178.87</td>
<td>59.62</td>
<td>$F_{3,39} = 0.25$</td>
<td>0.859</td>
</tr>
<tr>
<td>Season*Fish</td>
<td>3</td>
<td>126.33</td>
<td>42.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time*Fish</td>
<td>9</td>
<td>1957.44</td>
<td>217.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season<em>Time</em>Fish</td>
<td>9</td>
<td>2150.70</td>
<td>238.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3.4: Results of bottom orientation study.

<table>
<thead>
<tr>
<th>Fish n</th>
<th>Observations</th>
<th>Proportion of total observations</th>
<th>Mean distance above lake bottom (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>279</td>
<td>10</td>
<td>9</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>18</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>22</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>15</td>
<td>0.88</td>
</tr>
<tr>
<td>365</td>
<td>19</td>
<td>2</td>
<td>0.11</td>
</tr>
<tr>
<td>610</td>
<td>16</td>
<td>13</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>15</td>
<td>0.94</td>
</tr>
<tr>
<td>2236</td>
<td>15</td>
<td>15</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>22</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>13</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>MEAN</strong></td>
<td></td>
<td><strong>0.81</strong></td>
<td><strong>6.89</strong></td>
</tr>
</tbody>
</table>
Figure 3.2: Distribution of catches (±SE) across depth strata in the spring and summer. Area of stratum is expressed as a proportion of the total surface area of the South Arm of Lake Opeongo, and was used to weight the CUE of each stratum in the stratified estimate of CUE.
Figure 3.3: Stratified estimate of the mean CUE (±SE) for Spring and Summer.
Figure 3.4: Light levels (lux) associated with spring and summer gillnet samples conducted on Lake Opeongo.
Figure 3.5: Mean swimming speed (±SE) of tagged lake trout during the spring and summer. Data were square-root transformed.
Figure 3.6: Maps generated from ARCVIEW of the locations recorded during the Spring (left) and Summer (right) for tracked fish 2335, A; 3579, B; 610, C; and 2236, D. Symbols correspond to distinct sampling periods conducted on different days.
Figure 3.6: Maps generated from ARCVIEW of the locations recorded during the Spring (left) and Summer (right) for tracked fish 2335, A; 3579, B; 610, C; and 2236, D. Symbols correspond to distinct sampling periods conducted on different days.
Figure 3.7: Mean short-term range of movement (±SE) during the spring and summer for tagged lake trout.
Figure 3.8: The proportions of cisco, A; warm water fishes, B; unidentified fishes, C; terrestrial insects, D; and aquatic insects, E; in the stomachs of adult lake trout (>450mm fork length) in the spring (I) (n=243) and summer (II) (n=348).
In the spring, while Lake Opeongo is isothermic, the highest catches of lake trout occurred in the shallow stratum, at 2-10 m. In the summer, following thermal stratification, lake trout catches were highest at 20-30 m. Lake trout have been reported to aggregate in the deeper, colder parts of the lake below the thermocline to remain within 10-12 °C (Martin and Olver 1980; Christie and Regier 1988; and Galligan 1962). Despite the thermal limitation imposed on lake trout in the summer, their compression into a smaller, deeper area of the lake was not accompanied by a proportional increase in CUE in the deep stratum. The result is a lower stratified CUE in the summer (0.57 ± 0.12 (SE) adults/sample) compared to the spring (1.13 ± 0.28 (SE) adults/sample) when the catch from each stratum is weighted by relative area. This indicates that lake trout gillnet catchability is lower in the summer than the spring, assuming that adult lake trout density in the South Arm does not change between seasons.

The density of adult lake trout in the South Arm is not expected to change between spring and summer due to emigration between basins (see section 3.2.2) and changes in lake trout abundance due to angling would only account for, at most, an 18% reduction in CUE. Therefore, the change in CUE between spring and summer is most likely caused by a seasonal change in adult lake trout gillnet catchability. As mentioned, catchability is a function of the probability of encounter, the probability of contact given encounter, and the probability of retention given contact and encounter (Hamley 1975). The probability of retention is not expected to change seasonally because the same gear was used.

Next, we examined the hypothesis that seasonal changes in the probability of contact (P_c) are responsible for the observed change in CUE. Increased light intensity has been shown to reduce the catchability of pikeperch and ruffe in trawl nets due to increased gear visibility and subsequent gear avoidance (Buijse et al. 1992). In Lake Opeongo, light
was found to attenuate at the same rate in the spring and summer so that at a given depth, the probability of contact should not change seasonally. The deeper distribution of lake trout in the summer means lower ambient light levels. Therefore a reduction in the incidence of gear avoidance is expected to result in an increase in $P_C$ in the summer. Yet, CUE was lower in the summer compared to spring.

Given that the decreased CUE associated with summer gillnet sampling is not due to changes in adult lake trout abundance or increased gear avoidance, the seasonal difference in catchability must be due to variation in the probability of encounter ($P_E$). Encounter probability models for predator-prey interactions predict the probability of a stationary predator encountering cruising prey is directly related to the velocity of the prey (Gerritsen and Strickler 1977; Giguère et al. 1982) and thus the distance traveled during the sampling period (Rudstam et al. 1984). To test the hypothesis that a seasonal change in the probability of encounter is responsible for the observed reduction in CUE, we tested for a seasonal effect on lake trout swimming speed. The short-term range of movement was also measured since the swimming speed of a lake trout may not provide information on the net displacement of an individual during a sampling period if the complexity and direction of the path varies across comparisons. Seasonal differences in lake trout bottom orientation were also considered since the catching height of the gear and the vertical range of the fish limit encounter probabilities.

A seasonal effect on the swimming speed of lake trout was not detected by the continuous tracking study. Individuals for which a seasonal comparison could be made showed little difference between spring and summer movement. The power of the analysis is limited due to a small sample size, but it is unlikely that a type II error caused this non-significant result since there was not even a consistent trend in the direction of change.

Tagged lake trout consistently traveled over a larger area during the 1-2 hour sampling period in the summer relative to the spring, though the increase was non-
It was hypothesized that an increase in the short-term range of movement would translate into an increased Pe, yet lake trout catches in bottom-set gillnets were lower in the summer.

Seasonal variation in the diet composition of adult lake trout, and an associated change in foraging behaviour, are most likely responsible for the seasonal change in gillnet catchability. The diet of adult lake trout consists primarily of littoral organisms in the spring, but the summer diet is dominated by a pelagic prey fish, the cisco (Coregonus artedii). Cisco were found to be closely associated with the lake bottom in the spring, directly after ice-out, in Pallette Lake, Wisconsin, but were restricted to the metalimnion and upper hypolimnion during the summer (Engel and Magnuson 1976).

Suspended nets in Lake Opeongo caught the highest number of cisco at 10-20 m off the lake bottom during daytime sets in the summer (Scott Milne, Department of Zoology, University of Toronto, unpublished data), confirming a pelagic distribution of cisco in Lake Opeongo.

A shift from a springtime diet of littoral organisms towards a summer diet of a pelagic prey fish suggests lake trout move from the littoral and benthic zones of a lake in the spring to the pelagic zone in the summer. Tagged lake trout were found to be suspended above the lake bottom by greater than the height of a gillnet (2.4 m) during 80% of the summer. Temperature lags provide only a rough measure of depth; these findings are further supported by a hydroacoustic study on Lake Tahoe that found lake trout were, on average, suspended 5 m above the lake bottom in the summer (Dave Beauchamp, University of Washington, personal communication).

The probability of encounter is limited by the catching height of the gear. Clearly, a fish must be within the vertical range of the gear in order to encounter it. In the case of this gear, organisms suspended above the lake bottom by > 2.4 m will be beyond the range of the lake trout. Organisms suspended above the lake bottom by > 2.4 m will be beyond the range of the gear, and therefore will not be caught. Despite the increase in the short-term range of movement, lake trout were lower in the summer.
movement, the decrease in the association of lake trout with the lake bottom decreases the probability of encountering bottom-set passive gear.

The seasonal change in gillnet catchability observed on Lake Opeongo is attributed to changes in the bottom orientation of lake trout in response to seasonal differences in foraging. Other studies have attributed diel variation in trawl catches to diel shifts in the bottom orientation of vertically migrating fish (Casey and Myers 1998; Michalsen et al. 1996). Fish species that vertically migrated at night to feed were found to have a decreased catchability in bottom trawl surveys conducted at night compared to daytime sampling since they were suspended in the water column and therefore less likely to encounter the bottom trawl.

In summary, depth-stratified gillnet sampling is more efficient during the spring as bottom-set gillnets do not sample the summer habitat of lake trout effectively. A reduction in the efficiency of gillnets during the summer is compensated by a longer sampling period during which more samples could be conducted. A drawback of a summer survey is the increased lake trout mortality in gillnets because lake trout are caught at greater depths than in the spring and pulled up to surface waters with lethal temperatures. Sellers et al. (1998) reported that lake trout distribution was best explained by the distribution of prey as opposed to abiotic factors. Similarly, the availability of lake trout to passive gear was largely influenced by predator-prey interactions in the current study. Lake trout populations vary widely in trophic position (Vander Zanden et al. 2000). Though differences in diet across populations are less distinct in the spring, upon thermal stratification, piscivorous populations shift to a diet of cisco in the pelagic zone while non-piscivorous populations are limited to feeding on zooplankton and benthic invertebrates in the summer (Martin 1966). Marked variation in lake trout foraging across populations during the summer is a caveat of a summer index-netting program for cross-lake comparisons of abundance. The variation in catchability across lakes may be more pronounced during the summer and the seasonal
change in gillnet catchability observed here may not be consistent across lakes varying in trophic structure.
General Conclusions

This thesis provides the first estimate of the catchability of SLIN, a standard method used to index the abundance of lake trout populations across Ontario. SLIN catchability was found to decrease as lake trout density increased, and increase with the surface area of lakes. Incorporating these factors into a model of catchability supplies an improved tool for interpretation of CUE data. The implication of a density-dependent catchability coefficient is that large reductions in the lake-wide density of lake trout could occur and catches in the preferred habitat would remain unchanged. Across-lake comparisons of CUE would overestimate the density of lake trout in large lakes if the lake size effect on catchability were not accounted for. Misinterpreting CUE data from large lakes is especially dangerous because large lakes offer more fishing opportunities and therefore greatly influence the overall state of the resource (Lester and Dunlop 2000; Lester et al. 2001).

The implications of replacing SLIN with a summer index method were also examined. Gillnet sampling was more efficient during the spring in Lake Opeongo because bottom-set gillnets do not effectively sample the summer habitat of lake trout in this lake. Lake trout switch from a littoral/benthic distribution in the spring towards a more pelagic distribution in the summer following a shift from a springtime diet of littoral and benthic organisms to a diet of pelagic prey fish in the summer. Decreased gear efficiency during the summer is compensated by a longer sampling period during which more samples can be conducted. A caveat to a summer index-netting program is that lake trout populations vary widely in trophic position (Vander Zanden et al. 2000) and differences in foraging are more distinct in the summer. Therefore, the variation in catchability across lakes may be more pronounced during the summer making interpretation of CUE data from a broad scale monitoring program more difficult.
Abundance is a good indicator of the health of a lake trout population and so accurate interpretation of index netting data is crucial to monitor the state of the resource. The Ontario Ministry of Natural Resources (OMNR) monitors lake trout populations to properly manage the angling exploitation of lake trout and maintain the resource at a sustainable level. This thesis is the first step towards calibrating the catches of lake trout from the index netting method currently used with known estimates of lake trout abundance. The next step is to generate an equation predicting lake trout density from CUE data using the model of catchability developed here.

Historically, SLIN has been used to monitor lake trout populations in response to a perceived problem with the stock (Lester and Dunlop 2000). The OMNR is currently moving towards a monitoring program that samples an unbiased selection of lakes to obtain a fair assessment of the state of the resource (Lester et al. 2001). This type of program may offer a broader range of values to measure the relationship between CUE and density from and to test hypotheses about the effects of trophic structure or secchi depth. For example, on catchability.

SLIN offers a logistically simple way to monitor a lake trout population as it focuses netting effort to one habitat. Recently, a lake-wide netting survey has been proposed to reflect the lake-wide abundance of lake trout (Lester and Dunlop 2000). The suggested lake-wide survey involves stratifying lakes into several depth zones and pelagic layers (Lester and Dunlop 2000). This type of design would lend itself to comparing the spatial distribution of lake trout across seasons in lakes of different trophic structures. This type of sampling design would also minimize the effect of abundance related shifts in spatial distribution on an index of abundance since the entire lake is sampled (Winters and Wheeler 1985). Additionally, a lake-wide survey would supply data relating the littoral density of lake trout to the overall population abundance, thus providing a means to calibrate data from index surveys focused on a single habitat to those sampling the entire lake.
REFERENCES


Shuter, B. J.,


Appendix A:

Spring Littoral Index Netting

The Lake Trout Synthesis Group (Ontario Ministry of Natural Resources) developed a low impact method for obtaining an index of lake trout abundance to be used province-wide. A description of the method provided by Lester et al. (1991) has been adapted for presentation here.

A.1. Fishing gear

Recommended gear is a 91 m gillnet gang, comprised of six 15.2 m panels tied together at the brail loops. All six panels are of the same mesh size, either 38 mm, 51 mm, or 64 mm stretched mesh. The panels are 2.4 m tall. The mesh is made from double-knotted monofilament with a diameter of 0.20 mm (38 and 51 mm meshes) or 0.25 (64 mm mesh). Traditionally, the nets are dyed light green (Miracle R-13L) but in more recent years, silver-gray nets have also been employed. They are hung on a 2:1 basis, implying that there is twice as much web as lead/cork line and that the ratio of the diagonals in the meshes is 1.73:1. Monofilament research gill nets are available from Biological Equipment (5606 Toronto Road, P.O. Box 46165, Station G, Vancouver, B.C., V6R 4G5).

A.2. Sampling method

The survey occurs during daylight hours after ice melt and before surface temperature reaches 13°C. Sample days should be randomly selected from expected available days. If previous catch data are available, Lester et al. (1991) provides an equation to determine the number of sets required to estimate mean catch (CUE) at a desired level of precision:

\[ n = \frac{1.791}{C\cdot CV^2} \]
where, \( c = \text{mean catch} \), and \( CV = \text{coefficient of variation} \) (for 15% precision. \( CV = 0.15 \)).

The shoreline of the lake to be sampled should be partitioned into 120 equal length sections. On each sampling day, sections should be randomly selected without replacement, and set one gillnet gang in each section. The sections should be sampled in an order determined by the optimal survey path, such that distance between consecutive sections is minimized. Set gangs of different mesh sizes in sequence so that different mesh sizes are distributed randomly throughout the lake. Gangs are to be set perpendicularly to the shoreline starting at a depth of 2.5m and lifted after 90-minutes.

A.3. Data collection

Upon lifting each gillnet, the total number of fish captured should be recorded by species. The fork length and round weight of lake trout caught should also be recorded and scale samples should be taken. Lake trout that are found dead in nets should be sampled for otoliths and sex. Any lake trout clips, tags or other marks observed or applied also need to be recorded.