American eel (*Anguilla rostrata*) prey consumption in the Upper St. Lawrence River, the Ottawa River and Eastern Lake Ontario: Stomach Contents in a Declining Population

Erin Moffatt

Student Number 20015303

Undergraduate independent study research project

submitted in fulfilment of an undergraduate thesis,

Queen's University, Environmental Science 502

Co-Supervisor: Adjunct Professor Casselman john.casselman@queensu.ca

Co-supervisor: Emeritus Professor Hodson pvh@queensu.ca

Abstract

In their peak abundance, the American eel, *Anguilla rostrata*, comprised 50% of the nearshore fish assemblage in the upper St. Lawrence River and Eastern Lake Ontario. Since the 1980s the population has faced rapid decline and is now classified as an endangered species in Ontario. This study used 1513 eels collected from Eastern Lake Ontario, the St. Lawrence River and the Ottawa River between 2008 and 2016, 880 of which had stomach contents that were the focus of this stomach content analysis. Variables affecting ingestion were assessed through statistical analysis and descriptive summaries. The main prey types ingested by eels were fish, crayfish and invertebrates. In the spring, 60% of stomachs had contents, 67% in the summer and 37% in the fall. The strongest seasonal correlation was observed in the increased abundance of crayfish in the summer, the season in which they do not moult. The composition of prey types in stocked eels and non-stocked eels was very similar. Stomachs of stocked eels were three times as full as those from non-stocked eels. This difference was attributed to variation caused by location. Stomach fullness varied based on location, the greatest influence was observed in the Ottawa River. The composition of the prey types remained constant throughout locations. Eels caught in hoop-nets had increased stomach fullness compared to those caught in electrofishing surveys. The length of eel had the most predominate influence on prey ingestion. Small eels consumed mainly invertebrates, transitioning with increasing size to feed primarily on crayfish and eels greater than 400mm in length fed most heavily on fish. The stomach contents demonstrated unique ecological interactions that were not previously observed. There are benefits associated with ecological services that a higher population of eels provide, positively impacts the ecological integrity of this system. The results of this study provided a clear

understanding of American eel feeding ecology that can be used as a historical reference for long term monitoring.

Acknowledgements

I would like to offer my sincerest gratitude to my supervisor Dr. John Casselman, for his support, insights and guidance throughout the entirety of this project. I also would like to thank my co-supervisor Dr. Peter Hodson, for acting as a committee member, providing me with guidance and the critical feedback that I have needed. Both of their expertise has allowed for my success in completing this project. Additionally, I would like to thank my family and friends for their endless encouragement.

Table of Contents

Abstract 2
Acknowledgements 3
List of Tables and Figures 5
List of Appendices 6
List of Abbreviations 6
Introduction 7
Materials and Methods 16
Analysis 22
Results 27
Discussion 37
Conclusions 54
Summary of Main Points 56
Citations 58
Appendices 65

List of Tables and Figures

Tables

Table 1. Stomach content analysis methodologies…….………………………………..………12

Table 2. Locations frequency distribution of stomach with and without contents………………24

Table 3. Distribution of stomachs with and without contents…………………...………………28

Table 4. Stomach contents location comparison of 300-399 mm eel …………….…………….31

Table 5. Stomach contents location comparison of 700-799 mm eel …………….…………….31

Table 6. Comparisons of linear regression results………………………….……………………33

Table 7. Occurance of fish species in eel stomach contents…………………………...………37

Figures

Figure 1. Seasonal comparison of stomach contents………………………...………………..28

Figure 2. Origin of eel stomach content comparison……………………………………...…..29

Figure 3. Capture comparison of different eel capture methods affecting digestion …...….….…32

Figure 4. Linear regression of stomach contents and prey types…………………………...……33

Figure 5. All Length and location mean stomach contents………………………………………36

Figure 6. Summary of eel length distribution of Stomach contents………………..……………47

List of Appendices

Appendix A: List of Fish Species 65

Appendix B: List of Invertebrate Taxons 66

Appendix C: Summary Statistics for eels 100-599 mm at all Locations…………….………..67

Appendix D: Summary Statistics for eels 600-1000mm or greater at all Locations……..……..68

List of Abbreviations

PBW – Percent of Body Weight

Introduction

Species Status

The American eel is a catadromous species that spawns in the Sargasso Sea and matures in a range of freshwater ecosystems along the Atlantic coast of North America, Greenland and northeastern South America (Schmidt 1922; Jacoby et al. 2014). In Canada, American eels migrate through the brackish coastal waters as juvenile glass eels and enter the St. Lawrence River as they transition into a juvenile stage known as elvers. Juvenile eels continue to migrate into the Ottawa River and Eastern Lake Ontario as they sexually mature. They inhabit this ecosystem for 8-20 years until they migrate back to their spawning grounds as sexually mature silver eels (Jessop 1987; MacGregor et al. 2013; Lloyst et al. 2015). American eels are panmictic, they spawn in one cohort and mature in varying geographical locations. This study looks at the Ontario stock of Americans eels which is primarily female. When jeopardized, this stock has the potential to affect the entire population as it contributes to alone 19% of all spawning American eel females (Casselman 2003; Gagnaire et al. 2012). Due to the potential impact on the overall population, this subpopulation of American eels is important to the species integrity and is ecologically, economically and traditionally important.

Due to the high nutritional value of American eels, Aboriginal groups and the first explorers discovering Canada relied on eels as a key food source (Casselman 2003). Their high historical abundance contributed to their status of an ecologically important species as they are a top predator feeding heavily on the lower tropic levels. Commercial fisheries relied heavily on the abundance of Americans eels as a key economic resource (Casselman 2003). The utilization of this resource is crurrentl limited due to the decline in the American eel population.

In peak abundance, the American eel population contributed to 50% of the nearshore fish biomass of the St. Lawrence River and Eastern Lake Ontario (Casselman 2003). Since the 1970s their population abundance has declined significantly (Casselman 2003). The Moses-Saunders dam eel ladder passage records showed that recruitment of this highly fecund stock has been almost completely disapeared from this area (Casselman 2003; MacGregor et al. 2013). Furthermore, commercial fisheries activity recorded peak harvesting from 1978-1981, followed by a decline in stock in the 1990s (Casselman 2003). The general decline of the American eel population can be attributed to commercial fisheries overharvesting, contaminants, the construction of the hydroelectric dams and their turbines, changes to the shoreline, and changing environmental conditions such as water quality and temperature shifts (Casselman 2003; MacGregor et al. 2013).

A major contributor to the decline of the American eel was the installation of the Moses-Saunders Dam in the late 1950s, causing habitat alteration and acting as a barrier to migration through the Upper St. Lawrence River to eastern Lake Ontario (Cairns et al. 2008; Lafontaine et al. 2010; Pratt and Threader 2011). Immigrating eels would be chopped up by the turbines, leading to high death rates and operational issues for the dam (Casselman personal communications, 2019). In the 1970s an eel ladder was installed. Even so there was still an 18% and 27% mortality rate (Cairns et al. 2008). Commercial eel fisheries statistics show how fisheries exploitation of all ages of eels in both the Maritimes and Upper St. Lawrence River and Lake Ontario contributed to the decline in eel populations (Cairns et al. 2008). In response the Lake Ontario commercial eel fisheries operations closed in 2004, followed by recreational fisheries in 2005 (Pratt and Threader 2011). Despite these measures, there was still a 99%

reduction in the recruitment of the St. Lawrence River and Lake Ontario stock (Casselman 2003; MacGregor et al. 2013).

To mitigate the turbine mortality of emigrating eels, eel stocking in the upper St. Lawrence River and Eastern Lake Ontario commenced in 2006 and continued until 2010 by the Ontario Ministry of Natural Resources and Ontario Power Generator (Pratt and Threader, 2011). Stocking involved the translocation of 3.8 million glass eels from the Canadian Maritimes to various locations in eastern Lake Ontario and the St. Lawrence River (Pratt and Threader 2011). All eels that were stocked were marked with tetracycline antibiotic, which produces a yellow fluorescent label in calcified structures when placed under an ultraviolet light. Otoliths (sagittae) are the basic structure used to confirm an eels origin and assess the age of an eel. Ultimately stocking was discontinued until the success of stock recovery was further assessed. The St. Lawrence River and eastern Lake Ontario have also undergone significant changes. The ability for this stock of American eels to recover and their changing roles within this ecosystem will be further expanded upon.

Lake Ontario as a Changing Ecosystem

The invasion of the benthic round gobies, *Neogobius melanostomus,* in the late 1990s has had a profound effect on the nearshore environment of Lake Ontario and the St. Lawrence River (Rush et al. 2012). Their ability to establish in this ecosystem was defined by their rapid reproduction rates and aggressive nature (Lee and Johnson 2005). Round gobies reproduce 3-4 times a year and have large brood sizes (Lee and Johnson 2005). Their aggressive nature has allowed them to out-compete other benthic species for habitat and food resources (Dubs and Corkum 1996; French and Jude 2001) Dubs and Corkum (1996) recorded that gobies have an increased ability to detect food in the substrate, out-competing native species such as mottled sculpin, *Cottus Bairdii,* and logperch, *Percina caprodes,* for resources (Dubs and Corkum 1996). Their establishment has caused many changes to the nearshore benthic prey fish and invertebrate community.

Round gobies feed primarily on Zebra mussels, *dreissenid polymorpha*, and small fish. The high abundance of these predators has decreased the density and diversity of the native invertebrate community (French and Jude 2001). Round gobies feed heavily on other fish species nests, consuming eggs and larvae. This has negative impacts on the recruitment of native fish species (Killourhy 2013). The negative effects of a the invasion of the round goby can been highlighted by the decline in near shore diversity of prey fish as a result of their establishment.

Other invasive species such as dreissenid mussels have caused further alterations to this ecosystem. Both quagga mussels and dreissenid mussels, also known as zebra mussels, established in the Great Lakes in 1991, and since has resulted in substantial physical and chemical alterations (Mills et al. 2003; Higgins and Vander Zanden 2010). In pelagic zones, there was a dramatic decline in planktivorous fish and their predators. Populations of hirundea, amphipoda, and gastropoda, increased in abundance in benthic ecosystems and macrophyte depth increased (Higgins and Vander Zanden 2010). Rush et al. (2012) found that these alterations have reduced the capacity for the food web to support the energy requirements of large predatory fish. In profundal pelagic and littoral benthic zones, water clarity increased as a result of filtration by the zebra mussels. This increased water transparency had a significant effect on light-sensitive species, such as the American eel, affecting behaviour, habitat preference and species distribution (Casselman 2003). To accurately assess how these changes may affect the success of future American eel stocks, their feeding ecology and roles within the trophic system needs to be further determined.

The study of feeding ecology

The feeding ecology of a species is defined as the interactions associated with a species prey ingestion. These interactions include but are not limited to: predator prey relationships, prey abundance, ingestion rates, feeding habitat and specific ingestion patterns (Braga et al. 2012). The feeding ecology of a species is strongly linked to its population dynamics and contributes to the understanding of habitat preference, predator-prey interactions, evolution, competition and trophic ecology (Braga et al. 2012). Stomach content analysis is the primary method used to define a species feeding ecology. There are many different methods used to analyze stomach contents and major constraints on each method are time and over/underestimation of relative prey types within the contents (Table 1) (Amundsen and Sánchez-Hernández 2019). Various studies using stomach content analysis have increased the understanding of the Anguillid eel families feeding ecology (Döner and Berg, 2016).

Table 1 Stomach content analysis methods summarized from Amundsen and Sánchez-Hernández (2019).

Method	**Description**	**Benefits**	**Limitations**
Presence-Absence	Positive indication of a prey type or identifiable feature.	Relatively fast and easy.	Provides mass variation in results. Can provide misleading relative amounts of different prey types with varying digestion speeds. Does not include any estimate of the significance of variation in prey type.
Numerical	Count of all prey items present in the stomach, expressing the total number of individual prey types as a frequency of the number of individual prey items.	Good estimator for benthivores and piscivores species. Accurate when taxa are of the same size.	Requires that items in the stomach can be easily counted, not heavily fragmented. Meaningless if there is great variety in prey types. Overemphasis on small prey
Gravimetric	Mass of prey type and importance of relative type expressed as a fraction of total of all prey.	Highest precision of the estimated diet composition. Good when there are only large prey items.	Difficult to separate and weight contents with varying digestion levels. Mucus may be present, adding bias to data. Time-consuming. Overestimate slowly digesting prey.
Reconstruction	Uses back calculations to find the original mass of the prey at the time of ingested.	Can be key in understanding energy flows of different sizes of prey.	Require a large amount of effort to estimate the live length and weight of prey items. Bias may be very large for small indigestible items.
Volumetric	Measurement of the bulk of prey in volumetric terms not weight	Good for large-sized prey.	Cannot be done for the small-sized taxa. Process of separating prey types and their measurements are unachievable
Point	Ranking of prey based on the scale in which prey type is awarded points due to their proportional contribution to overall stomach contents.	Highly practical and adaptable to individual studies. Most satisfactory for studies with time constraints.	Relies heavily on approximation.
DNA Analysis	Use the DNA micro barcoding to show high taxonomic resolution of prey.	Highly accurate and complimentary when other methods are used.	Database for DNA sequence of prey types is limited. Digestion limits the ability to fully assess each prey types abundance. Secondary prey types may be overestimated.
Relative fullness	The relative contribution of prey type to the whole stomach is visually assess and assigned a percentage.	Simple and relatively fast. Found to be consistent with the outcomes of other methods.	Has the potential to be highly subjective

Current understanding of American eel feeding ecology

Biologists have studied the stomach contents of the different Anguillid eel species globally. Döner and Berg (2016), provided an overview of the feeding ecology of the anguillid family and its various species at all life stages. They concluded that stomach contents of all anguillid species are a reflection of available prey and their benthic nocturnal feeding behaviour (Dörner and Berg 2016). They found that prey availability was controlled by seasonality and concluded that there is a need to develop an understanding of the ecological role of the differing eel species in their respective habitats (Dörner and Berg 2016).

Barak and Mason (1992), analyzed the stomach contents of European eels, *Anguilla anguilla*, using Levin's niche breadth, to summarize ingested prey data and to compare ingestion patterns among location and size of eel. Their results showed that location and prey ingestion of an eel is strongly dependant on eel size. This size correlation leads to larger eels being mainly piscivorous and smaller eels consuming higher amounts of invertebrates (Barak and Mason 1992). The diversity within each prey type was assumed to be a result of seasonal abundance (Barak and Mason 1992). Studies on Longfinned eels' (*Anguilla dieffenbachia)* feeding ecology established that as eels grew larger their ingestion diversified, transitioning from primarily invertebrates to consume crayfish and fish (Jellyman 1996). The feeding ecology of Japanese eels (*Anguilla japonica)* has been described as opportunistic, with the caveat that the consumption of fish depends on the availability of other prey in the ecosystem (Itakura et al. 2015).

Lookabaugh and Angermeier (1992) classified American eels as top predators and stated that American eel feeding behaviour is related to eel size. This relationship reflects how eels shift their ingestion of prey to fit their metabolic demands (Lookabaugh and Angermeier 1992). Furthermore they highlighted that when abundant eels, there is a decline in the abundance of benthic vertebrates and invertebrates (Lookabaugh and Angermeier 1992). Machut (2006) studied the feeding ecology of America eels in the Hudson River and documented that as eels increase in length they transition from ingesting mainly soft-bodied invertebrates (oligocheata) to hard-bodied prey (decapoda) Facey and Labar (1981) studied the Lake Champlain American eel populations stomach contents, recording that the frequency of invertebrates ingested was 43%, and generally was under 10% of total stomach contents weight. Crayfish and fish species occurred in 26% of the stomach contents and contributed to a higher percentage of the total mass of the stomach contents (Facey and Labar 1981). Denoncourt and Stauffer (1993), studied Americana eels in the Delaware River and compared their consumption of benthic invertebrates to their relative abundance in the river. Eels feed opportunistically on macroinvertebrates, but three orders were preferred, mayflies, caddisflies and stoneflies (See Appendix B) (Denoncourt and Stauffer 1993). Other orders of invertebrates were not ingested, even though they comprised a high abundance of the available macroinvertebrates in the ecosystem. In a summary of the various life stages of American eels, Greene et al., (2009) summarized that yellow-staged American eels can be defined as opportunistic feeders, feeding on the available prey.

Stacey (2013) most recently contributed significantly to the current understanding of eels feeding ecology of the St. Lawrence River and Lake Ontario populations. Stacey recorded that prey type was strongly correlated to eel size and noted that they were feeding heavily on macroinvertebrates. This study was constrained by a lack of diversity in eel size focusing mainly on small eels, under 350 mm. There is a current literature gap in the understanding of how a changing eel population and a changing ecosystem may be affecting feeding ecology of American eels. The literature does not address how American eel feeding ecology is related to their role within this ecosystem.

Objectives

To address these knowledge gaps, this study examines feeding patterns of American eels in the St. Lawrence River, the Ottawa River and eastern Lake Ontario, through an in-depth quantitative analysis of eel stomach contents. This study was comprised of 1513 eels, 880 of which had stomachs with contents (58%). By investigating the stomach contents, the primary objectives are to:

1. Establish whether stomach contents suggest differences or ongoing changes in feeding patterns dependent on eel size.
2. Determine whether there are spatial and temporal differences in ingestion patterns. Temporal differences relate to any seasonal and annual changes. Spatial differences include different geographic locations.
3. Determine if changes in benthic community populations such as the establishment of invasive species and changing prey fish diversity has affected ingestion patterns.
4. Examine the differences in prey ingested between stocked eel populations vs. non-stocked eel populations.
5. Gain an understanding of the significance of an eel's ecological role and interactions within this dynamic ecosystem.

This study will provide a nuanced understanding of their ecological role which is hypothesized to be significant. This information can be used as a historic reference for future feeding ecology studies and add to the existing literatures understanding of the ecological importance of this species. This improved understanding may be especially relevant for ecologist, conservationist, species at risk specialist and environmental policy makers.

Materials and Methods

Sampling procedures

From 2008 to 2016, stomach contents were collected from American eels by several electrofishing surveys conducted on the St. Lawrence River including Lake St Francis and the River above the Moses-Saunders dam to the Thousand Islands section and the Ottawa River systems (Casselman and Marcogliese, 2014).

Eels were also collected from hoop-net fisheries in the upper St. Lawrence River, and since the closure of the eel fishery in 2005 they were acquired through special permits and in support of several research studies conducted for Species at Risk Ontario. The earlier samples came from the John Rorabeck fishery in the area of Mallorytown Landing and later years, from 2012 to 2016, from the Maurice Laframboise hoop-net fishery upstream in the Thompson Bay area. These hoop-net commercial fisheries harvest warm- and cool-water species, primarily focusing on yellow perch (*Perca* flavescens), and are essentially only spring and fall fisheries.

Eel handling and dissection

In all cases, eels were live-captured and sacrificed with permits, and immediately the primary biological data were collected on the fresh eels. This was done by trained fisheries technicians working for a fisheries research company, AFishESci, which provides services in applied fisheries and environmental sciences for studies. The date of capture (year, month day, written in full with no spaces [e.g., 20200115]), and fish number (the number assigned to the fish in chronological order for the day of capture) were collected on fresh carcasses. The general and specific location of capture and various attributes of the fish (such as length (mm), weight (g), and girth (mm)) were measured and recorded, along with urogenital pore and anal content classification. The presence of other marks, fin clips, tags, or anomalies was recorded, as well as the primary morphological features indicating gonadal development. All data is recorded on a standard 7.2 cm x 12.7 cm scale storage envelope (3-x-5-inch).

Internal biological data were collected, or more frequently on the frozen and thawed carcases, when processed later. A ventral incision was made along the entire body cavity to expose the internal viscera. The visceral fat content was ranked and the gonads were described in detail, including dissection, extraction, and individual weighing of both right and left.

Almost all of the eels were almost all female but in a few cases males of stocked eels were observed. Stocked female eels had ovaries that were usually two to four times larger than those of natural eels from the same location. Otoliths were removed from all eels for age assessment and in recent years otoliths were used to confirm stock origin. Otolith assessment was not undertaken for all eels used in this study limiting age and origin data were somewhat limited. Quite generally, all eels before 2008 were migratory; after that, the majority were stocked, with very few natural eels in these samples.

Of special importance for this study, contents of the stomach, intestines, and rectum were all examined in detail. The size of the stomach, intestines, and rectum were frequently ranked as small (S), medium (M), or large (L), or with a numeric rank. This ranking could be used instead of stomach fullness, which was not specifically reported because further more detailed stomach analysis was planned. This provided an increased precision when measuring digested contents.

The intestinal tract was opened, and the contents were teased out separately and identified to the lowest possible taxa, provided stage of digestion (reported as percent present) and quantity, and individually placed on a pre-weighed piece of paper, approximately 15 x 15 cm. This made it possible to weigh each item and accumulate the total weight of all the contents. If identification was difficult and required higher magnification, a microscope was used to confirm and more precisely identify the individual items. The length of the individual items were measured to the nearest millimetre, describing total length of the contents that showed various signs of digestion. This was called an actual present length. Live length was estimated, also to the nearest millimetre, using length-age keys to determine the weight of the item at time of ingestion. Live length-age keys were located in the published literature. When length-age keys for specific taxons were not all available, Professor J. Casselman inferred the live length according to the state of ingestion in comparison to the actual length and the biological features present (example is vertebrate) (Casselman personal communications, 2019).

The contents were examined to document the stage of digestion, and the percent present of the original organism was estimated to the nearest 5%. Although this is a subjective estimation, the reproducibility was tested by replicate estimates for each observer, and this replication was compared among observers. It was observed that the variance among the estimates was quite low (± 10%). Most of the stomach analysis was conducted by three or four experienced research technicians, remaining consistent. Usually the dissections were conducted by two individuals, one making the observations and the other recording the data in hard-copy form. The individuals recording the data varied somewhat but were well trained and experienced in the methods being used, and recorded the data on standard fish sampling forms, printed on data and "scale collection" envelopes.

Stomachs contents identification

Identification of taxa focused primarily on the stomach contents, although similar information was acquired on the intestines and to a lesser extent the rectum. This provided information on the temporal stages of digestion. Mucus was taken off the items ingested to examine the item in more detail. The weight of mucus (g) was obtained through either a direct measurement or percent calculation and then subtracted from the weight of all stomach contents. This confirmed that the weight of the stomach contents only represented items which had been ingested.

The majority of the stomach contents collected in recent years were dried on sample papers. These were re-examined in more detail to make sure that the data collected were consistent and the identifications were accurate. Much of the identification was checked again in recent years by an experienced technicians who had taken courses in aquatic invertebrate identification as part of their formal technical training at Fleming College (Dan Cooper and Tom Howson).

For the purpose of this specific project, the re-examination of the samples and data was also conducted by Professor J. Casselman. There was other information in the stomach contents that was added to the dataset at this time, such as more precise identification and documentation of calcareous bodies and boney elements which often remained relatively undigested in the stomach, intestines, and rectum. Calcareous bodies are known as gastroliths. During the pre-moulting period, calcium is extracted from the exoskeleton of a crayfish and is stored in the gastroliths. Through this process, crayfish transition from being hard-shelled to soft-shelled, until a new exoskeleton is rejuvenated (Travis, 1960). This allows for certainty in conjunction with the amount and type of exoskeleton present, whether the crayfish were pre-moulting or recently moulted. These bodies, along with careful identification of persisting fish otoliths and boney elements made it possible to more specifically identify items that had been previously ingested but were too well digested to provide other diagnostic clues.

Often stomachs contained multiple items. When invertebrate taxa were present, and to a lesser extent crayfish and fish, the lower taxons, such as species, were often difficult to differentiate. In this case they were later examined in more detail to find diagnostic features such as appendages, heads, and antennae. This identification was carried out under high magnification, using a dissecting microscope and in-hand keys. The keys and identifying characteristics for the invertebrates that were found to be most useful are found in Pennak (1978); for crayfish identification, Dutton (2017); and for fish features such as scales and other boney material and musculatures, a number of keys were used including Scott and Crossman (1969); Scott and Crossman (1985); Oates et al. (1993); and Zale et al. (2012). Digested fish parts did not pose any difficulty for identification by the technicians, as they had considerable field experience with fish identification.

Raw data extraction

Once identification of all stomach contents were completed, the raw data were entered into an Excel file along with the fish identifier, which uses date and process number of the fish for that date. The variables extracted from the raw data were as follows: an indicator of present contents (yes or no), an indicator of mucus present (yes or no), the total weight of combined stomach contents with mucus, and the weight of total stomach contents without mucus. The ingested items in the stomach contents were categorized and variables specific for these categories were defined.

Prey types in the identified contents were categorized as fish, crayfish, other invertebrates and other items. Crayfish, or Decapoda, were not included in the invertebrate category as they were recognized as a primary prey source separate from all other invertebrates and were important items. Firstly, all fish species were categorized together by a singular “fish” category in which total weight and number of individuals were recorded. If identifiable, an indicator of the species ID was assigned. Additionally, round goby, yellow perch and alewife (*Alosa pseudoharengus*) were each reported individually and categorized due to their high-frequency occurrence, and significance outlined in past literature. For these three species, total weight and number of individuals were combined.

The same variables were recorded for crayfish. Specifically, a variable was entered if documents gastroliths. Invertebrate data followed the same format, sending total weight, the number of individuals and percent present if only one individual was identified. A final variable was defined for the total weight of any other contents present in the stomach, this would include vegetation, sediments, and miscellaneous items such as fishhooks.

The eels biological data, which was written on the standard 3-x-5-inch scale envelope were then entered in a separate data file for all the eels used in this study. Each eel was listed by their unique date of capture and fish number. Specific information unique to each eel was entered into the database including location caught, total length (mm), total weight (g), girth (mm), fat content, sex (when mature enough to recognize) and method of collection (electro-fishing or hoop-net). The locations of eel capture were defined and entered in seven general locations these were; 1) the Ottawa River and Tributaries, 2) the St. Lawrence River below the Moses-Saunders dam, 3) the St. Lawrence River above the Moses-Saunders Dam, 4) Jones Creek, including the St. Lawrence River within the vicinity of the mouth of Jones Creek, 5) The St. Lawrence River at Mallorytown Landing area, 6) The St. Lawrence River at Thompsons Bay Area and 7) eastern Lake Ontario. Stomachs with and without contents were differentiated by a single variable. For this study, the total length and weight that was used that was measured in the laboratories. This may have been after the initial freezing or thawing and there is potential for this to be different then the live length and weight recorded. The biological data were then merged with the raw stomach content data to form the dataset used in the analysis.

Analysis

Prey Consumption

To assess the distribution of feeding occurrence, the sum of the eels that had no stomach contents were calculated. To ensure that statistical analysis did not reflect empty stomachs, eels with no stomach contents were separated from the eels with stomach contents (N=633). Eels were grouped determined by their location caught and total length (Table 2). Based on the distribution of lengths, consecutive sizes groupings of 100 mm were determined (example 100-

199 mm), starting at a minimum of 100-199 mm ending with a final group of 1100 mm or greater.

To uniformly assign the proportion of stomach contents for each eel, the total combined weight of all stomach contents and total weight for each prey type (*iw)* were converted to a percentage of the total weight of the eel (*tw*) using the following formula:

$$PBW = \left(\frac{iw}{tw}\right) \times 100.$$

Percent values were assigned the acronym PBW, which represents the percent weight of an item in the total body weight of the eel. PBW is used throughout the whole statistical analysis, using Statistix 9 software program and excel when needed. Summary statistics were used to compute the lower and upper 95% confidence limit (CL) and mean value of the total stomach contents, and each prey type in association with the investigated variable.

Table 2 Frequency distribution of stomachs with and without contents for locations and lengths. SLR represents the St. Lawrence River

	Location						
	Ottawa River	SLR Below dam	SLR above the dam	Jones Creek	Mallorytown Landing	Thompsons Bay	Lake Ontario
	Total length of eel 100-199 mm						
Percent With Contents	0%	0%	0%	49%	92%	0%	0%
Percent Without	0%	100%	0%	51%	8%	0%	0%
Total Number of Eels	0	1	0	98	12	0	0
	Total length of eel 200-299 mm						
Percent with Contents	0%	62%	100%	65%	80%	33%	0%
Percent without Contents	0%	38%	0%	35%	20%	67%	0%
Total Number of Eels	0	121	3	91	59	3	0
	Total length of eel 300-399 mm						
Percent with Contents	50%	56%	80%	69%	70%	0%	67%
Percent without Contents	50%	44%	20%	31%	30%	100%	33%
Total Number of Eels	4	161	5	93	93	3	3
	Total length of eel 400-499 mm						
Percent with Contents	75%	40%	33%	64%	71%	25%	67%
Percent without Contents	25%	60%	67%	36%	29%	75%	33%
Total Number of Eels	8	53	3	14	75	4	6
	Total length of eel 500-599 mm						
Percent with Contents	73%	47%	100%	64%	74%	33%	100%
Percent without Contents	27%	53%	0%	36%	26%	67%	0%
Total Number of Eels	15	17	1	11	84	3	4
	Total length of eel 600-699 mm						
Percent with Contents	71%	54%	50%	67%	67%	69%	100%
Percent without Contents	29%	46%	50%	33%	33%	31%	0%
Total Number of Eels	21	13	2	3	57	13	1
	Total length of eel 700-799 mm						
Percent with Contents	86%	0%	0%	50%	68%	46%	38%
Percent without Contents	14%	100%	0%	50%	32%	54%	63%
Total Number of Eels	28	10	0	2	34	84	8
	Total length of eel 800-899 mm						
Percent with Contents	76%	45%	0%	0%	33%	12%	27%
Percent without Contents	24%	55%	0%	0%	67%	88%	73%
Total Number of Eels	17	121	0	0	15	58	11
	Total length of eel 900-999 mm						
Percent with Contents	75%	22%	0%	100%	10%	0%	22%
Percent without Contents	25%	78%	0%	0%	90%	100%	78%
Total Number of Eels	12	9	0	1	10	16	9
	Total Length of eel 1000-1099 mm						
Percent with Contents	0%	50%	0%	0%	44%	0%	63%
Percent without Contents	0%	50%	0%	0%	56%	0%	38%
Total Number of Eels	0	2	0	0	9	0	16
	Total Length of eel 1100-1199 mm						
Percent with Contents	0%	100%	0%	0%	0%	0%	0%
Percent without Contents	0%	0%	0%	0%	100%	0%	0%
Total Number of Eels	0	1	0	0	1	0	0

Seasonality

To assess the effects of seasonality on feeding rates, the total percent of stomachs with and without contents was compared for each month and combined by season. All locations were used in this comparison as temperature related to seasonality is thought to impact all the locations relatively equally.

The significance of seasonality, which may affect feeding selection, was assessed by comparing summary statistics of prey items PBW of eels from the same location (Jones Creek), and same length groups over the seasons. The three seasons are defined as spring (March, April, May), summer (June, July, August), and fall (September, October, November). The three length groups used were 100-199 mm, 200-299 mm, and 300-399 mm. Only stomachs with contents were analyzed to show the significance of each prey type and total stomach weights. In the spring there were 72 stomachs with contents (100-199 mm N= 25, 200-299 mm N =17, 300-399 mm N=30), 50 eels caught in the summer had stomachs with contents (100-199 mm N= 9, 200-299 mm N =22, 300-399 mm N=19), 29 eels caught in the fall had stomachs with contents (100-199 mm N= 6, 200-299 mm N =11, 300-399 mm N=12).

Origin of eels

The ingestion patterns of eels from different origins, stocked vs. non-stocked, were analyzed by comparing the summarized statistics for the stomach contents of eels that are 600-799 mm in length. A sample of eels caught in the Ottawa River and tributaries from 2009 and 2010 were representative of a non-stocked population (N=16 eels with stomachs with contents). In comparison eels caught in the St. Lawrence River at Mallorytown landing from 2013 and

2014 were used to represent a primarily stocked population (N=45 eels with stomachs with contents).

Location

To analyze how location may cause variation within eels feeding patterns, we performed statistical summaries and compared the PBW values for eels of the same length caught in 3 differing locations. The length group 300-399 mm consisted of eels from St. Lawrence River below Moses-Saunders Dam (N=90 stomachs with contents), Jones Creek (N=64 stomachs with contents) and St. Lawrence River at Mallorytown Landing area which had a mix of stoacked and non stocked eels (N=65 stomachs with contents). For eels in the length group of 700-799 mm, the sample consisted of eels from the Ottawa River and its tributaries (N=24 stomachs with contents), St. Lawrence River at Mallorytown Landing area (N=23 stomachs with contents), and St. Lawrence River at Thompsons Bay area (N=40 stomachs with contents).

Capture methods

Method of capture as a variable which may affect stomach contents was analyzed by comparing the stomach contents PBW between eels that were captured by different methods, either hoop-net or electrofishing. All the eels in this comparison were from the St. Lawrence River at Thompsons Bay area, and between 700-799 mm in total length. There were 70 eels caught by hoop-net, 29 with stomach contents. There were 20 electro-fished eels, 11 having containing stomach contents. To assess how capture method affects the stomach fullness of eels, total percentage of the stomachs were compared.

Size of eels

Using the 10 different length groups, eels were separated by location. Eels from the same location were grouped using the 10 length groups defined. In these groupings, summary statistics were performed on the combined stomach contents and the primary prey types. Linear regressions were performed on the length of eel in relation to the combined stomach contents PBW and each primary prey type was also performed to assess the significance of the pattern observed.

Results

Seasonality

Among all sizes of eels, in the spring 60% of stomachs had contents, 67% in the summer, and 38% in the fall **(**Table 3**).** In the spring, invertebrates comprised 94% of the total mean stomach contents, and crayfish and fish 3% (Figure 1). In the summer, crayfish comprised 54% the stomach contents, invertebrates 37% and fish species 9%. In the fall, 59% of the mean total stomach contents was comprised of invertebrates, 38% crayfish and 1% fish species.

Table 3 Number and percentage of eels with and without stomach contents for all locations used in the study.

	Season							
	Spring		Summer			Fall		
	April	May	June	July	August	September	October	November
With Contents	28	94	405	58	137	118	40	0
Empty	11	69	144	29	120	209	47	3
Total	39	163	549	87	257	327	87	3
Frequency of Contents	60.4%		67.1%			37.8%		

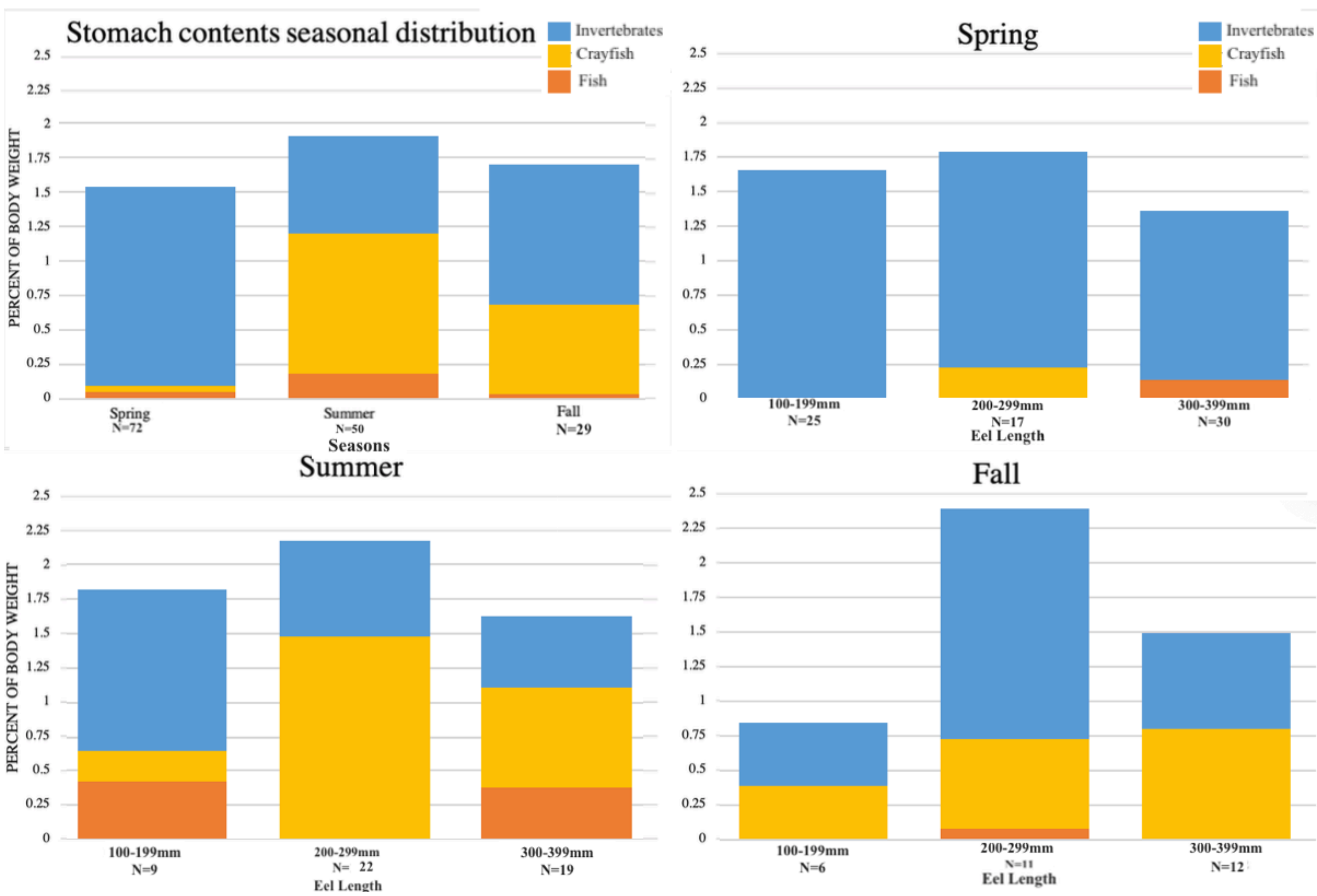

Figure 1 Weight of stomach contents in relation to body weight by season, based on total length groups. Eels compared in this analysis are from one location which is Jones Creek. The top right graphs shows the composition of stomach contents for all lengths among the three seasons.

Origin of eels

Both stocked and non-stocked eels used in this comparison are 600-799mm. Fish were the primary food source and crayfish were the secondary for stocked eels, were non stocked eels consumed more invertebrates (Figure 2). Stocked eels' stomach PBW was 3.15 times greater than non-stocked eels, 0.5 PBW compared to 1.58 PBW.

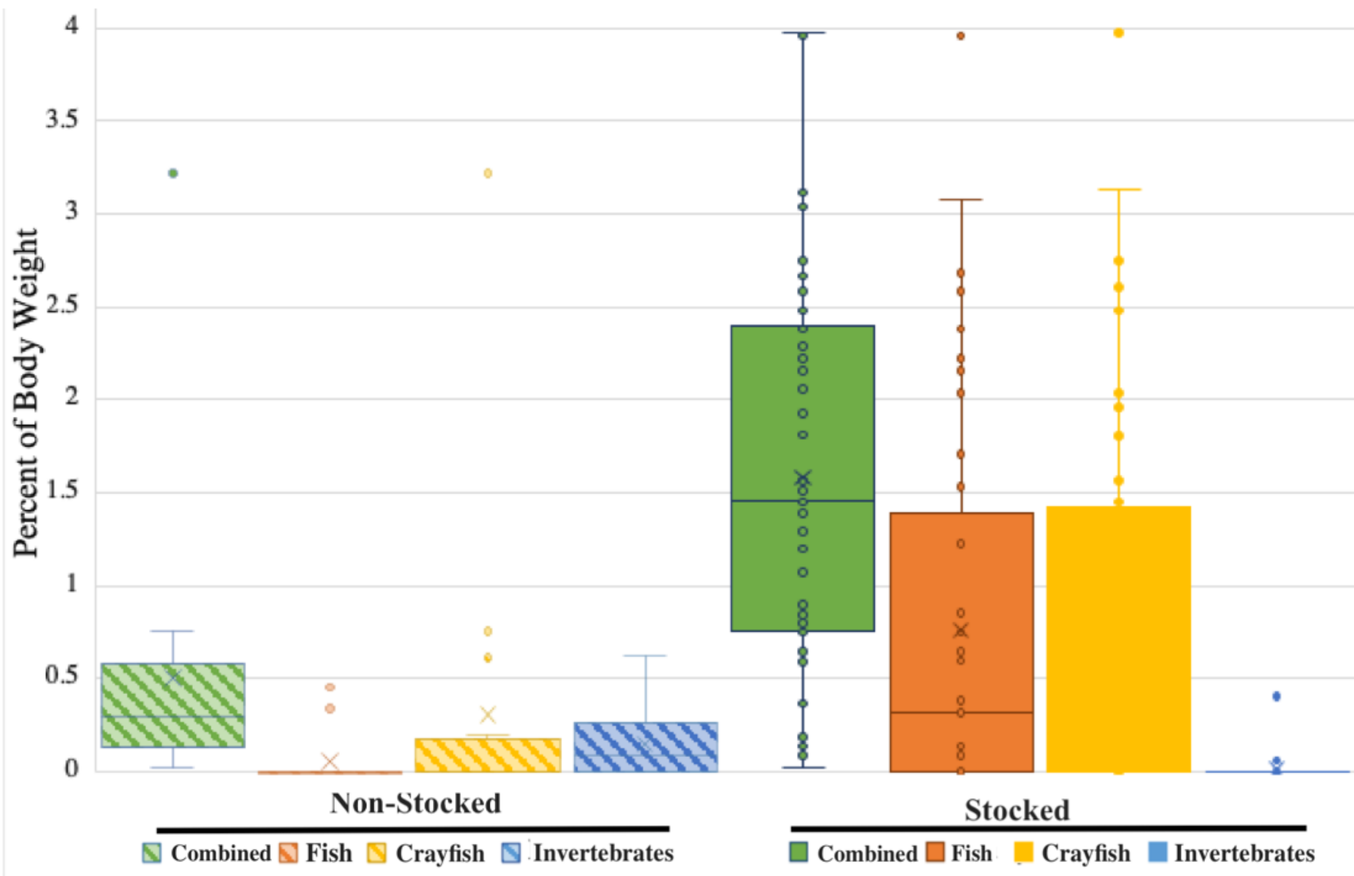

Figure 2 Percentage of body weight that is the total stomach contents and the three primary prey types of eels from (**left**) non-stocked eels from the Ottawa River and Tributaries (N=16) and (**right**) stocked eels from the St. Lawrence River at Mallorytown landing (N=45). All eels range between 600-799 mm, stocked eels had a mean length of 680 mm, and non-stocked had a mean on 714 mm.

Location

For eels 300-399 mm in length, their location specific data displayed varying ingestion patterns (Table 4). Eels from the St. Lawrence River below the Moses-Saunders Dam location ingested 75% crayfish, secondarily 13% fish, and 11% invertebrates. At Jones Creek, eels ingested 58% invertebrates, 28% crayfish and 14% fish. Eels at the St. Lawrence River at Mallorytown Landing area had a more equally distributed feeding pattern. Stomach contents were comprised of 35% fish, 33% crayfish, and 32% invertebrates.

Eels 700-799mm, at the Ottawa River and tributaries, stomach contents were comprised of 49% invertebrates, 36% crayfish, and 17% fish (Table 5). Eels of the same size, from the St. Lawrence River at Mallorytown Landing Area, stomach contents comprised 73% fish, 26% crayfish and 1% invertebrates. Same sized eels caught in the St. Lawrence River Thompson’s Bay area displayed similar ingested prey distribution, 93% fish, 6% crayfish and 1% invertebrates.

Table 4 Eels that were 300-399mm in total stomach contents composition and three main prey types, low 95% confidence limits (CL), mean value and high 95% confidence limits (CL) from 3 locations.

St. Lawrence River below Moses-Saunders Dam (N=90)				
	Combined	Fish	Crayfish	Invertebrates
Low 95% CL	1.28	-0.24	1.08	0.09
Mean	1.18	0.25	1.34	0.19
High 95%CL	2.32	0.75	1.6	0.281
Percentage		14%	75%	11%
Jones Creek (N=64)				
	Combined	Fish	Crayfish	Invertebrates
Low 95% CL	1.19	-0.07	0.07	0.64
Mean	1.60	0.19	0.40	0.83
High 95% CL	2.01	0.46	0.732	1.12
Percentage		13%	28%	58%
St. Lawrence River Mallorytown Landing area (N=65)				
	Combined	Fish	Crayfish	Invertebrates
Low 95% CL	1.7	0.33	0.41	0.49
Mean	2.14	0.72	0.69	0.66
High 95% CL	2.6	1.14	0.97	0.91
Percentage		35%	33%	32%

Table 5 Eels that were 700-799mm in total had stomach contents composition (percentage) and three main prey types, low 95% confidence limits (CL), mean value and high 95% confidence limits (CL) from 3 locations.

Ottawa River and Tributaries (N=24)				
	Combined	Fish	Crayfish	Invertebrates
Low 95% CL	0.35	<.01	<.01	0.1
Mean	0.50	0.08	0.165	0.23
High 95% CL	0.67	0.16	0.32	0.35
Percentage		17%	36%	49%
St. Lawrence River at Mallorytown Landing Area (N=23)				
	Combined	Fish	Crayfish	Invertebrates
Low 95% CL	1.05	0.58	0.07	-<.01
Mean	1.49	1.06	0.38	0.02
High 95% CI	1.94	1.54	0.71	0.01
Percentage		73%	26%	1%
St. Lawrence River at Thompsons Bay Area (N=40)				
	Combined	Fish	Crayfish	Invertebrates
Low 95% CL	0.63	0.55	-0.05	<.01
Mean	0.88	0.81	0.05	0.01
High 95% CI	1.15	1.07	0.16	0.03
Percentage		93%	6%	1%

Capture methods

Eels caught by hoop-net had 1.2 times greater the amount of combined stomach contents in comparison of electro fished eels. Hoop-net eels ingested was comprised of 98% fish, 2% invertebrates, and 1% crayfish (Figure 3). Stomach contents from eels caught in the electrofishing survey were comprised of 73% fish, 25% crayfish), and 2% invertebrates.

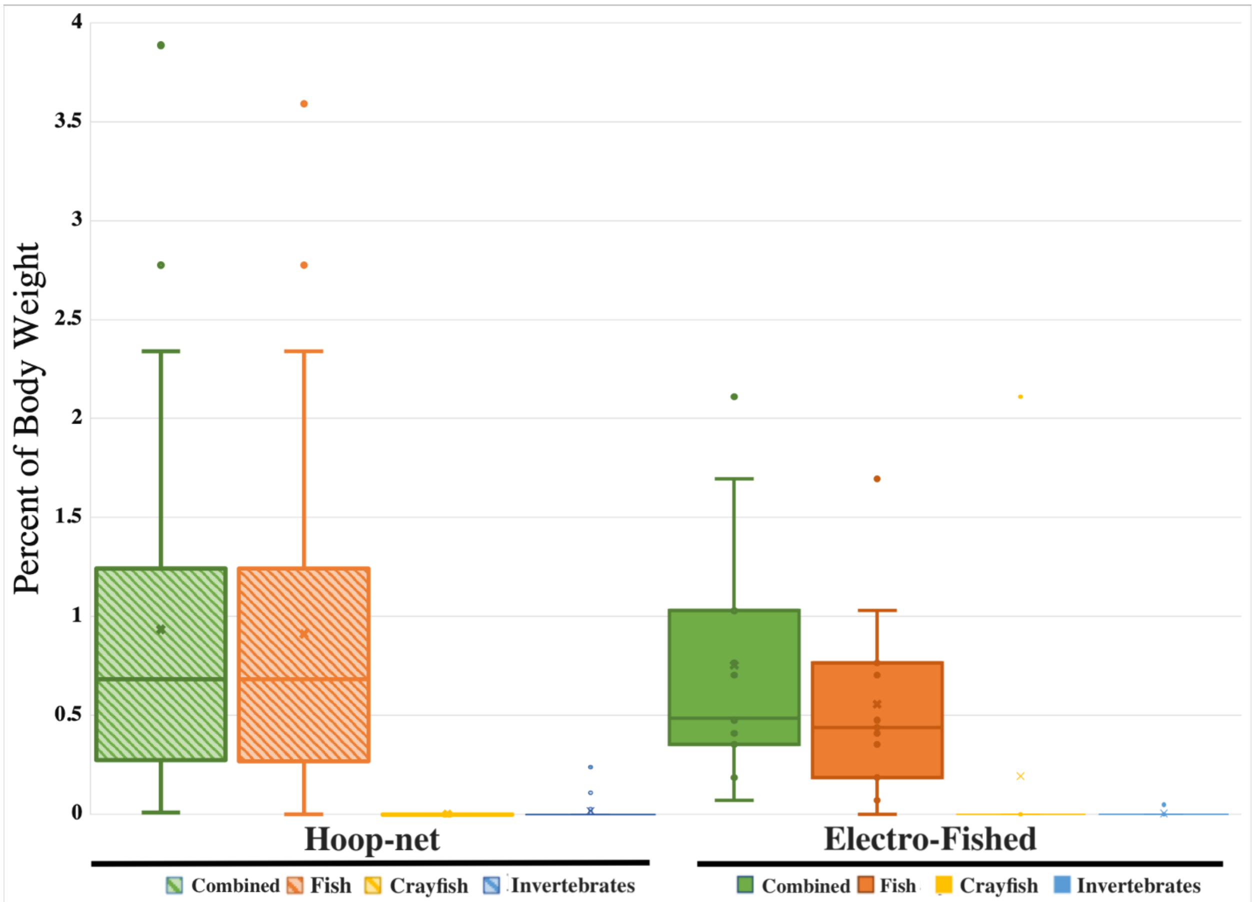

Figure 3. Distribution of stomach contents of 700-799mm eels caught **(left)** by hoop-net in the St. Lawrence River by Thompsons bay area (N=29),(**right**) by electrofishing in the St. Lawrence River by Thompsons Bay area (N=11).

Size of eels

Linear regression results showed that the length of eel and percent of fish ingested in body weight had a significant positive correlation (P Value of <.01) (Table 6. Figure 4). Percent of body weight that is total ingested stomach contents, invertebrates and crayfish all had a significant negative correlation (P value of <.01).

Table 6 Weight of the stomach contents (percent) in relation to total body weight of the eel (g), as length increases.

Type of Ingested Contents	P-Value	Equation of Linear Regression	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Invertebrates	<.001	Y = -0.0015x + 1.125	1.000	1.250
Crayfish	<.001	y = -0.0011x + 1.127	0.936	1.318
Fish	<.001	y = 0.001x + 0.0224	-0.178	0.223
Total Combined Contents	<.001	y = -0.0017x + 2.3589	2.108	2.609

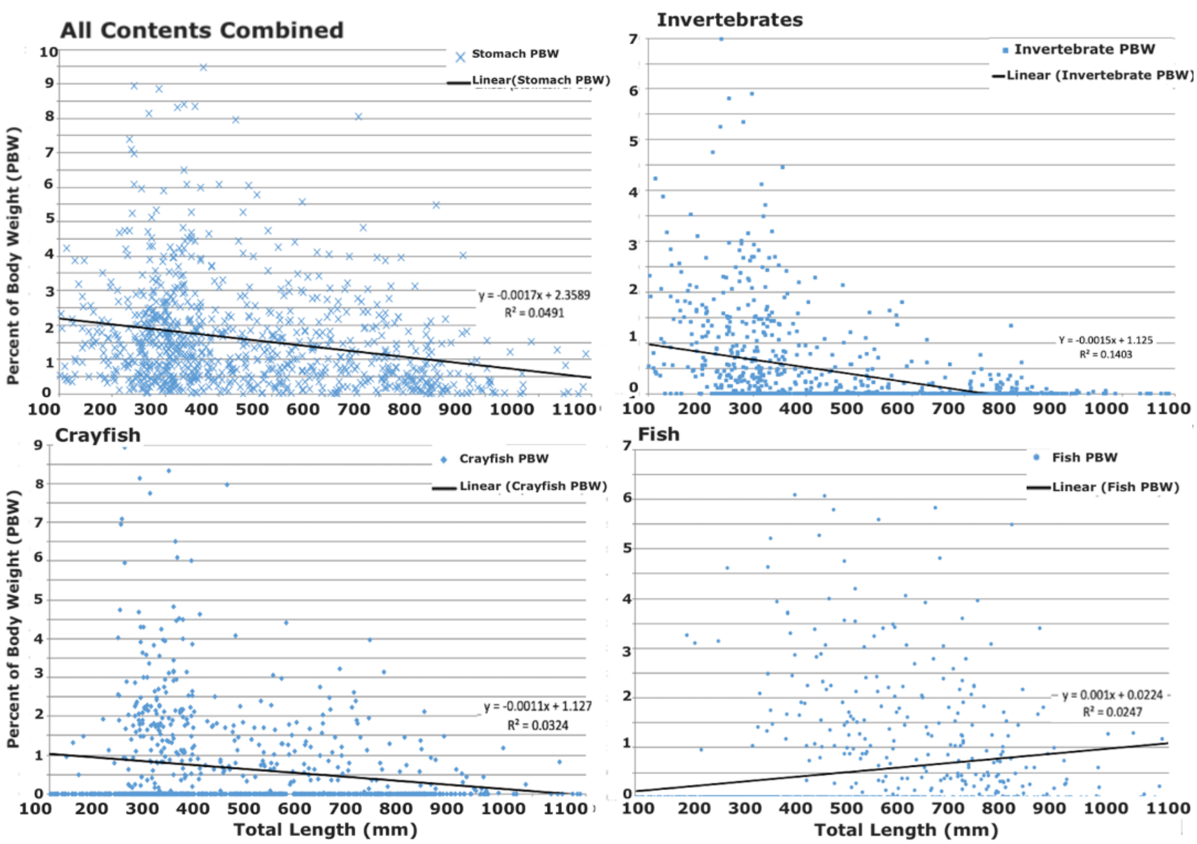

Figure 4. Stomach contents and prey types percent of eel body weight vs. total length of eels. Top left: Percent of body weight that is the stomach contents. On observation off scale (22.76, 345); Top right: Percent of body weight that is the invertebrates contents; Bottom left: Percent of body weight that is the crayfish contents. On observation off scale (22.76, 345);Bottom right: Percent of body weight that is the fish contents.

Eels 100-199 mm in length depended on invertebrates for 86% of their prey ingestion (See Appendix C and D, Figure 5). The consumption of invertebrates declined in eels of the length 200-299 mm to 44% which was secondary to the amount of crayfish ingested. Eels 300-399 mm in length continued to consume invertebrates secondarily to crayfish, comprising 24% of the combined stomach contents. For all eels greater than 400 mm invertebrates consistently comprised less than 10% of all stomach contents.

In eels, 100-199 mm crayfish were the secondary food choice while still comprising less than 5% of the total stomach contents. Eels from 200-399 mm fed primarily on 55% crayfish. Eels with a total length greater than 400 mm relied on crayfish as a secondary food choice. However, the proportion of the total stomach contents which is which crayfish fluctuated depending on the specific length group.

Ingested fish species comprised < 4% of the total stomach contents for eels under 300 mm, having an insignificant influence on prey composition. Eels 300-399 mm increased feeding on fish (0.37 PBW), comprising 19% of total stomach content PBW however, this did not exceed the proportion of crayfish or invertebrates. For eels >400mm in length, 55% or more of their total stomach content PBW was composed of fish. Although this percentage was high, the total PBW of fish and the total PBW of stomach content decreased as eel size increased.

Figure 5. Mean values of stomach contents PBW in the American eels, sorted by length and location; Top right: 1 is 100-199 mm; Top left 2 is 200-299 mm; 3 is 300-399 mm; 4 is 400-499mm; 5 is 500-599 mm; 6 is 600-699 mm; 7 is 700-799mm; 8 is 800-899 mm; 9 is 900-999 mm; 10 is eels 1000 mm or greater in length. Within each figure. Location is represented by a letter on the x axis, A is the Ottawa River and the Tributaries; B is the St. Lawrence River below the Moses-Saunders Dam; C is the St. Lawrence River above the Moses-Saunders Dam; D is Jones Creek including the St. Lawrence River at the Mouth of Jones Creek; E is the St. Lawrence River at Mallorytown landing; is the St. Lawrence River at Thompson’s Bay area; is Lake Ontario. N is the number of eels used in sample.

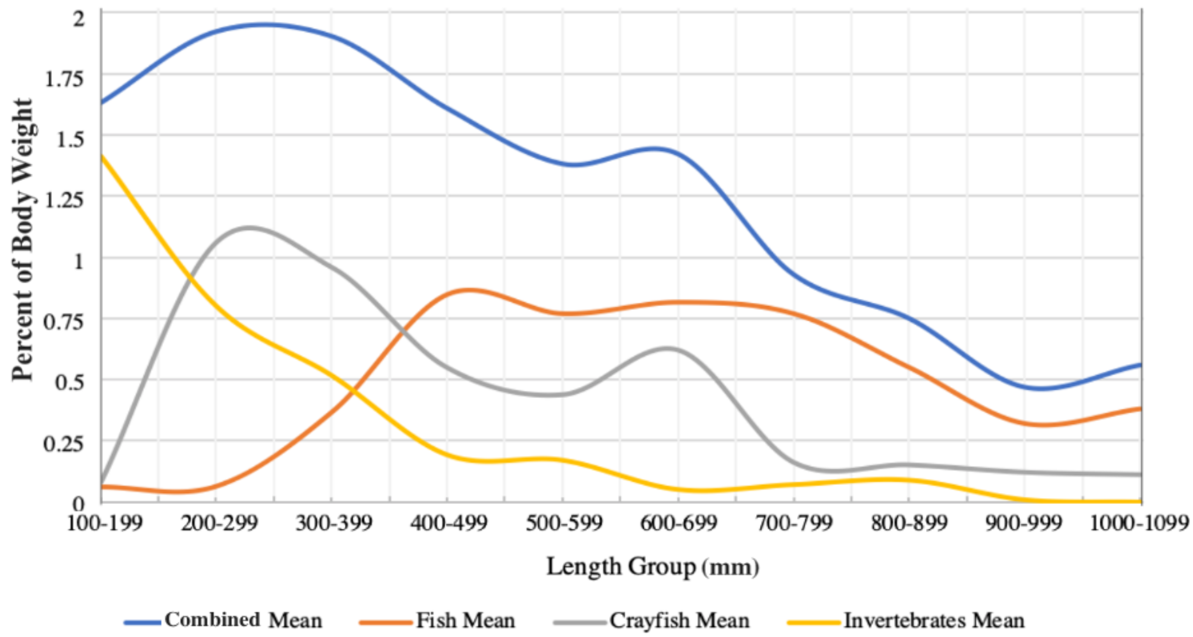

Figure 6 Trend lines for the mean value of prey types ingested as length of eel increases.

Fish species occurred in 239 eels stomachs, seven containing more than one species (Table 7)**.** Species diversity at each location is shown by the number of different species in the stomach contents of American eels. There were 13 fish species identified, as well as 20 stomachs with unidentified fish species (see Appendix A).

Macrophytes were present in 39 stomachs. Unidentified vegetation occurred in 15 stomachs. Eel grass was in one stomach, *Elodea* species were present in one stomach, *Potamegeton* species were present in four stomachs, *Najas* species were found in four stomachs, and *chara* species were the most abundant macrophyte genus occurring in 10 stomachs.

Table 7. Frequency occurrence of fish species in the eel's stomach contents.

		Fish Species														
										Cyprinid						
Location	**Season**	Round Goby	Yellow Perch	Rock Bass	Large Mouth Bass	Ale wife	Pumpkinseed	Brown Bullhead	Unidentified Cyprinid	Blunt Nose Minnow	Fathead Minnow	Blackchin Shiner	Spottail Shiner	Johnny Darter	Sculpin spp.	Unidentified Species
Ottawa River	Spring	1														
	Summer	1	3	2	1			1	2	1	4	1	1			1
	Fall								1							
St. Lawrence River below the dam	Summer	4		1					2	1						1
	Fall	14														
St.Lawrence River Above the Dam	Spring	1														
Jones Creek	Spring	4			1		1		1							
	Summer	3														1
	Fall	2			1											1
St.Lawernce River at Mallory town Landing	Spring	2														
	Summer	93	2			1			3	6		1	1	1	1	1
	Fall	1														1
St.Lawrence River at Thompson's Bay Area	Spring	32	6													1
	Summer	1	2													
	Fall	14	1													2
Lake Ontario	Spring					2										
	Summer	10							1							1
Total	All Seasons	183	14	3	3	3	1	1	10	8	4	2	2	1	1	10
	Percent Frequency Occurrence	76.6	5.9	1.3	1.3	1.3	0.4	0.4	4.2	3.3	1.7	0.8	0.8	0.4	0.4	4.2

Discussion

By identifying the variables affecting an eel's feeding patterns such as seasonality, the origin of eel, method of capture, location caught and size of eel we were able to properly assess the magnitudes of their influence. Capture method and origin of the eel had minimal effects on eel's ingestion patterns. Seasonality influenced the abundance of crayfish as they have seasonal molting periods. This affects small eel ingestion as they appear to rely on crayfish as a primary food source. Separate locations with unique habitats had varying amounts of stomach contents and differing prey diversities. Although these variations exist, their importance is minimal as size was determined to be the main influence on prey ingestion. Assessing each variable separately allowed for unique ecological interactions to be defined, contributing to an improved understanding of the American eel feeding ecology.

Seasonality

The significance of seasonality on feeding frequency is shown through the distribution of stomachs with contents and empty. Seasonality is defined by the increase of solar radiation as the summer solstice is approached (Guan et al. 2010). This in turn, increases the temperature of the aquatic environment, as it reaches heat capacity in the summer (Dove-Thompson et al. 2011). When analyzing stomach contents on a seasonal scale, it is evident that in times of peak seasonal temperature there is a peak in the rate of feeding occurrence. Rates of feeding occurrence were measured by comparing the number of stomachs with and without contents. Summer have the highest rates of feeding, and fall had the least.

The current literature has shown that temperature influences eel behaviour. Seasonal fasting for eels occurs between November and March, with low temperatures governing the feeding of American eels (Barak and Mason. 1992). As temperature decreases, metabolic rates decrease, lipid storage increases, and eels rely on these lipids as a source of energy during time of starvation (Mayerle and Butler 1971; Walsh et al. 1983). They burrow in mud throughout their hibernation, emerging in mid-April (mean emergence date is April 11th) to return to feeding (Tomie 2012). Their optimal growth temperature range is believed to be 22°C-23°C, whereas their preferred temperature range is believed to be 16.7-17.4°C, which is the temperature range in summer (Jessop 2010; Stacey 2013; Ouellet et al. 2014). This provides insight into the displayed feeding occurrence across seasonal variation and confirms that eels will have increased feeding with increased water temperatures. To understand the differences in eels' feeding and ecosystem dynamics in the varying seasons, the consumption patterns across the seasonal variation were further investigated.

In the spring, invertebrates were 30 times more abundant than crayfish and fish. As the seasons progressed, invertebrates composed over 40% of the stomach contents and the relative abundance of crayfish increased. There was a notable increase in crayfish consumed in the summer, comprising over 55% of all food consumed whereas invertebrates only comprised 36%. In the fall, crayfish remained present but contributed to a lower amount of total composition of 37%, 58% of the composition was invertebrates. In the spring, both crayfish sexes undergo moulting, and only the males moult again in the fall (Grover 1955; Travis 1960). Thus, this flux in invertebrates and crayfish composition is a result of the moulting seasons of crayfish.

Cambarus and *Orconectes* species moult several times throughout their first year; mature females then moult annually every spring, whereas males moult biannually, every spring and mid-summer (Grover 1955; Travis 1960). The spring moult of the males typically occurs two to three weeks earlier than the females due to their reproductive roles (Grover 1955; Travis 1960) Egg-bearing females require their exoskeleton to carry their eggs and protect their hatched young for approximately one week in mid-May, with moulting than commencing late-May to mid-June. For males, their second moult period can begin during mid-August and continue as late as early October (Scudamore 1947).

Moulting crayfish, unable to move or feed due to loss of exoskeleton, hide themselves in protected environments such as burrows to avoid predation (Wheatly and Gannon 1995; Guiaşu and Dunham 2001). This is reflected in our data, as their abundance was extremely low in the spring (less than 5%), peaking in the summer and decreasing in the fall. This indicates moulting periods that reflect a decrease of crayfish available for predation. Our data further reinforces this relationship by examining gastrolith presence as a representation of moulting seasons.

Gastroliths are calcareous bodies that are essential in the moulting process of crayfish (Travis 1960). Moulting occurs in crayfish as periodic events of discontinuous growth. To simplify, the pre moult stage, in which gastroliths are formed, can occur 16-30 days before moult takes place (Scudamore 1948). In the moult, the exoskeleton softens, storing calcium in gastroliths. The exuvium is then shed and recalcification takes place. This moult may take 11-22 days. The recalcification occurs through transferring the stored calcium from the gastroliths and from the environment and depositing it to create a new exoskeleton (Scudamore 1947).

Thirty-three of the stomachs in all our data contained gastroliths. Fourteen were consumed in the month of June, three in the months of July, eleven in the month of August, three in the month of September, and one in the month of October. The occurrence of these gastroliths coincided with crayfish moulting time. This indicates that eels feed on soft shelled crayfish. In many instances we were able to identify soft shelled crayfish remains in the stomach contents along with gastroliths. The presence of gastroliths in stomachs beyond the moulting season may reflect the eel's inability to digest these calcareous bodies (Amundsen and Sánchez-Hernández 2019). It can be speculated that American eels feed opportunistically on soft shelled crayfish when found in comparisons to hard shelled crayfish as they are less defensible and easier to digest. This data shows that eels seek out crayfish as a food source, when soft shelled and low in abundances highlighting the importance of crayfish to an eel overall feeding patterns.

The abundance of crayfish in the environment, eels from 200-499 mm fed opportunistically on crayfish as a primary food type ingested. In time of crayfish scarcity, these eels alternatively eat higher amounts of invertebrates and fish. This trend has been shown in other predators, such as river otters, that respond to low crayfish abundance by transitioning their food consumption to rely more heavily on fish species (Dekar et al. 2010). The significance of seasonality is thus important for eels between 200-399 mm, which rely heavily on crayfish as a food source. Establishing this importance of crayfish and their seasonal distribution within the stomach contents of eels provides critical information on the importance of temperature in relation to an eels' feeding behaviour.

Crayfish are aquatic ectotherms, and seek out an ideal water temperature of 25°C to regulate their body temperatures (Westhoff and Rosenberger 2016). Eels temperature preference is lower than crayfish, yet they still rely heavily on this prey source. This highlights an important trophic relationship in which American eels will move beyond their preferred temperature range to feed upon crayfish which are reliant upon temperature. Seasonal temperatures show key ecosystem dynamics which affects eel's ingestion patterns, specifically eels 200-399 mm who rely significantly on crayfish as a primary food source.

Origin of eels

To ensure an equal comparison was made, all eels used in the comparison ranged between 600-799 mm. Stocked eels had a mean length of 680 mm, and non-stocked had a mean length of 714 mm. Stocked eels had over three times the weight of combined stomach contents than that of non-stocked eels. Literature highlights that stocked eels have higher growth rates than non-stocked populations (Pratt and Threader 2011; Stacey 2013). Our data does not explore growth rates, and thus cannot be further explained. Other possible explanations for this difference is not the origin of the eels but rather the differences in location. The lowered total consumption shown in non-stocked eels from the Ottawa River is a trend closely related to all ingestion rates from eels at that location.

Location

Each location has specific environmental, geomorphological, and ecological characteristics that create somwhate differing habitat types that could result in differences of prey availability and diversity. There were minimal differences in the comparison of 300-399 mm eels over the three locations. When comparing eels 700-799 mm, there was a significant difference in the Ottawa River and the two St. Lawrence River locations. To explore if these differences associated with a particular location were substantial, we compared all locations for all lengths. These comparisons showed trends of certain locations, specifically eels caught in the Ottawa River had lower amounts of stomach contents in comparison to all other locations.

Ottawa River and tributaries are characterized by fast flowing water over pre-Cambrian bed rock (Haxton 2007; Lowles 2013; Hudon et al. 2017). This creates an ideal habitat for crayfish and benthic invertebrates, while foraging benthic fish are not in high abundance (Haxton 2007). This ecology is reflected in the eels feeding patterns, showing more equal dependence of crayfish, invertebrates and fish at all lengths, while overall stomach contents weight remains lower than any other location.

The stomach contents of eels from Lake Ontario are comprised almost entirely of fish. Fish are known to be a key food source for eels greater than 400 mm. However, at other locations, food sources are represented within the data, even if only comprising a small amount of the total stomach contents. Lake Ontario eels were collected from the Bay of Quinte, Main Duck Island and Yorkshire Islands. Eels in the Bay of Quinte have been found in habitats that are composed heavily of boulders, cobble stone and bedrock (Pratt and Threader 2011; Lloyst 2013; Stacey 2013). This provides refuge for many fish species such as round gobies, which were the most heavily fed upon fish species in our data (Brousseau et al. 2011). In contrast, the habitats in the St. Lawrence River where eels were found are more abundantly in diverse habitat types including silt and sandy habitats as well as cobble stone. This provides opportunity for increased diversity of invertebrates and crayfish (Lloyst 2013; Stacey 2013). This difference in habitat is shown by eels from Lake Ontario primarily feed on fish and those from the St. Lawrence river relying more equally on the three various prey types, invertebrates, crayfish and fish. Furthermore, the differences in habitat may not occur naturally but rather be altered by anthropogenic activities.

The installation of hydroelectric dams has been shown to alter habitats through destruction during construction and flow diversion leading to hydrological differences such as upstream head ponds and downstream fast flowing waters (MacGregor et al. 2013). To assess these effects, we compared the prey ingestion of American eels captured below (410 eels total, 216 with stomach contents) and above the Mosses-Saunders dam (13 eels total, 9 with stomach contents). Eels from above the dam consumed primarily crayfish, with one eel ingesting a round goby. Eels of all sizes below the dam consumed the various prey types, feeding most heavily on crayfish. Below the dam there is a diversity of habitat types and their associated prey types (Ribey 1997; Lima et al. 2016). Upstream lack of habitat diversity could be causing the decreased amount of prey fish diversity in eels stomach contents from this location (Ribey 1997).

A larger sample size is needed to establish if this lack of diversity is caused by habitat associations or if lack of diversity is a limitation of the small sample size. The data collected from eels below the dam reflects the feeding ecology of eels in an environment where diversity of prey is high. This provides strong insights into the actual ingestion of eels and is a crucial source of data for our study.

Through analysing the varying locations and their associated habitats, it is evident that certain locations may provide unique circumstance of bias within the overall data and others that more accurately reflect ingestion patterns. The differences in eels from eastern Lake Ontario and the Ottawa River location are understood to be associated with their respective habitats. To better understand the relationship between prey and location, further data needs to be collected on the abundance of prey at each location (Machut 2006). Calculations for electivity indices can then be applied to assess the selectivity of eel's prey ingestion. Electivity indices help to understand what prey are available in the neviornment, and the degree to which an eel with elect to eat certain prey items. Considering a comparisons of results by location, eel size was shown to be the most important variable influencing type of prey and amount of total stomach contents. Further factorial analysis would distinguish variances and assess the significance of interactive terms. This would assign a statistical importance for each variable.

Capture methods

Stomach contents among eels captured in hoop-nets and electrofishing surveys did not display vast differences in their composition of prey types. Fish were the primary source of food for both sets of eels. Overall electro-fished eels had lower amounts of stomach contents than those captured by hoop-nets.

The eels caught in electrofishing surveys, were immobilized following capture and regurgitation is known to not occur. In contrast eels that were captured in the hoop-net may not have been removed from the aquatic environment and processed for a period of 24 hours. It can be hypothesised that the stomachs of eels caught in hoop-nets would be less full as digestion would occur in this period. Our data disproves this hypothesis showing that hoop-net captured eels had higher percent fullness of their stomachs compared to those that were electro-fished. The stomach contents of eels caught in hoop-nets used in this study were collected consistently in the morning and the relative high percent fullness highlights their nocturnal feeding behaviour. Furthermore 41% of eels caught in hoop-nets had stomachs with contents, and 55% from eels electro fished showing no significant difference related with either capture method or the digestion times associated with them both. The use of this data in our study is essential in accurately representing the stomach contents of American eels and does not impose the potential for bias associated with the use of differing types of capture method.

Size of eels

The size of eels had the most noteworthy effect on the selection of prey. Eel feeding ecology resembles that of many predatory fish as predator length increases, so does the overall size of the prey, transitioning from invertebrates to fish (Gaeta et al. 2018) (Figure 6). Small eels, 100-199 mm in size, had stomach contents comprised of 85% invertebrates and less then 15% was comprised of fish and crayfish. Eels from 200-299 mm transitioned to feeding on crayfish for 52% of their total ingested prey, 40% invertebrates and 8% fish. Crayfish is the main food source of 300-399 mm eels. At this length, invertebrate abundance continued to decrease, and fish abundance increased. For all eels 400 mm in length or greater, fish comprised 55% or more of all combined stomach contents. The proportion of crayfish fluctuated, but remained as the secondary food source. Invertebrates contribute to less than 25% of the stomach contents of all eels greater then 400 mm, highlighting a transition to a mainly piscivorous feeding behaviour. The variance from this pattern depends upon the specific habitat associations at these locations and the season in which the eels were collected.

Invertebrates

Eels fed most heavily on the orders of trichoptera, odonata, ephemeroptera and amphipoda. Of the other orders found in the stomach contents (see Appendix B), oligochaeta was noteworthy as they are found most commonly in terrestrial environments. Their presence in the stomach contents signify specific environmental events that lead to their translocation to the aquatic environment such as increased land run off and flooding. They occurred predominantly in the Ottawa River during June of 2013, which followed a season of late snowmelt and high rainfall resulting in strong flooding events (Government of Canada 2020). By identifying an increase in oligochaetas in the stomach contents, we have gained insight into an unique environmental event that has periodically resulted in changes to the benthic community. The presence of these outliers highlights the heavy feeding of invertebrates by eels 100-399 mm.

This dependence on invertebrates as a primary food source is related to a number of potential factors associated with eel size, such as predatory abilities, gap width and habitat utilization (Gaeta et al. 2018). Gap width specifically suggest that a predator's prey selection is limited to items which can fit in the width of their mouths, resulting in smaller eels feeding on smaller prey items (Juanes et al. 2002; Machut 2006; Stacey 2013; Lloyst et al. 2015; Gaeta et al. 2018). Invertebrates are an easier prey source to capture as they lack the defence mechanisms and mobility that fish and crayfish have with their increased mobility and speed (Stein and Magnuson, 1976). As size increases the extent of these limiting factors diminishes and eels' transition to increase their feeding on crayfish, while feeding less than 25% on invertebrates.

Crayfish

Crayfish have a key role in the prey ingestion of American eels are a main food source for eels 200-400 mm in size, contributing to approximately 50% of all ingested prey. Crayfish are the secondary prey source in eels greater than 400 mm. There is currently a lack of knowledge in understanding why crayfish may be of specific nutritional value to the American eel. It can be speculated that this is because eels are larger in size, and have a more complex feeding than invertebrates thus resulting in a higher nutritional value. To supplement the lack of crayfish during the moulting periods, eels from 200-299 mm feed heavily upon invertebrates, and eels 300-499 mm have increased feeding on other invertebrates and fish. When eels increase in size they may catch fish more successfully, becoming less dependent on crayfish.

Fish

There is a positive correlation between eel size and the composition of fish. Larger eels have increased swimming speed,burst capabilities, and visual acuity, which could result in increased capture rates of mobile species such as fish (Juanes et al. 2002; Gaeta et al. 2018). Research on other northern freshwater predators highlights that beyond these increased capabilities, foraging success reflects search time, opportunity and prey behavior (Juanes et al. 2002; Gaeta et al. 2018). Eels are shown to transition to piscivore behaviour as their metabolic needs increase, but supplement their bioenergetic needs by feeding on prey where capture success is increased but caloric value is decreased (Juanes et al. 2002). Of all prey ingested, fish contribute to over 55% of large eels feeding (400 mm or greater). When fish are unavailable, or eels have unsuccessful captures they feed opportunistically on invertebrates and crayfish. Fish contributed to a significant proportion of the total prey ingested, and the relationship between eel ingestion and fish species diversity become increasingly important when understanding how eels interact within the entire ecosystem.

Of the fish species recorded, alewife (*Alosa Pseudoharengus)* have been previously believed to be a significant prey choice for American eels (Fitzsimons et al. 2013; MacGregor et al. 2013). In contradiction, our data shows that alewife contribute to less than 2% of the fish found in the stomach contents and thus are not a significant prey source for American eels. Furthermore the diversity of fish species highlights important ecological information.

Ottawa River was the most diverse location, having nine different identified species, and four unidentified species. Whereas in all other locations, gobies were the most abundant species found within the stomach contents. Using this information it can be understood that the round goby in the Ottawa River and tributaries must be newly invaded by gobies in comparison to the other more heavily invaded locations, and has not caused a loss of species diversity (King 2019; Miller 2019). American eels are not defined as selectively feeding on specific fish species, but rather feed opportunistically on the species available within this ecosystem (Facey and Labar 1981; Machut 2006). Thus the stomach contents can be used to accurately depict prey species diversity within an ecosystem, and act as an indicator of changes in this diversity, such as invasion of the round goby.

Other important relationships

Where round gobies had become well established, they were the fish species most frequently consumed (77%). The importance of gobies has the potential for bias as gobies found in stomach contents from eels the St. Lawrence River at Mallorytown landing comprised 50% of all gobies found (N=96). Despite this high proportion from one location, the number of gobies from all other locations remained proportionally higher than any other species (21% higher than yellow perch next most abundant fish (6%)). This further proved the importance of gobies as a species in the overall stomach contents even though there is the potential for bias in percent frequency.

American eels act as a key predator in these environments, reflecting their ecological role of controlling benthic fish populations through predation (Stranko et al. 2014). Gobies invaded at a time when eels were in a historically low abundance. It can be hypothesized that if eels had been abundant, they would have preyed upon the gobies when they first invaded, potentially slowing the invasion of this species. This ecological service would have allowed this system to maintain the natural integrity of species diversity, that is now jeopardized due to the predatory nature of round gobies (Lee and Johnson 2005). Other invasive or alien species, such as rock bass and dreissenid mussels, occurred in the stomachs, but are not as prevalent as round gobies.

Dreissenid mussels, specifically zebra mussels were present in thirteen of the eels stomach contents, often appearing with other prey types specific to the benthic environment. As eels feed on benthic species, the presence of these mussels in stomach contents is assumed to be an accidental ingestion. Likewise, the accidental ingestion of these mussels showcases the environment in which they are ingesting their prey in, and the high likelihood that this environment has been altered by zebra mussels. It is still unclear if the effect of these dreissenid mussels on the ecosystem has had a positive or negative influence on the feeding ecology of eels, because eels still maintain feeding behaviour in habitats that were previously recorded. Rather the presence of invasive dreissenid mussels in the stomach contents is not a reflection of prey selection but rather their feeding habitat in which an invasion has occurred.

Although native to parts of central North America, the rock bass, *Ambloplites rupestris*, is a well-established introduced species in the Upper St. Lawrence River, the Ottawa River and Lake Ontario, residing in nearshore rocky environments (Scott and Crossman 1985; Holm et al. 2009). The spiny rays of the rock bass make them hard to digest and avoided by predatory fish and they outcompete larger predators for resources (Trumpickas et al. 2011). With a lack of predation, this highly competitive and aggressive fish has been linked to decreasing prey fish diversity of rocky near shore habitats (Grossman et al. 1995; Vander Zanden et al. 1999; Trumpickas 2010). However, rock bass were found only in three eels stomach contents, two from the Ottawa River and one from the St. Lawrence River below the Moses-Saunders dam. American eels do have the ability to ingest rock bass despite their spiny rays. Despite this, rock bass remain insignificant to American eel overall prey ingestion in comparison to other prey fish known to be found at these locations. This ingestion highlights the ability for stomach content analysis to give insight into key trophic relationships that may be poorly understood through other observational and experimental studies. The presence of rock bass, and their interaction with American eels was further highlighted by the ingestion of eggs, which were identified by Professor Casselman as rock bass eggs.

Thirty four of the eels had stomachs containing eggs, of which 18 stomachs were identified to contain specifically goby eggs. Eels are speculated to have ingested the eggs as a by-catch while preying upon a parent guarding the nest. Gobies are known to guard their nest aggressively, and specifically the presence of goby eggs often coincided with an adult gobies in the stomach contents. Four stomachs contained crayfish eggs, and other stomachs were recorded to contain larval sized crayfish. Female crayfish carry their eggs in their pleopods, thus these eggs were speculated to be ingested as bycatch when a whole crayfish was consumed (Scudamore 1947, 1948). Seven other stomachs contained fish eggs one was identified as rock bass. As prey fish are frequently ingested by American eels, it may be assumed that the eel attempted to capture a mature fish that was guarding a nest full of eggs, and either successfully or unsuccessfully caught the parent, incidentally ingesting eggs at the same time. However, eggs were present in a stomach containing yellow perch which is a non-nesting species. Furthermore, five stomachs contained eggs and no other contents thus suggesting a selected ingestion of eggs. American eels have been cited to feed heavily upon fish eggs as a source of food (Greene et al. 2009; Stacey 2013). The occurrence of eggs alone highlights that American eels do not only accidently ingest eggs as a by-catch but specifically ingesting them.

The macrophytes that were ingested in the stomach contents are commonly described as fine leafed macrophytes. One stomach had only vegetation in the stomach, with no other contents. As eel size increases they shift from rocky habitat to silty habitats with increased density of macrophytes such as *Chara vulgaris* (Lloyst et al. 2015). Eels have been observed to use macrophytes as camouflage while they stalk prey and avoid predation (Lloyst, 2013). The presence of this genus of macrophyte within the stomach contents gives us insight into the habitat utilized by the eels when they're feeding, ingesting vegetation accidentally. Stomachs that contained vegetation often contained invertebrates.

Limitations

The major limitation to remaining accurate in calculating weights of ingested items is that the total body weight of a stomach that has assorted items reflects different digestion rates. This causes a lack of certainty in the amount of a specific prey type ingested and may over represent hard bodies that are more difficult to digest. To limit the extent of this bias, further calculations of present frequency of each prey type and further specific invertebrate identification should be performed. This would transition the data from placing importance of frequency rather than a proportion of total weight ingested.

It is impossible to pinpoint how long ingested items were in a stomach and this time lapse has the potential to influence the quantity that is estimated. This may under represent the amount of quickly digested prey in the stomach contents as eels were observed to be nocturnal feeders (Lookabaugh and Angermeier 1992). The extent of this bias is unknown but is believed to be minimal due to methodical capturing of the eels in the original surveys as well as careful identification skills. To overcome this bias, other studies have used stable isotope indicators to track long term feeding patterns within each eel (Machut, 2006). However, stable isotope indicators limit the insight that can be gained by generalising prey type to groups such as fish and invertebrates (Machut, 2006). Furthermore various prey types, soft bodies and hard bodies are known to have different digestion rates (Amundsen and Sánchez-Hernández 2019). To overcome this limitation, identification was done by trained technicians and reconfirmed by Professor Casselman. Furthermore, during analysis invertebrates were categorized together, limiting the significance of specific genera and species. Rather we focused on the group of invertebrates, showing their importance to the disgestion patterns of the American eels.

Another limitation that may have occurred in this study is the absence of intestinal contents in the analysis. A number of intestinal contents were collected and preserved along with the stomach contents. However, during this study, we only analyzed the stomach contents due to their greater frequency.

When investigating the origin of the eel, our data did not conclude any differences associated specifically with origin of eel. This was limited by our ability to control location as a factor which affects feeding. Intuitively there may be difference in location specific data which included eels that may be from varying origins, either stocked or migrated. The extent of this bias is uncertain but believed to be minimal as clear patterns in ingestion were identified and overall the abundance of non-stocked eels is extremely low among various locations (Casselman and Marcogliese, 2014). Further studies comparing ingestion patterns from eels of different origins should be done using historical stomach content data from one location to avoid the differences observed. Identifying the extent to which each variable may be affecting feeding and the understanding of the relative importance of a combination of factors was limited. To overcome this, factorial analysis of variances should be used to assess and assign the statistical significance of interacting variables. In doing so, this would enhance the knowledge gained throughout this study.

Conclusion

The results from the study are unique in that they represent an extensive, large scale description of American eel feeding ecology in the St. Lawrence River, Ottawa River and eastern Lake Ontario. Previously, Stacey (2013) was only able to describe the feeding patterns of eels from two locations either in spring or fall. Stauffer and Denoncourt (1993) were limited to only having 325 eels in their study and did not consider size of eel. Facey and Labar (1981) examined 427 eels, with a limited size range of 430-920 mm. These limitations were not present within our study as 1513 eels, and 880 (58%) with contents. These eels were from varying origins, capture methods, dates of capture, locations, and sizes were all included. The effect of these individual variables on prey ingestion was determined, providing a new and important understanding of American eel's feeding ecology.

By controlling the factors that may potentially influence eel ingestion we were able to describe the feeding ecology of American. Our results showed that the capture method and origin of the eel do not greatly affect the feeding ecology of an eel. Location differences producing microhabitats may have varying energy flows and can thus affect prey diversity and availability broadly. More specifically within microhabitats, seasonal differences governed by changing temperature are seen to influence ectotherm behaviour, resulting in changes in eel feeding and specific prey availability i.e., crayfish. When these associations are taken into considerations and differentiated, ingestion patterns are most strongly related to the size of the eel.

Prey dependence shifts with eel size, transitioning from small eels feeding heavily on invertebrates, to increased dependence on crayfish, with the largest eels displaying piscivorous behavior. As the size of eels increased overall stomach fullness decreased. Using eel size as a scale of prey ingestion, the specific influence of microhabitats and seasonal fluctuations can be further understood. Our large data set has clearly identified the patterns associated with eel feeding ecology and as a result highlighted the ecological services that an eel provides.

American eels stomach contents provide an accurate sample of the current nearshore prey communities, as they act as top predators. In previous high abundances, the American eel could have acted as a control on nearshore benthic prey population. If this high abundance was maintained, eels might delay the establishment of invasive species, predominantly the round goby. If populations are maintained or increased, stomach content analysis could be used as part of a long term monitoring, that could provided insights concering prey community. This would allow for accurately identifying the timing of ecological events, which would provide information needed to improve on current conservation efforts that lack the insights gained through stomach content analysis. Specifically, the analysis of stomach contents of small eels show insight into benthic community structure, specifically outlining a predator influence on the invertebrate assemblage. Stomach contents of larger eels alternatively offer insight into prey fish community diversity and structure. Stomach contents specifically show interactions between species which may not be clear through traditional fish communities, such as seine netting and electrofishing which often only collect quantitative data. As seen through stomach content analysis, the decline of the American eel has resulted in the tragic loss of an ecological service which richly benefited this ecosystem.

The American eel is a tragic example of how anthropogenic stressors can endanger a species existence subsequently jeopardizing an ecosystem's integrity. This study has used stomach content analysis to exemplify how maintaining and increasing the population of American eels has many positive attributes. The benefits of an increased eel population have the potential to help mitigate long term negative effects associated with invasive species and change ecosystem structures.

Summary of Main Points

1. The general objectives of this study were to identify the main variables influencing eel ingestion patterns and describe what has occured. Once identified, the importance of the ecological services associated with the American eels feeding patterns were clearly identified.
2. The factors that have the potential to affect ingestion patterns were seasonal timing, location of eel capture, origin of the eel, capture method, and size of eel.
3. Seasonality affected the frequency of feeding and the abundance of crayfish. There was a decrease in feeding on crayfish during the spring and to lesser extent the fall, coinciding with the crayfish molting periods. Concurrently in times of low crayfish abundance, fish and invertebrate's consumption increased
4. Location affected the amount of prey ingested as well as the diversity of prey found. The Ottawa River was a location where eels consumed less than three-fold the amount of prey in comparison to eels from different locations. Differences in prey diversity were related to habitats at each location that are specific to prey type. Different habitats included rocky boulder habitats of Lake Ontario yielding an increase in gobies, both sandy and rocky habitats of the St. Lawrence river showing an increased overall prey diversity and similar environments shaped by hydrological activity upstream of a dam which results in a lack of diversity.

5. Origin of the eel, both stocked and non-stocked showed to not have a strong influence on ingestion patterns due to the overriding importance that location has. In further studies, stocked and migrated eels caught in the same location should be used to assess the further potential of this variable.
6. Both methods of capture, electrofishing and hoop-net, showed similar composition of prey. The total mean stomach contents from hoop-net caught eels weighed 18% more than the mean total stomach contents of electro fished eels.
7. Considering a comparison of results by location, eel size was shown to be the most important variable influencing type of prey consumed.
8. Small eels, 100-199 mm in size, had stomach contents comprised of 86% invertebrates and less then 15% was comprised of fish and crayfish. Eels from 200-299mm transitioned to feeding on crayfish for 54% of their total ingested prey, 40% invertebrates and 8% fish. Crayfish is the main food source of 300-399 mm eels. At this length invertebrate abundance continued to decrease, and fish abundance increased. For all eels larger than 400 mm, fish comprise a
9.
10.
11. t least 50% of all stomach contents, the proportion of crayfish changes although they continue to be the secondary food source, and invertebrates contribute to less than 25% of the stomach contents.
12. The stomach contents reflected a diversity of prey types, highlighting specific ecosystem interactions. In many instances the stomach contents gave unique insight into specific

interactions such as the eel's heavy predation on gobies, ingestion of eggs and an the timing of an increase of oligochaeta in the aquatic ecosystem following a flooding event.

13. Eels act as an important predator that preys heavily on invasive species such as round gobies. The benefits of having an increased American eel population are shown to have substantial positive effects on the aquatic environment that in low populations may bot be substantial.

Citations

Amundsen, P. A., and J. Sánchez-Hernández. 2019. Feeding studies take guts – critical review and recommendations of methods for stomach contents analysis in fish. Journal of Fish Biology 95(6):1364–1373.

Barak, N. A. E., and C. Mason. 1992. Population density, growth and diet of eels, *Anguilla Anguilla* L., in two rivers in eastern England. Aquaculture Research 23(1):59-70

Benchetrit, J., M. Béguer-Pon, P. Sirois, M. Castonguay, J. Fitzsimons, and J. J. Dodson. 2017. Using otolith microchemistry to reconstruct habitat use of American eels (*Anguilla rostrata)* in the St. Lawrence River–Lake Ontario system. Ecology of Freshwater Fish 26(1):19-33.

Braga, R. R., H. Bornatowski, and J. R. S. Vitule. 2012. Feeding ecology of fishes: An overview of worldwide publications. Reviews in Fish Biology and Fisheries 22(4):915–929.

Brousseau, C. M., R. G. Randall, J. A. Hoyle, and C. K. Minns. 2011. Fish community indices of ecosystem health: How does the Bay of Quinte compare to other coastal sites in Lake Ontario? Aquatic Ecosystem Health and Management 14(1):75–84.

Cairns, D. K., V. Tremblay, F. Caron, J. M. Casselman, G. Verreault, B. M. Jessop, Y. De Lafontaine, R. G. Bradford, R. Verdon, P. Dumont, Y. Mailhot, J. Zhu, A. Mathers, K. Oliveira, K. Benhalima, J. P. Dietrich, J. A. Hallett, and M. Lagacé. 2008. American eel abundance indicators in Canada. Canadian Data Report of Fisheries and Aquatic Sciences 1207.

Casselman, J. M. 2003. Dynamics of Resources of the American Eel, Anguilla rostrata: Declining Abundance in the 1990s. Pages 255–274, Chapter 18 in K. Aida, K Tsukamoto, K Yamauchi (eds) Eel Biology. Springer Japan.

Dekar, M. P., D. D. Magoulick, and J. Beringer. 2010. Bioenergetics assessment of fish and crayfish consumption by river otter (*Lontra canadensis*): Integrating prey availability, diet, and field metabolic rate. Canadian Journal of Fisheries and Aquatic Sciences 67(9):1439–1448.

Denoncourt, C. E., and J. R. Stauffer. 1993. Feeding Selectivity of the American Eel (*Anguilla rostrata LeSueur*) in the Upper Delaware River. American Midland Naturalist 129(2):301-308.

Dörner, H., and S. Berg. 2016. Feeding Ecology. Pages 171–192 Chapter 9 *in* T. Arai, (ed). Biology and Ecology of Anguillid Eels, 1st edition.

Dove-Thompson, D., C. Lewis, P. A. Gray, C. Chu, and W. I. Dunlop. 2011. A Summary of the Effects of Climate Change on Ontario's Aquatic Ecosystems. Pages 1–2 Climate Change Research Report. Applied Research and Development Ontario Forest Research Institute, Ministry of Natural Resources, Sault Ste. Marie, Ontario.

Dubs, D. O. L., and L. D. Corkum. 1996. Behavioral interactions between round gobies (*Neogobius melanostomus*) and mottled sculpins (*Cottus bairdi*). Journal of Great Lakes Research 22(4):834-844.

Dutton, E. 2017. Ontario Crayfish Dichotomous Key. Credit Valley Conservation Authority.

Facey, D. E., and G. W. Labar. 1981. Biology of American eels in Lake Champlain, Vermont. Transactions of the American Fisheries Society 110(3):396–402.

Fitzsimons, J. D., S. B. Brown, L. R. Brown, G. Verreault, R. Tardif, K. G. Drouillard, S. A. Rush, and J. R. Lantry. 2013. Impacts of diet on thiamine status of Lake Ontario American eels. Transactions of the American Fisheries Society 142(5):1358–1369.

French, J. R. P., and D. J. Jude. 2001. Diets and diet overlap of nonindigenous gobies and small benthic native fishes co-inhabiting the St. Clair River, Michigan. Journal of Great Lakes Research 27(3):300-301

Gaeta, J. W., T. D. Ahrenstorff, J. S. Diana, W. W. Fetzer, T. S. Jones, Z. J. Lawson, M. C. McInerny, V. J. Santucci, and M. J. Vander Zanden. 2018. Go big or . . . don't? A field-based diet evaluation of freshwater piscivore and prey fish size relationships.Plos one 13(3):1–20.

Gagnaire, P. A., E. Normandeau, C. Côté, M. M. Hansen, and L. Bernatchez. 2012. The genetic consequences of spatially varying selection in the panmictic American eel (*Anguilla rostrata*). Genetics 190(2):725–736.

Government of Canada. 2020. Real-Time Hydrometric Data Graph for Outaouais (Riviere Des) A Terrerasse-Vaudreuil (02OA107) [QC]. https://wateroffice.ec.gc.ca/report/historical_e.html?stn=02OA107&dataType=Daily&parm

eterType=Flow&year=2013&mode=Graph.

Greene, K. E., J. L. Zimmerman, R. W. Laney, and J. C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs. Atlantic States Marine Fisheries Commission Habitat Management Series No. 9, Washington, D.C.

Grossman, G. D., R. E. Ratajczak, and M. K. Crawford. 1995. Do Rock Bass (A*mbloplites rupestris*) Induce Microhabitat Shifts in Mottled Sculpin (*Cottus bairdi*)? Copeia 1995(2):343–353.

Grover, S. C. 1955. Induction of moulting in the crayfish, *Cambarus sp* by modification of daily photoperiod. Biological Bulletin108(2):235–241.

Guan, Z., C. Lu, S. Mei, and J. Cong. 2010. Seasonality of interannual inter-hemispheric oscillations over the past five decades. Advances in Atmospheric Sciences 27(5):1043–1050.

Guiaşu, R. C., and D. W. Dunham. 2001. Observations on the timing of moulting events in the crayfish Cambarus *robustus Girard*, 1852 (Decapoda, Cambaridae). Crustaceana 74(11):1365–1378.

Haxton, T. 2007. Impacts of waterpower management on select fish in the Ottawa River, Canada with emphasis on Lake Sturgeon.(Masters Thesis) University of Ottawa. Ottawa Ontario

Higgins, S. N., and M. J. Vander Zanden. 2010. What a difference a species makes: a meta-analysis of Dreissenid Mussel impacts on freshwater ecosystems. Ecological Monographs 80(2):179–196.

Holm, E., N. Mandrak, and M. Burridge. 2009. The ROM field guide to freshwater fishes of Ontario. ROM, Toronto Ontario.

Hudon, C., P. Gagnon, M. Rondeau, S. Hébert, D. Gilbert, B. Hill, M. Patoine, and M. Starr. 2017. Hydrological and biological processes modulate carbon, nitrogen and phosphorus flux from the St. Lawrence River to its estuary (Quebec, Canada). Biogeochemistry 135(3):251–276.

Itakura, H., T. Kaino, Y. Miyake, T. Kitagawa, and S. Kimura. 2015. Feeding, condition, and abundance of Japanese eels from natural and revetment habitats in the Tone River, Japan. Environmental Biology of Fishes 98(8):1871–1888.

Jacoby, D., J. Casselman, M. DeLucia, G. A. Hammerson, and M. Gollock. 2014. American eel, (*Anguilla rostrata)*. The IUCN Red List of Threatened Species.

Jellyman, D. J. 1996. Diet of longfinned eels (*Anguilla dieffenbachii)* in Lake Rotoiti, Nelson Lakes, New Zealand. New Zealand Journal of Marine and Freshwater Research.30(3): 365-

369

Jessop, B. M. 1987. Migrating American eels in Nova Scotia. Transactions of the American Fisheries Society 116(2):161–170.

Jessop, B. M. 2010. Geographic effects on American eel (*Anguilla rostrata*) life history characteristics and strategies. Canadian Journal of Fisheries and Aquatic Sciences 67(2):326–346.

Juanes, F., J. A. Buckel, and F. S. Scharf. 2002. Feeding Ecology of Piscivorous Fishes. Pages 267–283 *in* P. J. . Hart and J. D. Reynolds, editors. Handbook of Fish Biology and Fisheries, Volume 1. Blackwell Publishing.

Killourhy, C. 2013. Predation on centrarchid nest in the St. Lawrence River Following Introduction of the Round Goby (*Neogobius melanostomus*). (Masters Thesis) State University of New York, Syracuse New York.

King, L. 2019. Gobies in the Rideau Canal. Ontario Out of Doors. Peterborough Ontario.

Lafontaine, Y. de, P. Gagnon, and B. Côté. 2010. Abundance and individual size of American eel (*Anguilla rostrata*) in the St. Lawrence River over the past four decades. Hydrobiologia 647(1):185–198.

Lee, V. A., and T. B. Johnson. 2005. Development of a bioenergetics model for the round goby (*Neogobius melanostomus)*. Journal of Great Lakes Research 31(2):125–134.

Lima, A. C., D. Sayanda, A. M. V. . Soares, F. J. Wrona, and K. A. Monaghan. 2016. Integrating taxonomic and trait analyses to asses the impact of dammin on fish communities in a northern cold region river. Canadian Journal of Fisheries and Aquatic Sciences 74(4):452–463.

Lloyst, M. H. M. 2013. The distribution and habitat associations of stocked American Eel, *Anguilla rostrata*, in Lake Ontario and the Upper St. Lawrence River. (Masters Thesis) Trent University. Peterborough Ontario

Lloyst, M. H. M., T. C. Pratt, S. M. Reid, and M. G. Fox. 2015. Nearshore habitat associations of stocked American eel (*Anguilla rostrata*) in Lake Ontario and the upper St. Lawrence River. Journal of Great Lakes Research 41(3):881–889.

Lookabaugh, P. S., and P. L. Angermeier. 1992. Diet patterns of American eel, (*Anguilla rostrata)*, in the James river drainage, Virginia. Journal of Freshwater Ecology 7(4):425–431.

Lowles, A. G. 2013. Effect of envrionmental factors, physical barriers and season on the fish community copmositionof the Lower Ottawa and Mississippi River systems as determined from Quantitative Electrofishing. (Masters Thesis) Queen's Univeristy. Kingston Ontario

MacGregor, R., J. Casselman, L. Greig, W. Dettermers, W. . Allen, L. McDermott, and T. Haxton. 2013. American Eel (*Anguilla rostrata*) in Ontario; Ontario Recovery Strategy Series. Ontario Ministry of Natural Resources, Peterborough Ontario.

Machut, L. . 2006. Population dynamics, *Anguillicola Crassus* infectionn, and feeding selectiviity of American eel (*Anguilla Rostrat*a) in tributaries of the Hudson River, New York. (Masters Thesis) State University of New York, Syracuse New York.

Mayerle, J. A., and D. G. Butler. 1971. Effects of temperature and feeding on intermediary metabolism in North American eels (A*nguilla rostrata LeSueur*). Comparative Biochemistry and Physiology Part A: Physiology 40(4):1087–1095.

Miller, R. 2019, July 21. Invasive round goby fish found in Rideau Canal. CBC News. Ottawa Ontario.

Mills, E. ., J. M. Casselman, R. Dermott, J. D. Fitzsimons, G. Gal, K. . Holeck, J. . Hoyle, O. . Johannsson, B. F. Lantry, J. . Makarewicz, E. . Millard, I. . Munawar, M. Munawar, R. O'Gorman, R. . Owens, L. . Rudstam, T. Schaner, and T. . Stewart. 2003. Lake Ontario: food web dynamcs in a changing ecosystem (1970-2000). Canadian Journal of Fisheries & Aquatic Sciences 60(4):471–491.

Oates, D. W., L. M. Krings, and K. L. Ditz. 1993. Field Manual for the Identification of Selected North American Freshwater Fish by Fillets and Scales, 19th edition. Nebraska Game and Parks Commision, Lincon, Nebraska.

Ouellet, V., Y. Secretan, A. St-Hilaire, and J. Morin. 2014. Daily average 2D temperature model for the St. Lawrence River. Journal of River Research and Applications 30(1):132–133.

Pennak, R. W. 1978. Fresh-Water Invertebrates of the United States. John Wiley & Sons, Inc., United States of America.

Pratt, T. C., and R. W. Threader. 2011. Preliminary evaluation of a large-scale American eel conservation stocking experiment. North American Journal of Fisheries Management 31(4):619–628.

Ribey, S. C. 1997. Characterization of littoral fish sssemblages and their habitat in the St. Lawrence River near Cornwall, Ontario. (Masters Thesis) University of Ottawa, Ottawa Ontario.

Rush, S. A., G. Paterson, T. B. Johnson, K. G. Drouillard, G. D. Haffner, C. E. Hebert, M. T. Arts, D. J. Mcgoldrick, S. M. Backus, B. F. Lantry, J. R. Lantry, T. Schaner, and A. T. Fisk. 2012. Long-term impacts of invasive species on a native top predator in a large lake system. Freshwater Biology 57(11):2342–2355.

Schmidt, J. 1922. The Breeding Places of the Eel. Philosophical Transactions of the Royal Society of London 211:179–208.

Scott, W. ., and E. . Crossman. 1969. Checklist of Canadian Freshwater Fishes with Keys for Identification. Page G. . Wiggins and R. . Peterson, editors. Royal Ontario Museum, Toronto Ontario.

Scott, W. ., and E. . Crossman. 1985. Freshwater Fishes of Canada. Page Department of Fisheries and Oceans, editor. Royal Ontario Museum, Ottawa Ontario.

Scudamore, H. H. 1947. The Influence of the sinus glands upon moulting and associated changes in the crayfish. Physiological Zoology 20(2):187–208.

Scudamore, H. H. 1948. Factors influencing moulting and the sexual cycles in the crayfish. The Biological Bulletin 95(2):229–237.

Stacey, J. A. 2013. The life history strategy, growth, body condition, and diet of stock American eel (*Anguilla rostrata*) in the upper St. Lawrence River and Lake Ontario. (Masters Thesis) Trent University. Peteborough Ontario

Stein, R., & Magnuson, J. 1976. Behavioral response of crayfish to a fish predator. Ecology*,* 57(4)751-761.

Stranko, S. A., M. J. Ashton, R. H. Hilderbrand, S. L. Weglein, D. C. Kazyak, and J. V. Kilian. 2014. Fish and benthic macroinvertebrate densities in small streams with and without American eels. Transactions of the American Fisheries Society 143(3):700–708.

Tomie, J. P. . 2012. The ecology and behavior occupancy by the American eel. (Masters Thesis) Cape Breton University. Sydney Nova Scotia

Travis, D. 1960. The deposition of skeletal structures in the crustacea . I . the histology of the gastrolith skeletal tissue complex and the gastrolith in the crayfish Orconectes (*Cambarus Virilis*). Biological Bulletin 118(1):137–149.

Trumpickas, J. 2010. Impacts of introduced piscivores on lake fish assemblages.(Masters Thesis) McGill University. Montreal Quebec

Trumpickas, J., N. Mandrak, and A. Ricciardi. 2011. Nearshore fish assemblages associated with introduced predatory fishes in lakes. Aquatic Conservation: Marine and Freshwater Ecosystems 21(4):338–347.

Walsh, P. J., G. D. Foster, and T. W. Moon. 1983. The Effects of Temperature on Metabolism of the American Eel Anguilla rostrata (LeSueur): Compensation in the summer and torpor in the winter. Physiological Zoology 56(4):532–540.

Wantola, K. E. 2013. Fanning behaviour and communication in the Round Goby (*Neogobius Melanostomus*), an invasive fish. (Masters thesis) Department of Biological Sciences, University of Windsor, Windsor Ontario.

Westhoff, J. T., and A. E. Rosenberger. 2016. A global review of freshwater crayfish temperature tolerance, preference, and optimal growth. Reviews in Fish Biology and Fisheries 26(3):329–349.

Wheatly, M. G., and A. T. Gannon. 1995. Ion regulation in crayfish: Freshwater adaptations and the problem of moulting. American Zoologist 35(1):49–59.

Zale, A. V, D. L. Parrish, and T. M. Sutton, editors. 2012. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethseda, Maryland, USA.

Vander Zanden, M. J., J. M. Casselman, and J. B. Rasmussen. 1999. Stable isotope evidence for the food web consequences of species invasions in lakes. Nature 401(6752):464–467.

Appendices

Appendix A: List of Fish Species

Names of Fish Species, Scientific Names (Common Names)	
Family Name	Species Names
Clupeidae (Herrings)	
	Alosa Pseudoharengus (Alewife)
Cyprinidae (Minnows)	
	Notropis hudonius (Spottail Shiner)
	Notropis heterodon (Blackchin Shiner)
	Pimephales notatus (Bluntnose Minnow)
	Pimephales promelas (Fathead Minnow)
Icaluridae (Bullhead Catfishes)	
	Ameiurus nebulosus (Brown Bullhead)
Centrarchidae (Sunfishes)	
	Ambloplites rupestris (Rock bass)
	Lepomis gibbosus (Pumpkinseed)
	Micropterus dolomieu (Largemouth Bass)
Percidae (Perches)	
	Perca flavescens (Yellow Perch)
	Etheostoma nigrum (Johnny Darter)
Gobiidae (Gobies)	
	Neogobius melanostomus (Round goby)
Cottidae (Sculpins)	
	Cottus Bairdi (Mottled sculpin)

Appendix B: List of Invertebrate Taxonomy

Phylum Subphylum	Class Subclass	Order Suborder	Family	*Genus*
Platyhelminthes				
	Cestoda (Tapeworms)			
	Trematoda (Flukes)			
	Turbellaria (Flatworms)			
Annelida				
	Nematoda (roundworms)			
	Hirudinea (Leech)			
	Oligochaeta (earthworms)			
Arthropoda				
Crustaceans				
	Ostracoda			
	Copepoda			
	Branchiopoda			
		Cladocera		*Daphia*
		Amphipoda		
		Decapoda		
		Isopoda		*Acellus*
	Arachnida			
			Hydracarina (Water-mite)	
	Insecta			
		Diptera		
			Simuiidae (Blackflies)	
			Chironomidae (Bloodworms, Midges)	
				Nematocera (Misquitoes)
				Chaoboridae *Chaoborus*
		Odonata		
			Anisoptera (Dragonflies)	
			Zygoptera (Damselflies)	
		Ephemeroptera (Mayflies)		
		Plecoptera (Stoneflies)		
		Trichoptera (Caddishflies)		
		Megaloptera (Domsonflies)		
		Coleoptera (Water-pennies)		
		Hemiptera (Water-bugs)		
Mollusca				
	Gastropoda (Snails)			
	Pelecypoda (Clams)			

Appendix C: Summary Statistics for length groups 100-599 mm at all Locations

Total Length 100-199mm

		PREY TYPE				
Location		Total	Fish	Crayfish	Inv.	Other
Jones Creek (N=40)						
	Low 95% C.L	1.25	-0.08	<.01	1.01	-0.02
	Mean	1.58	0.08	1.06	1.36	0.02
	High 95% C.L	1.91	0.24	0.217	1.72	0.08
St. Lawrence River Mallorytown Landing area (N=11)						
	Low 95% C.L	1.16	0	0	0.96	-0.37
	Mean	1.87	0	0	1.57	0.3
	High 95% C.L	2.58	0	0	2.17	0.97
Total (N=51)						
	Low 95% C.L	1.35	-0.64	-3.32	1.11	-0.05
	Mean	1.64	0.06	0.08	1.42	0.08
	High 95% C.L	1.93	0.19	0.17	1.7	0.22

Total Length 200-299mm

		PREY TYPE				
Location		Total	Fish	Crayfish	Inv.	Other
St. Lawrence River below Moses-Saunders Dam (N=75)						
	Low 95% C.L	1.34	-0.06	0.91	0.19	<.01
	Mean	1.6	0.06	1.18	0.35	<.01
	High 95% C.L	1.86	1.83	1.46	0.51	0.02
St.Lawernce River Above Moses-Saunders Dam (N=3)						
	Low 95% C.L	-1.16	0	-1.16	0	0
	Mean	1.12	0	1.12	0	0
	High 95% C.L	3.41	0	3.41	0	0
Jones Creek (N=59)						
	Low 95% C.L	1.63	-0.02	0.41	0.78	-0.01
	Mean	2.18	0.02	0.96	1.13	0.07
	High 95% C.L	2.74	0.05	1.51	1.48	0.12
St. Lawrence River Mallorytown Landing area (N=47)						
	Low 95% C.L	1.57	-0.05	0.21	0.73	-0.05
	Mean	2.14	0.14	0.72	1.17	0.11
	High 95% C.L	2.71	0.32	1.24	1.59	0.29
St. Lawrence River Thompsons Bay Area (N=1)						
	Low 95% C.L	0	0	0	0	0
	Mean	1.91	0	1.91	0	0
	High 95% C.L	0	0	0	0	0
Total (185)						
	Low 95% C.L	1.66	<.01	0.75	0.62	<.01
	Mean	1.92	0.063	1	0.79	0.05
	High 95% C.L	2.17	0.13	1.24	0.97	0.11

Total Length 300-399mm

		PREY TYPE				
Location		Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=2)						
	Low 95% C.L	0	0	0	0	0
	Mean	2.72	0	2.31	0.41	0
	High 95% C.L	0	0	0	0	0
St. Lawrence River below Moses-Saunders Dam (N=90)						
	Low 95% C.L	1.28	-0.24	1.08	0.09	<.01
	Mean	1.8	0.252	1.34	0.18	0.01
	High 95% C.L	2.31	2.31	8.34	0.28	0.04
St. Lawrence River above Moses-Saunders Dam (N=4)						
	Low 95% C.L	-0.65	0	-0.65	0	0
	Mean	3.85	0	3.85	0	0
	High 95% C.L	8.34	0	8.34	0	0
Jones Creek (N=64)						
	Low 95% C.L	1.19	-0.07	0.07	0.64	0.02
	Mean	1.6	0.19	0.4	0.88	0.12
	High 95% C.L	2.01	0.46	0.73	1.12	0.22
St. Lawrence River Mallorytown Landing area (N=65)						
	Low 95% C.L	1.68	0.33	0.41	0.41	<.01
	Mean	2.64	0.73	0.69	0.65	<.01
	High 95% C.L	2.6	1.14	0.96	0.91	0.11
Lake Ontario (N=2)						
	Low 95% C.L	0	0	0	0	0
	Mean	3.09	0	2.99	0.1	0
	High 95% C.L	0	0	0	0	0
Total (N=227)						
	Low 95% C.L	1.62	0.126	0.77	0.4	0.02
	Mean	2.19	0.367	0.95	0.52	0.05
	High 95% C.L	2.17	0.61	1.14	0.62	0.09

Total Length 400-499mm

		PREY TYPE				
Location		Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=6)						
	Low 95% C.L	0.15	-0.49	-0.16	-0	0
	Mean	0.9	0.32	0.1	0.48	0
	High 95% C.L	1.65	1.13	0.37	1	0
St. Lawrence River below Moses-Saunders Dam (N=21)						
	Low 95% C.L	0.63	-0.11	0.31	<.01	0
	Mean	1.18	0.47	0.65	0.05	0
	High 95% C.L	1.73	1.06	0.99	0.65	0
St. Lawrence River above Moses-Saunders Dam (N=1)						
	Low 95% C.L	0	0	0	0	0
	Mean	0.69	0	0.69	0	0
	High 95% C.L	0	0	0	0	0
Jones Creek (N=9)						
	Low 95% C.L	0.19	0	0.04	-0	0
	Mean	1.1	0	0.9	0.2	0
	High 95% C.L	2.02	0	1.76	0.48	0
St. Lawrence River Mallorytown Landing area (N=53)						
	Low 95% C.L	1.38	0.617	0.18	0.08	<.01
	Mean	1.84	1.05	0.54	0.22	0.02
	High 95% C.L	2.36	1.48	0.89	0.36	0.05
St. Lawrence River Thompson's Bay area (N=1)						
	Low 95% C.L	0	0	0	0	0
	Mean	0.75	0	0	0.75	0
	High 95% C.L	0	0	0	0	0
Lake Ontario (N=4)						
	Low 95% C.L	0.62	0.62	0	0	0
	Mean	3.26	3.26	0	0	0
	High 95% C.L	5.19	5.91	0	0	0
Total (N=95)						
	Low 95% C.L	1.29	0.54	0.32	0.1	<.01
	Mean	1.6	0.84	0.35	0.19	0.01
	High 95% C.L	1.91	1.15	0.77	0.28	0.03

Total Length 500-599mm

		PREY TYPE				
Location		Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=11)						
	Low 95% C.L	0.5	-0.02	-0.05	0.31	0
	Mean	0.89	0.03	0.16	0.71	0
	High 95% C.L	1.28	0.07	0.38	1.09	0
St. Lawrence River below Moses-Saunders Dam (N=9)						
	Low 95% C.L	0.34	-0.05	-0.13	-0	0
	Mean	0.95	0.49	0.44	0.02	0
	High 95% C.L	1.54	1.03	1.02	0.05	0
St. Lawrence River above Moses-Saunders Dam (N=1)						
	Low 95% C.L	0	0	0	0	0
	Mean	1.36	1.36	0	0	0
	High 95% C.L	0	0	0	0	0
Jones Creek (N=7)						
	Low 95% C.L	0.72	0.32	-0.01	-0.2	0.04
	Mean	2.21	1.87	0.01	0.3	0.03
	High 95% C.L	3.7	3.4	0.04	0.89	0.1
St. Lawrence River Mallorytown Landing area (N=62)						
	Low 95% C.L	1.12	0.45	0.35	0.03	<.01
	Mean	1.43	0.75	0.57	0.1	0.04
	High 95% C.L	1.73	1.04	0.8	0.16	0.09
St. Lawrence River Thompson's Bay area (N=1)						
	Low 95% C.L	0	0	0	0	0
	Mean	2.4	2.4	0	0	0
	High 95% C.L	0	0	0	0	0
Lake Ontario(N=4)						
	Low 95% C.L	0.72	0.72	0	0	0
	Mean	1.35	1.35	0	0	0
	High 95% C.L	1.98	1.98	0	0	0
Total (N=95)						
	Low 95% C.L	1.15	0.54	0.27	0.09	<.01
	Mean	1.38	0.77	0.44	0.17	0.03
	High 95% C.L	1.61	1.01	0.6	0.25	0.06

Appendix D: Summary Statistics for length groups 600-1000mm or greater at all Locations

Total Length 600-699mm

	PREY TYPE				
Location	Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=15)					
Low 95% C.L	0.17	-0.04	-0.19	0.06	0
Mean	0.61	0.11	0.26	0.24	0
High 95% C.L	1.05	0.27	0.72	0.42	0
St. Lawrence River below Moses-Saunders Dam (N=7)					
Low 95% C.L	0.34	-0.19	0.03	0	0
Mean	0.95	0.25	0.69	0	0
High 95% C.L	1.55	0.7	1.36	0	0
St. Lawrence River above Moses-Saunders Dam (N=1)					
Low 95% C.L	0	0	0	0	0
Mean	2.39	0	2.39	0	0
High 95% C.L	0	0	0	0	0
Jones Creek (N=2)					
Low 95% C.L	0	0	0	0	0
Mean	0.82	0.81	0	0.02	0
High 95% C.L	0	0	0	0	0
St. Lawrence River Mallorytown Landing area (N=38)					
Low 95% C.L	1.12	0.37	0.51	<.01	<.01
Mean	1.45	0.7	0.85	<.01	<.01
High 95% C.L	1.77	1.02	1.19	0.01	0.03
St. Lawrence River Thompson’s Bay area (N=10)					
Low 95% C.L	1.47	1.55	-0.28	0	<.01
Mean	3.11	2.86	0.22	0	0.03
High 95% C.L	4.74	4.16	0.72	0	0.06
Lake Ontario(N=1)					
Low 95% C.L	0	0	0	0	0
Mean	0.36	0.36	0	0	0
High 95% C.L	0	0	0	0	0
Total (N=74)					
Low 95% C.L	1.12	0.51	0.39	0.01	0
Mean	1.46	0.81	0.61	0.04	0
High 95% C.L	1.75	1.19	0.84	0.09	0

Total Length 700-799mm

	PREY TYPE				
Location	Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=24)					
Low 95% C.L	0.34	<.01	<.01	0.1	-0.02
Mean	0.5	0.08	0.16	0.23	0.02
High 95% C.L	0.67	0.16	0.32	0.35	0.07
Jones Creek (N=1)					
Low 95% C.L	0	0	0	0	0
Mean	1.99	1.89	0	0.1	0
High 95% C.L	0	0	0	0	0
St. Lawerence River At Mallorytown Landing (N=23)					
Low 95% C.L	1.05	0.58	0.07	<.01	-0.01
Mean	1.49	1.07	0.39	0.02	0.01
High 95% C.L	1.94	1.54	0.71	0.05	0.06
St. Lawrence River Thompson’s Bay area (40)					
Low 95% C.L	0.62	0.56	-0.05	<.01	<.01
Mean	0.88	0.81	0.05	0.01	<.01
High 95% C.L	1.15	1.07	0.16	0.02	0.01
Lake Ontario (N=3)					
Low 95% C.L	<.01	-0.32	0	-0	0
Mean	0.22	0.33	0	<.01	0
High 95% C.L	0.75	0.77	0	0.01	0
Total Locations (N=91)					
Low 95% C.L	0.75	0.49	0.06	0.03	<.01
Mean	0.93	0.67	0.16	0.07	0.02
High 95% C.L	1.11	0.85	0.26	0.11	0.03

Total Length 800-899mm

	PREY TYPE				
Location	Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=13)					
Low 95% C.L	0.16	<.01	<.01	<.01	<.01
Mean	0.44	0.19	0.12	0.11	0.02
High 95% C.L	0.72	0.51	0.22	0.21	0.05
St. Lawrence River below Moses-Saunders Dam (N=10)					
Low 95% C.L	0.03	<.01	<.01	0	0
Mean	0.89	0.56	0.33	0	0
High 95% C.L	1.75	1.31	0.7	0	0
St. Lawrence River Mallorytown Landing area (N=5)					
Low 95% C.L	-1.24	-1.53	-1.5	-0.3	<.01
Mean	1.53	1.35	1.35	0.17	<.01
High 95% C.L	4.3	4.25	4.25	0.66	<.01
St. Lawrence River Thompson’s Bay area (N=7)					
Low 95% C.L	0.12	0.02	0	<.01	<.01
Mean	0.91	0.85	0	0.05	<.01
High 95% C.L	1.7	1.67	0	0.12	0.01
Lake Ontario (N=3)					
Low 95% C.L	-0.04	-0.04	0	-0	0
Mean	0.02	0.01	0	<.01	0
High 95% C.L	0.08	0.08	0	<.01	0
Total (N=38)					
Low 95% C.L	0.39	0.19	0.04	<.01	<.01
Mean	0.75	0.55	0.15	0.04	<.01
High 95% C.L	1.12	0.92	0.25	0.08	0.01

Total Length 900-999mm

	PREY TYPE				
Location	Total	Fish	Crayfish	Inv.	Other
Ottawa River and Tributaries (N=9)					
Low 95% C.L	0.2	0.03	<.01	<.01	0
Mean	0.68	0.48	0.17	0.01	0
High 95% C.L	1.15	0.94	0.47	0.03	0
St. Lawrence River below Moses-Saunders Dam (N=2)					
Low 95% C.L	0	0	0	0	0
Mean	1.86	1.85	<.01	0	0
High 95% C.L	0	0	0	0	0
Jones Creek (N=1)					
Low 95% C.L	0	0	0	0	0
Mean	0.25	0.18	0	<.01	0.05
High 95% C.L	0	0	0	0	0
St. Lawrence River Mallorytown Landing area (N=1)					
Low 95% C.L	0	0	0	0	0
Mean	0.42	0	0.42	0	0
High 95% C.L	0	0	0	0	0
Lake Ontario (3)					
Low 95% C.L	-0.23	<.01	<.01	0	0
Mean	0.11	0.09	0.02	0	0
High 95% C.L	0.46	0.48	0.11	0	0
Total (N=16)					
Low 95% C.L	0.19	0.06	-0.03	<.01	<.01
Mean	0.47	0.32	0.12	0.01	<.01
High 95% C.L	0.75	0.58	0.29	0.02	0.01

Total Length 1000 and Greator

	PREY TYPE				
Location	Total	Fish	Crayfish	Inv.	Other
St. Lawrence River below Moses-Saunders Dam (N=2)					
Low 95% C.L	0	0	0	0	0
Mean	0.85	0.43	0.42	0	0
High 95% C.L	0	0	0	0	0
St. Lawrence River Mallorytown Landing area (N=4)					
Low 95% C.L	-0.33	-0.33	0	0	0
Mean	0.67	0.67	0	0	0
High 95% C.L	1.69	1.69	0	0	0
Lake Ontario (N=2)					
Low 95% C.L	0	0	0	0	0
Mean	<.01	0	0	<.01	0
High 95% C.L	0	0	0	0	0
Total (N=8)					
Low 95% C.L	<.01	<.01	<.01	<.01	0
Mean	0.50	0.37	0.12	<.01	0
High 95% C.L	1.03	0.92	0.41	<.01	0