Bait Selection Study of the Invasive European Green Crab (Carcinus maenas) in Newfoundland, Canada.

Mary Alliston Butt

Advisor: Dr. Brett Favaro

University of Akureyri
Faculty of Business and Science
University Centre of the Westfjords
Master of Resource Management: Coastal and Marine Management
Ísafjörður, February 2017
Supervisory Committee

Advisor:
Brett Favaro, PhD.

Reader:
Guðbjörg Ásta Ólafsdóttir, PhD.

Program Director:
Catherine Chambers, PhD.

Mary Alliston Butt
Bait Selection Study of the Invasive European Green Crab (Carcinus maenas) in Newfoundland, Canada.
45 ECTS thesis submitted in partial fulfilment of a Master of Resource Management degree in Coastal and Marine Management at the University Centre of the Westfjords, Suðurgata 12, 400 Ísafjörður, Iceland
Degree accredited by the University of Akureyri, Faculty of Business and Science, Borgir, 600 Akureyri, Iceland

Copyright © 2017 Mary Alliston Butt
All rights reserved

Printing: Háskólaprent, Reykjavik, March 2017
Declaration

I hereby confirm that I am the sole author of this thesis and it is a product of my own academic research.

________________________________________
Mary Alliston Butt
Abstract

The European green crab (*Carcinus maenas*) is an ecosystem engineer due to their advanced resiliency to environmental factors. They can tolerate a wide range of salinity and temperature, and have great dispersal capabilities. As true opportunistic scavengers and with low preference to a specific habitat, green crabs have become a successful marine invasive species. Newfoundland and Labrador, Canada, is one of many locations affected by this invasive species. They are affecting eel grass (*Zostera marina*) beds, competing with native rock crab (*Cancer irroratus*), and foraging on juvenile American lobsters (*Homarus americanus*). This research is focused on the bait used in eradication efforts of green crabs, testing the commonly used Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), short-fin squid (*Illex illecebrosus*), and blue mussels (*Mytilus edulis*). Though all baits caught green crabs of similar carapace width and sex, Atlantic cod was resulted with a significant higher catch per unit effort than the other bait species tested in this study. This knowledge is significant for coastal management, as using a bait which provides a high catch per unit effort will ultimately decline green crab populations, reducing the negative impacts they introduce to the environment.
Útdráttur


Translation Credit: Ari Baldur Baldursson
I dedicate this thesis to my mother and grandmother, as they have always inspired me to succeed, and to my brother who has always been my best friend.
# Table of Contents

Declaration ..................................................................................................................... iii  
Abstract ......................................................................................................................... v  
Útdráttur ........................................................................................................................... vii  
Acknowledgements .......................................................................................................... v  
1. Introduction ................................................................................................................. 1  
   1.1. Invasive Species ........................................................................................................ 1  
   1.2. Marine Invasive Species and Dispersal Mechanisms .............................................. 4  
   1.3. Responses to Aquatic Invasions ............................................................................. 6  
2. Theoretical Overview ................................................................................................. 9  
   2.1. Green Crabs (*Carcinus maenas*) ........................................................................... 9  
   2.1.1. Green Crab Ecology .......................................................................................... 9  
   2.1.2. Green Crab Feeding Ecology .......................................................................... 11  
   2.2 Economic and Ecologic Impacts of the Green Crab Invasion in Newfoundland ... 12  
   2.2.1. Habitat Overlap of the Native Rock Crab (*Cancer irroratus*) ......................... 13  
   2.2.2. Habitat Destruction of Eelgrass (*Zostera marina*) Beds .................................... 13  
   2.2.3. Lobster (*Homarus americanus*) Fishery ....................................................... 14  
   2.3. Green Crab Invasion Control in Newfoundland .................................................... 14  
   2.4 Bait Efficiency Studies ........................................................................................... 15  
   2.5 Goals of this Study ................................................................................................. 16  
3. Methodology ............................................................................................................... 17  
   3.1. Bait Selections ........................................................................................................ 17  
   3.2. Site Locations ......................................................................................................... 19  
   3.3. Fukui Trapping ...................................................................................................... 20  
   3.4. Data Recording – Measurements and Observations ........................................... 22  
   3.5. Analysis ................................................................................................................ 23  
4. Results ....................................................................................................................... 25  
   4.1. Data Exploration ..................................................................................................... 25  
   4.2. Bait Choice Findings ............................................................................................. 30  
5. Discussion .................................................................................................................. 37  
   5.1. Hypothesis Evaluation ......................................................................................... 37  
   5.2. Data Exploration Discussion ............................................................................... 38  
   5.3. The Effect of Bait Choice and Green Crab Catch ............................................... 40  
   5.4. Bycatch ................................................................................................................ 41  
   5.5. Limitations .......................................................................................................... 42  
   5.6. Further Research ................................................................................................. 43  
   5.7. Can Green Crab Become Economically Useful? ................................................. 44  
6. Conclusion .................................................................................................................. 45  
References ..................................................................................................................... 47
List of Figures

Figure 1: Brooding female green crabs caught in Fox Harbour, Newfoundland............ 10

Figure 2: Five spines of the anterolateral margin of the carapace of green crabs.......... 11

Figure 3: Green crab fukui trap locations, blocks A and B, positions 1 through 4, in Fox Harbour, Newfoundland................................................................. 19

Figure 4: Green crab fukui trap locations, blocks C and D, positions 1 through 4, in North Harbour, Newfoundland................................................................. 20

Figure 5: Fukui trap with orange plastic bait can (Gillespie et al., 2007)...................... 21

Figure 6: Comparison of female (left) and male (right) abdominal shape for sex determination ............................................................................................................ 22

Figure 7: Measuring the carapace width of a green crab at the fifth spine/tooth of the anterolateral margin, using digital calipers ......................................................... 22

Figure 8: Total catch of green crabs per fukui trap in relation to soak time in Fox Harbour and North Harbour, Newfoundland. Linear model smooth line function with a 95% confidence interval is used to better visualize trends. ......................... 26

Figure 9: Violin plot of total number of crabs per fukui trap in relation to block and bait type in Fox Harbour and North Harbour, Newfoundland. Median represented by points ...................................................................................................................... 27

Figure 10: Change of catch rates over time in Fox Harbour and North Harbour, Newfoundland, throughout the study period of June 16 to August 11, 2017. Smooth line function with a 95% confidence interval is used to better visualize trends. ...................................................................................................................... 29

Figure 11: Water temperature trends in Fox Harbour and North Harbour, Newfoundland, throughout the study period of June 16 to August 11, 2017. Smooth line function with a 95% confidence interval is used to better visualize trends. ......................... 29

Figure 12: Violin plot of the total number of crabs per fukui trap in relation to bait type in Fox Harbour and North Harbour, Newfoundland. Median is represented by points. ...................................................................................................................... 31

Figure 13: Segmented bar chart of the number of female green crabs per trap (brooding – Y, non-brooding – N), in relation to bait type in Fox Harbour and North Harbour, Newfoundland. ...................................................................................................................... 33
Figure 14: Violin plot of carapace width of total catch of green crabs in relation to bait
type in Fox Harbour (FH) and North Harbour (NH), Newfoundland. Boxplots
(line – median, boxes – upper and lower quartiles) added for statistical clarity. 34

Figure 15: Violin plots of carapace width of male (M) and female (F) green crabs in
relation to bait in Fox Harbour and North Harbour, Newfoundland. Boxplots (line
– median, boxes – upper and lower quartiles) are added for statistical clarity. 35

Figure 16: Violin plots of carapace width of brooding (Y) and non-brooding (N) female
green crabs in relation to bait type in Fox Harbour and North Harbour,
Newfoundland. Boxplots (line – median, boxes – upper and lower quartiles) are
added for statistical clarity. 36

Figure 17: Scatterplot of total green crab catch per fukui trap and the location (block and
position) of baited traps in Fox Harbour (A-B) and North Harbour (C-D),
Newfoundland 39

Figure 18: Bar graph of total bycatch (AE: American Eel (Anguilla rostrate), CU: Cunner
(Tautogolabrus adspersus), RC: Rock Crab (Cancer Irroratus), RG: Rock Gunnel
(Pholis gunnellus), WF: Winter Flounder (Pseudopleuronectes americanus))
caught with each bait type in North Harbour and Fox Harbour, Newfoundland. 42
List of Tables

**Table 1:** Alternative hypothesis in regards to this optimal bait selection study .................. 24

**Table 2** Generalized linear model results from glm(Total.Catch~Bait.x*Block, family=poisson, data=AllData) to determine Block and Bait effectiveness. One coefficient not defined because of singularities .................................................. 28

**Table 3:** Generalized linear model results from glm(Total.Catch~Bait.x*Location, family=poisson, data=AllData) to determine Bait effectiveness. ......................... 32

**Table 4:** Hypothesis evaluation based on results. Bolded text indicates the hypothesis that is accepted for this study, based on results. ................................................................. 38
Acknowledgements

This Master’s program could not have been successful without the help, support, and love from family and friends. A special thank you to Sarah Kennedy for opening my eyes to Ísafjörður and to Dr. Brett Favaro for accepting me as a student, without you this research would not exist. In turn, thank you to Marine Environmental Observation Prediction and Response Network for funding this study, and to Jonathan Bergsheoff for letting me join his field season and continuously being of help. Lastly, thank you to the staff of Háskólasætur Vestfjarða for being my home away from home, for your support and always being there during my magical year in Ísafjörður.
1. Introduction

Conservation biology became a notable field in science in the mid-1980s, and since has been adapted into biological science and natural resource fields, as the importance of conservation is exponentially growing (Sodhi & Ehrlich, 2010). The International Union for the Conservation of Nature (IUCN) defines conservation as “the protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence” (IUCN, n.d.). Conservation is substantial in the prevention of biodiversity loss. Biodiversity is defined by the United Nations Convention of Biology Diversity (CBD) as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (CBD, 2007). Prevention of biodiversity loss is imperative as an increase in biodiversity provides many benefits to the environment and to people, such as enhanced ecosystem productivity and resilience, and the ability to maintain ecosystem services (Worm et al., 2006).

In recent decades, marine biodiversity has been declining at unprecedented rates (Selig et al., 2014). Marine biodiversity loss is caused by of a variety of factors including exploitation, pollution, invasive species, and climate change (Worm et al., 2006). Globally, this continues to be a concern, and countries are investing resources to reverse the declining trend in marine biodiversity loss (Selig et al., 2014).

1.1. Invasive Species

Throughout the world, flora and fauna populations are changing as their environments are hosting both native (or indigenous) and non-native species. A native species is defined as organisms which are historically and evolutionarily present in an area and have arrived by natural means, without human involvement or assistance (Pyšek & Richardson, 2010). Species that extend, via anthropogenic factors, from their native range and establish themselves (capable of surviving and reproducing successfully) in a new territory are...
termed non-native species (also commonly known as alien species or nonindigenous species), whether they introduce benefits, consequences, or having no effect at all (IUCN, 2000). Though there are many ways to define an invasive species, a broad terminology is a non-native species that has created a negative impact, whether it be ecologically, economically, or socially (Davis et al., 2011; McNeely et al., 2001; Molnar et al., 2008). This “negative impact” is therefore a calculation of human values, which are dynamic, changing from individual and area (Lodge et al., 2006). Species causing a net harm, allowing the identification of an invader, requires a collected view from individuals across a broad spectrum of professionals, from economists to ecologists. Time and spatial scale is another factor which requires determination for defining what is an invasive species and what is not (Lodge et al., 2006). In this paper, invasive species will be referred to by using the broad definition which was stated above. It is estimated that 5% to 20% of non-native species are invasive (IUCN, 2000). Invasive species are one of the leading causes of biodiversity loss (Bellard et al., 2012).

Invasive non-native species cause negative ecological impacts (Davis et al., 2011). Resource competition, including niche and food competitions between native and non-native species, is common. Non-native species outcompete the native species, causing a decline in native population levels (Mooney & Cleland, 2001). Another concern with invasive species includes the predation upon native species (Sodhi & Ehrlich, 2010). These ecological disruptions caused by invaders all pose the possibility of the extinction of native species (Mooney & Cleland, 2001). The environment’s physical structure can be modified by invaders, causing habitat loss and habitat destruction. Pathogens and parasites may also travel with invasive species, potentially causing an outspread of diseases and extinction of native species (Sodhi & Ehrlich, 2010). Lastly, hybridization of closely related native and non-native species is a concern as this may result in a genetic extinction of the native species, or the production of non-fertile offspring (Sodhi & Ehrlich, 2010).

Socioeconomic damage is another potential negative impact caused by invasive species. Ecosystem services such as tourism (Worm et al., 2006), and livelihoods dependent upon the use of natural resources, for example fisheries, can be compromised due to invasive species and their negative ecological impacts (Pyšek & Richardson, 2010). A decline in the availability of ecosystem services causes major impacts upon the livelihoods of people who depend on the environment for their income (Sodhi & Ehrlich, 2010). Pathogens and
parasites not only affect native species, but can also cause outbreaks to the human population, such as the case with severe acute respiratory syndrome (SARS) (Pyšek & Richardson, 2010). In monetary value, the United States of America alone spend approximately 137 billion dollars per year in environmental damages, economic losses, and invasion control (Pimental et al., 2000).

Cases throughout the world have experienced the ecologic and socioeconomic damages caused by non-native species. In Belize, small-scale fisheries comprise much of the country’s income. This revenue is being compromised by the invasive non-native red lionfish (*Pterois volitans*). The red lionfish has a high fecundity, allowing quick establishment. It also has three-times the prey consumption as native predators, causing a vast decline in fish populations, which is drastically affecting the fishing sector and livelihoods of Belizean peoples (Chapman et al., 2016). In the Mediterranean, the caulerpa seaweed (*Caulerpa taxifolia*) was introduced via aquarium waste. This seaweed can colonize with only a small segment, having the ability to quickly spread, smothering important nursery habitats, such as native sea grass beds (Lowe et al., 2000). The American comb jelly (*Mnemiopsis leidyi*) is an invasive non-native species which was transported to the Caspian Sea via ballast water. This invader is an opportunistic carnivore, predating upon zooplankton, pelagic fish eggs, and larvae, causing significant declines in local fish stocks (Ivanov et al, 2000).

As the globalized movement and exchange of people and commodities around the world is continuously increasing, so is the transfer of potential invasive organisms (Meyerson & Mooney, 2007). It has been estimated that approximately 50,000 non-native species are present and 42% of native species listed as threatened or endangered are at a higher risk due to these invaders, all in United States alone (Pimentel et al., 2005). To prevent future invasions, and to manage established invaded species, research and collaboration is imperative, on municipal to global levels (Bax et al., 2003). International and national networks such as Global Invasive Species Information Network (GISIN) and Nonindigenous Aquatic Species (NAS) provides information on invasive species such as taxonomy, life history, spatial information, etc., that can be used in other affected areas throughout the world to help manage and mitigate present or future invasions (Meyerson & Mooney, 2007).
1.2. Marine Invasive Species and Dispersal Mechanisms

Marine invasive species are a leading threat to marine and coastal biodiversity loss through destruction of native ecosystems, and the eventual extinction of indigenous species (DiBacco et al., 2012; Scriven et al., DiBacco et al., 2015). Though invasive species continues to be well studied and advancements in technology and policy have been achieved, it remains very difficult to eliminate this problem entirely (Pysek & Richardson, 2010; Steichen et al., 2014). Marine invasive species are transported predominately by anthropogenic factors, including boat hull fouling, ballast water, and sea-chests (Coutts et al., 2003; Hyytiäinen et al., 2012).

Fouling occurs when assemblages of organisms attach to unnatural substrates, such as boat hulls, allowing organisms to travel to the boat’s destination. The species can break off or detach themselves in the new location, potentially causing an invasion (Fernandes et al., 2016). Hull fouling also causes issues regarding fuel consumption, as it requires the boat to use 40% to 80% more fuel to overcome the frictional resistance. Anti-fouling (AF) paint and coatings are used to help reduce invasions caused by fouling, but not all boats are required to use them (Fernandes et al., 2016). Unfortunately, the most common anti-fouling coatings today contain compounds such as Irgarol 1051, diuron, Sea-Nine 211, chlorothalonil, dichlofluanid, and zinc pyrithione. These compounds have been reported to collect in coastal waters, accumulating to concentrations that are fatal to marine organisms. There is continuous research being conducted to discover a sustainable natural-product-based AF coating (Qian et al., 2010). It is estimated that 70% of Australia’s and 74% of Hawaii’s invasive species arrived via biofouling (AQIS, 2005; Godwin, 2003).

Before a ship leaves port, it must uptake sea water into its ballast. This will control stability and trim of the boat during its voyage (Scriven et al., 2015). Microscopic organisms, such as planktonic larvae, are also taken up with the water. The issue of alien invasions arises when the boat releases its ballast water, and therefore the organisms living within the water, into a new dock, in a new location, providing the organisms the chance to settle (Scriven et al., 2015). Approximately 65% to 70% of invasions in the Great Lakes are caused by the release of foreign ballast water (WSTB, 2008).
Similarly, marine invasive species are also commonly transported via water storage recesses called sea chests. Sea chests allow piping systems to draw out water for firefighting, engine cooling, and water ballast purposes (Coutts et al., 2003). Sea chests have metal grates with holes, approximately 15 to 25 mm in diameter, but this does not prevent planktonic organisms to enter as plankton are much smaller (Coutts et al., 2003). For example, plankton nets with a 500 μm mesh size are used to collect green crab larvae (zoea), as nets of larger size would allow the larvae to be filtered through (Harms et al., 1994). This fact validates that the holes in sea chest grates are large enough for the larvae to enter with the inflow of seawater. An example of this occurring was recorded from a 2003 study by Coutts et al., an adult green crab was found in a ship’s sea-chest. The green crab must have entered at its larval stage, as the sea chest grate holes are much too small for an adult green crab to enter. Growing to an adult stage inside of the sea chest, it was then too large to escape out. It was noted that the female green crab was ovigerous, thus able to release viable zoea outside of the sea chest into new territories (Coutts et al., 2003).

Research conducted by Coutts and Dodgshun (2007) between May 2000 and November 2004 unveiled that on 42 vessels visiting and, or operating in New Zealand contained 15% introduced species, 10% non-indigenous, and 35% were species of unknown origin.

Though dispersal of invasive species is most commonly spread via commercial shipping vessels, this is not the only method which organisms can travel beyond their native range. Other anthropogenic methods of dispersal include aquaculture and fisheries, drilling platforms (as they also provide concern of invasions through ballast water and hull fouling), artificial canals, aquarium industry, recreational boating, diving and snorkelling activities, and floating debris or garbage (Bax et al., 2003). Fish such as Asian black carp (*Mylopharyngodon piceus*), Channel catfish (*Ictalurus punctatus*), and Atlantic salmon (*Salmo salar*) have been introduced to non-native regions by escaping aquaculture pens, reproducing, and establishing themselves as an invasive species throughout the world (Naylor et al., 2001). A species of sea slug (*Chelidonura fulvipunctata*) invaded Meditterean Sea from the Red Sea through the artificial canal, Suez Canal (Malaquias et al., 2016). Similarly, the sea lamprey (*Petromyzon marinus*) invaded the Great Lakes due the deepening of the Welland Canal in 1919, allowing the lamprey to bypass Niagara Falls (Christie & Goddard, 2003).
This thesis focuses on a marine invasive species occurring in Newfoundland and Labrador, Canada, *Carcinus maenas*, commonly called green crabs, European green crabs, or shore crabs. From here on, they will be referred to as green crabs. Green crabs are well-known to be transported via ballast water exchange from ships, during their larval stage (Matheson & Gagnon, 2012; Scriven, et al., 2015; Yamada & Gillespie, 2008). Green crabs can survive long journeys across the globe due to their physiological plasticity, such as slowing its metabolic rate by 40% during their first week of starvation, and up to 60% for another three months (Edgell & Hollander, 2011). If settlement and colonization of the species succeeds through anthropogenic transportation in a non-native territory, the invasion is termed as a primary invasion (Wittenberg & Cock, 2001). With such a presence in both population and colonization, green crabs have been naturally expanding their range throughout the province and country, which is termed a secondary invasion of the species (Blakeslee, et al., 2010; DiBacco, et al., 2012).

### 1.3. Responses to Aquatic Invasions

With the increase in invasions of non-native species, there is also an increase in research into ways to prevent future invasions, how to manage established populations, and how to reverse the negative impacts these invaders have caused, whether it be ecologically, economically, or socially (Pyšek & Richardson, 2010).

Responses to aquatic invasions are often conducted on multi-scale bases, including municipal, provincial, national, and international governments. The primary laws designed to prevent the spread of invasive species such as trade agreements (Pyšek & Richardson, 2010), the Convention of Biology Diversity, the Law of the Sea Convention, and the Cartagena Protocol on Biosafety to the Convention on Biological Diversity (Bax et al., 2003). Research and risk assessments for biosecurity are one of the most cost-effective invasive species management strategies (Pyšek & Richardson, 2010). Researching the biology and behaviours of the species in their native environments informs what species are high risk potential invaders, allowing to better prepare and prevent future invasions (Pyšek & Richardson, 2010). This response stems into pathway and vectors of areas which these invaders can travel. Once their routes are identified, measures can properly be taken place to prevent more or future invasions (Scriven, et al., 2015; Yamada & Gillespie, 2008), such as green crabs travelling via boat hulls and ballast water (Matheson & Gagnon,
Early detection is imperative when managing an invaded species, as established species have a much larger population, are often further spread, and thereby more difficult to control (Myers et al., 2000).

Once an invaded species is established, different responses are required to either manage the population or eradicate the species entirely. Education and outreach are effective methods to address the issues and to get the public involved (Burtle, 2014). An example of education and outreach is the red lionfish (*Pterois volitans*), which has invaded throughout the Caribbean. Due to their lack of predators and unique biology (for example their high fecundity), lionfish are noted to be highly unlikely to become eradicated (Chapman et al., 2016). To ensure a long-term management plan, a targeted fishery (Chapman et al., 2016) and fishery derbies (Malpica-Cruz et al., 2016) are implemented as they are determined to be the most positively effective management solution, economically (benefitting local small-scale fisheries), environmentally, and ecologically (Chapman et al., 2016) To ensure a fishery with a new target species is successful, it is imperative that local people and participants are educated. It is shown that fishermen with higher awareness of issues associated with invasive species are more likely to participate in managing the invasion (Chapman et al., 2016; Malpica-Cruz et al., 2016).
2. Theoretical Overview

2.1. Green Crabs (*Carcinus maenas*)

Due to their global invasion, green crabs (Portunidae, Decapoda) are currently one of the most studied aquatic crustaceans (McGaw et al., 2011). Green crabs are naturally found in Northwest Europe, Northern Africa, and in Western Mediterranean. However, human activities have caused their introduction in North America (East and West), South Africa, and Australia. There have been sightings in South America, Southeast Asia, and Japan, but are believed to be isolated individuals (McGaw et al., 2011). Green crabs were first spotted in Canada in 1951, in Passamaquoddy Bay in the Bay of Fundy (Klassen & Locke, 2007). It was not for another 56 years, in 2007, when green crabs were first discovered in Newfoundland. A local fisherman, in North Harbour, Placentia Bay, reported the finding to the Department of Fisheries and Oceans Canada (DFO) (Best, 2013; Blakeslee et al., 2010; DFO, 2011).

From their infamous global distribution and physiological plasticity, they have gained two titles: Top 100 Worst Invaders by the International Union for Conservation of Nature (IUCN), the Species Survival Commission (SSC), and the Invasive Species Specialist Group (ISSG) (Klassen, & Locke, 2007; Leignel et al., 2014; Rey et al., 2015) and was the first marine organism to be titled as an aquatic nuisance species by the Aquatic Nuisance Species Task Force (ANSTF) (Leignel et al., 2014).

2.1.1. Green Crab Ecology

Green crabs are currently inhabiting a vast amount of countries, inhabiting estuaries, intertidal zones, to ocean depths up to sixty-meters (Cohen, 2011; Klassen & Locke, 2007). Green crabs often inhabit intertidal and estuarine areas and are adapted to large fluctuations in salinity from nearly freshwater to fully marine (0 to 35, respectively) (Penney et al., 2016). They are physiologically capable of this by increasing their urination rate four times their normal (Edgell & Hollander, 2011). They thrive in a variety of habitats, from rocky to sandy shores, salt marshes to lagoons, vegetated to muddy...
substrates (Amarala et al., 2009). Juveniles (newly settled instars) prefer sheltered, intertidal areas, such as mussel or eelgrass beds, to avoid predation (Moksnes, 2002). As they become more mature they migrate to deeper waters (Amarala et al., 2009).

Green crabs are poikilothermic, meaning their body temperature changes to that of its environment. Adults are also eurythermic, capable of tolerating a wide range of temperatures in their environment. Though eurythermic, they do have a preference range of 3 to 26°C, with a Critical Thermal Minimum of 0°C and a Critical Thermal Maximum of 35°C (Rodrigues et al., 2015). Though capable of surviving, some physiological processes are compromised when living outside their range of preferred tolerance. Successful reproduction and development for these species occurs between 9 and 22.5 °C (Klassen & Locke, 2007; Rodrigues et al., 2015).

Green crabs are highly fecund and have a prolonged larval stage. Females are able to carry up to 200,000 eggs, depending on their size, protruding from her abdominal pouch until they hatch (Klassen & Locke, 2007) (Figure 1). An extended planktonic larval stage allows for greater dispersal range. These two characteristics supports their ability to disperse and relocate throughout the world (Best et al., 2013; Lyons et al., 2012; Roman & Palumbi, 2004).

![Figure 1: Brooding female green crabs caught in Fox Harbour, Newfoundland](image)

For large females, gonadogenesis may occur two times a year, as opposed to the one (Audet et al. 2008). Newly released larvae begin their life cycle in the zoel stage (consisting of four stages, lasting approximately 5 to 7 days in total), and then a megalopae stage (for 8 days) where they then enter the adult habitat, and metamorphosis into their first fully benthic crab instar (Reyet al., 2015). Crustaceans, like green crabs, grow by
molting, shedding their old shell (exuvium) as they produce a larger one. Once mature, moulting slows down until they experience a terminal moult, the final exoskeleton they have until they die (Souza et al., 2011). Green crabs have a life expectancy of three to six years (Cohen, 2011).

There are distinct morphological features which can be used to differentiate green crabs from other native crabs, such as rock crabs (*Cancer irroratus*). Green crabs are not always green in color, as their ventral color ranges from green, yellow, orange to red, shifting as their exoskeleton ages (Styrishave et al., 2004). A defining feature of green crabs are the five spines anterolateral margin of the carapace (Figure 2) (Gillespie et al., 2007; Klassen & Locke, 2007; Laignel et al., 2014).

![Figure 2: Five spines of the anterolateral margin of the carapace of green crabs](image_url)

Green crabs have a slight projection and a rounded rostrum at the front of the carapace, and a dorsal fissure on the orbit. The abdomen, which differs between male and females, has three to five fused somite, and their fifth pair of legs has a wider unspatulated dactyl than the others (Leignel et al., 2014; Yamada & Hauk, 2001).

### 2.1.2. Green Crab Feeding Ecology

Feeding times for green crabs are dependent upon the tides. Green crabs forage for food during high tide, and seek shelter during low tide under rocks, seaweed, or by burrowing themselves in the mud, to avoid predation and desiccation (Amarala et al., 2009). These crabs consume a large diversity of food. During their zoel stage, green crabs are filter feeders, once in the megalopae stage they work their way up the food chain, consuming
detritus. Once past their first crab instar the diversity of their diet becomes much more apparent (Klassen & Locke, 2007). Green crabs prey on organisms from 104 families and 158 genera, allowing themselves to adapt to what is available to eat, defining a true omnivore and opportunistic scavenger (Cohen 2011; Klassen & Locke, 2007). Green crabs forage and predate upon these organisms by using their chelae, one crusher and one cutter. These are used to break open shells, cutting and tearing meat, cutting away seaweeds and eelgrass, and digging into the soil searching for prey. A loss of a cheliped reduces foraging rates and increases handling time (Flynn et al., 2015; Taylor, Keyghobadi, & Schmidt, 2009).

Green crabs are shown to follow optimal foraging theory in regards to food selection (Chakravarti & Cotton, 2014), with the assistance of chemosensory organs and environmental cues (Matheson & Gagnon, 2012). Chemical cues are relayed back to chemosensory organs providing information of their surroundings, the absence or present of predators and, or, prey. The crab then decides if the benefit is greater than the cost. Such decisions include crab remaining sheltered, to avoid predation, but being without food, or whether the cost of retrieving, handling, and consuming the prey is greater than the benefit of the nutritional value of the food itself. If the crab can out-compete existing predators, or have a clear pathway to the food, they will pursue the food source and consume it, if the prey is worth the handling effort (Chakravarti & Cotton, 2014; Flynn & Smee, 2010; Matheson & Gagnon, 2012), for instance, if the shell is of appropriate size (Sungail et al., 2013).

2.2 Economic and Ecologic Impacts of the Green Crab Invasion in Newfoundland

Invasive non-native species are causing a global concern as they are affecting marine ecosystems, from species to population levels. They have the capabilities of affecting native species, changing food web dynamics, to shifting evolutionary pathways. Furthermore, invasive non-native organisms are causing negative impacts upon the livelihoods of humans through social and economic stand-points (Baxa et al., 2003; Breen & Metaxas, 2009; Grosholz, 2002). Newfoundland and Labrador, Canada, is facing such consequences caused by the invasion of green crabs. Native species, critical habitats, the fishing industry, future aquaculture initiatives, and local incomes are being negatively
influenced by green crabs (DFO, 2011; Klassen & Locke, 2007). Green crabs are termed ecosystem engineers because they can impact coastal environments at many trophic levels (predator, competitor, and habitat modification in eelgrass beds) (Morris et al., 2011).

2.2.1. Habitat Overlap of the Native Rock Crab (Cancer irroratus)

Rock crabs (Cancer irroratus), is a native shore crab in Newfoundland and Labrador. Rock and green crabs occupy similar niches (DFO, 2011), with dietary and habitats overlapping, regardless of water temperature (Breen & Metaxas, 2009; Matheson, & Gagnon, 2012). In 2005, a dive study conducted by Tremblay et al., used transects to visualize habitat overlap of green crabs and rock crabs, where 47% of the transects (15 out of 32) showed habitat overlap. Crabs often rely on rocks, seaweed, and other areas for shelter, with such an overlap, shelter availability will be reduced from rock crabs potentially resulting in higher mortality due to predation and a decrease in recruitment (Matheson & Gagnon, 2012). In a laboratory study, 90% of the time green crabs were more successful of out-competing rock crabs by getting to the food source first (Matheson & Gagnon, 2012). Crabs that have a very limited food source experiences an increase in intermolt periods, a decrease in molt increments, and a decline in their overall health (Breen & Metaxas, 2009).

2.2.2. Habitat Destruction of Eelgrass (Zostera marina) Beds

In the nearshore waters of North America, including Newfoundland, Zostera marina is the most dominate species of eelgrass. To avoid desiccation during low tide, avoiding predators, and foraging for food, green crabs will dig into the soil, uprooting and tearing down aquatic plants and seaweeds, such as Zostera marina, causing damage to rhizomes and plant shoots (DFO, 2009; Matheson et al., 2016; Morris et al., 2011). High abundance of green crabs has been correlated with a decrease in eelgrass beds (DFO, 2011; Klassen & Locke, 2007). Termed an Ecologically Significant Species (ESS), Zostera provides shelter and habitat for countless species, especially during juvenile life stages (DFO, 2009; Morris et al., 2011). For example, the commercially valuable Atlantic cod (Gadus morhua), uses eelgrass beds for nursery and protection from predators, increasing survival rates of juvenile cod. Once mature, Atlantic cod will venture out into deeper waters (Lilley & Unsworth, 2014; Morris et al., 2011). A 2010 study by Warren et al. demonstrated that an increase in eelgrass beds coincides with an increase in Atlantic cod recruitment. Eelgrass beds are shown to provide some of the most productive habitats in the world. Loss of
eelgrass due to green crabs will negatively affect biodiversity and species abundance in modified areas (Morris, et al., 2011; Schmidt et al., 2011; Warren, et al., 2010).

2.2.3. Lobster (*Homarus americanus*) Fishery

Since the collapse of the Atlantic cod stocks in Newfoundland and Labrador, causing the cod moratorium of 1992, the province had to adapt to such a crash to the economy and livelihoods. Fishermen converted from being primarily a groundfish fishery to shellfish harvesting. Today, snow crab (*Chionoecetes opilio*), northern shrimp (*Pandalus borealis*), and the American lobster (*Homarus americanus*) are the three main fishing sectors (Mather, 2013).

Like with rock crabs, habitat and diet preferences of green crabs’ overlaps with lobsters, causing competition amongst the two species (DFO, 2011). Furthermore, it has been observed that green crabs predate upon juvenile lobsters (Haarr & Rochette, 2012). Lobsters eventually outgrow green crabs, where they then rely on crustaceans, especially crabs, for their diet, as they are high in protein content (Haar & Rochette, 2012). While juvenile, green crabs are outcompeting them for food; discovering and consuming prey before the lobster has a chance (Klassen & Locke, 2007; Williams et al., 2006). Green crabs are also reducing shelter availability, causing juvenile lobsters to be easily predated upon. Juvenile and sub-adult lobsters remain sheltered for a longer period than they are foraging, as a method to increase survival and avoid predation. Without shelter, recruitment drastically decreases (Lynch & Rochette, 2009; Rossong et al., 2011). Such interactions between lobsters and green crabs can pose negative impacts to the Newfoundland and Labrador lobster fishery (DFO, 2011; Klassen & Locke, 2007).

2.3. Green Crab Invasion Control in Newfoundland

As seen in Prince Edward Island, Nova Scotia, California, and now Newfoundland and Labrador (DFO, 2011), eradication is used as an effective method to remove invasive species (DFO, 2011; Myers et al., 2000). This approach reduces the population size below sustainable levels. Though quite challenging, with innovative research the efficiency of eradication can increase, thereby reducing the amount of destruction upon the natural ecosystem by the non-native species (Myers, et al., 2000).
Aside from eradication, there are other methods used to control green crab populations in the province. They may be naturally controlled as prey of several native bird species including Ringed, Herring, and Blackback gulls (Larus spp.), crows (Corvus spp.), and other shore-associated birds (Ellis et al., 2005). Mitigation through direct continuous trapping (a form of eradication) is being attempted in Placentia Bay, and other selected areas of the province, in hopes this will increase populations of native rock crabs, blue mussels, seaweeds and other species whose numbers may be threatened by the presence of the green crabs. However, trapping has not resulted in successful extirpation (DFO, 2011). Large cohorts of juveniles settle each year throughout the summer and fall, rendering extermination attempts to be futile (Thiel & Dernedde, 1994). As early as 2009, plankton sampling in Bonne Bay, Newfoundland observed large numbers of green crab larvae in the competent pre-settlement phase (Pers. com. Dr. Robert Hooper). This suggests that trapping may be ineffective.

To increase the effectiveness of trapping green crabs, it is important the bait that provides the highest catch per unit effort (CPUE) is used. Unveiling the optimal bait species, eradication efforts will be more efficient, more cost effective and will reduce bait usage, therefore reducing excess nutrient input into the ocean, a higher chance of complete removal (Archdale et al., 2008).

### 2.4 Bait Efficiency Studies

One of the major expenses of fisheries is the cost of bait, especially fresh bait. For example, 50% of total operating costs of crayfish harvesting is the fresh bait required for the pots (Archdale et al., 2008). This is a main reason why bait choice research is imperative to reduce costs, for fisheries and eradication efforts. Targeting optimal bait will reduce costs and reduce excess nutrients entering the waters (Archdale et al., 2008).

Bait efficiency studies are not only completed on marine species as the study of bait is necessary for management, catch, and eradication of many other organisms. For example, bait efficiency studies have been completed for the eradication of rodents from offshore islands (Weihong et al., 1999), determining which sugar bait (mimicking floral nectarines) mosquitos (Culex pipiens pallens) are most attracted to (Ding et al., 2016), to enhancing lobster fisheries (Harnish & Willison, 2009).
In regards to green crabs in Newfoundland and Labrador, bait efficiency research has only been completed through public participation and interest. Fishermen, workers, and volunteers contributing to the green crab eradication in Newfoundland simply use whatever they believe works the best, from standard bait species like cod and herring, to unusual baits like turkey and canned tuna (Pers. Comm.). No formal study of bait comparison and bait efficiency has been completed.

2.5 Goals of this Study

This research aims to evaluate the effectiveness of different bait species, to determine which provides a significant increase in the CPUE of green crabs. This study responds to a request from the local fishermen of Newfoundland and Labrador and will hopefully provide them and the government (DFO particularly) information in regards to increasing the efficiency of complete eradication of green crabs. Presently, the action being taken is not sufficient in reducing their populations.

My research questions are as follows:

1. Which tested bait species (Atlantic herring, Atlantic cod, short-fin squid, blue mussels) will have the highest catch per unit effort of green crabs?
2. Is there a significant difference in gender or carapace width of green crabs in regards to bait species (Atlantic herring, Atlantic cod, short-fin squid, blue mussels)?
3. Does intense eradication diminish population levels of an area?
3. Methodology

3.1. Bait Selections

Prey selection is used to observe the optimal foraging (Sungail et al., 2013) of green crabs, and in turn, the most effective bait to use for their eradication. A meeting with local fishermen and citizen scientists was conducted to determine what they use to trap green crabs. Bait species were selected on the list which they provided, based on votes, and from literature reviews. This study tested four different species to be used as bait: Atlantic herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), short-fin squid (*Illex illecebrosus*), and blue mussels (*Mytilus edulis*).

Herring is the standard bait for the Department of Fisheries and Oceans Canada (DFO) for their green crab removal projects (Gillespie, et al., 2007; Zargarpour, et al., 2016). Herring has also been used to catch green and rock crabs for laboratory experiments (Matheson & Gagnon, 2012; Matheson & Gagnon, 2012), and to collect green crabs to analyze biological characteristics (Audet, et al., 2008).

Green crabs held in tanks are often fed squid (order: Teuthida), whether at an aquarium or during an experiment (Fehsenfeld & Weihrauch, 2013; Lovett, Tanner, Glomski, Ricart & Borst, 2006; Serrano & Henry, 2008; Towle, Henry & Terwilliger, 2008). Short-fin squid is also a common bait choice in Newfoundland, due to its high availability and effectiveness in snow crab (*Chionoecetes opilio*) and Atlantic cod (*Gadus morhua*) fisheries, and is therefore used by many fishermen to trap green crabs (Grant & Hiscock, 2009; O’Dor & Dawe, 1998).

Through gut content analysis, it has been found that green crabs’ diet predominantly consists of bivalves (Best et al., 2013; Sungail et al., 2013). Laboratory observations suggests they prefer blue mussels over other food choices, such as fish, kelp, and shrimp (Chakravarti & Cotton, 2014; McGaw & Penney, 2014; Miron et al., 2005; Murray, et al., 2007; Sungail et al., 2013). Mussels are also frequently used in laboratory experiments when comparing feeding ecology and competitive behaviors of green crabs amongst rock
crabs and, or, lobsters (Matheson & Gangon, 2012; Matheson & Gangon, 2012; Sungail et al., 2013). A study by Moksnes (2002), revealed that 47% of second to ninth star green crabs preferred a mussel bed habitat, perhaps due to the high food supply. Aquaculture in Newfoundland and Labrador is increasingly becoming an important economic driver (DFA, 2016) and is the second largest producer of farmed blue mussels in North America (Best et al., 2013). Green crabs feeding on commercial mussels are decreasing blue mussel populations and costing more money in research and development for reducing predation rates (Flynn et al., 2015; Miron et al., 2005). Furthermore, green crab predation has been shown to correlate with an increase in mussel shell thickness (Wong, 2013). As the mussel uses more energy to create a thicker shell for more protection, their meat yield decreases, causing a reduced value for the product. Another risk is the potential dispersal of green crabs via transportation of mussel seeds to other farms in Newfoundland (Best et al., 2013). This study used mussels to see if green crabs do indeed prefer them over the other bait choices, and to determine if future aquaculture research is required.

Lastly, the fourth bait chosen was Atlantic cod. Juvenile Atlantic cod is known as a common predator of green crabs (Isaksson et al., 1994; Moksnes, 2002). However, local fishermen often use cod as bait as it is easily accessible, especially during recreational fishery (DFO, 2016). In Newfoundland, local fishermen most frequently use Atlantic cod for bait in Fukui traps to catch green crabs (Pers. Comm).

Fishermen in Newfoundland and Labrador are constantly using different baits to catch green crabs, usually whatever is easily accessible or the cheapest, and therefore bait selection is not conducted systematically. For example, during the recreational fishery, Atlantic cod scraps, such as the fillet skeletons and trimmings, are often used because it is both readily available and free. Personal communications have unveiled that during hunting seasons fishermen and locals have even use moose (Alces alces) scraps.

These four baits are often used for different things: squid as feed (Fehsenfeld & Weihrauch, 2013), Atlantic Herring and Atlantic Cod used to bait (Gillespie, et al., 2007; Zargarpour, et al., 2016), and Blue Mussels used in behavioral studies (Matheson & Gangon, 2012) and commonly found in their diets (Best et al., 2013; Sungail et al., 2013), which provides an interesting baseline to this study and to test their bait preference. Furthermore, these species are also found on different trophic levels in the marine food
web: Atlantic cod sits high on the food chain, herring is at a mid-trophic level, and mussels and squid sit lower on the food chain. This will provide information on this dynamic portion of ecology through the examination of four ecologically and practically-appropriate bait species.

3.2. Site Locations

This experiment was conducted in two locations in Placentia Bay, Newfoundland, Fox Harbour (Figure 3) and North Harbour (Figure 4). These locations have been noted to have a large population of green crabs (Pers. Comm. Jonathan Bergshoff). A block system was used in each town, meaning the location was further divided into two sections, A and B in Fox Harbour and C and D in North Harbour. Each block was treated independent of the other. This also allowed testing in different habitats: rocky (Block A), muddy (Block B and C) and sheltered (Block D). Within each block were positions, 1 through 4. Each position was 10 m apart from the other (Gillespie, et al., 2007; Yamada & Gillespie, 2008). Positions were used to allow randomization of Fukui trap deployments in each block. This was to ensure one trap was not situated in the exact same position during the entire experiment, potentially causing a skew in catch per unit effort results.

**Figure 3:** Green crab fukui trap locations, blocks A and B, positions 1 through 4, in Fox Harbour, Newfoundland
3.3. Fukui Trapping

Green crabs were caught using Fukui traps (63 x 46 x 23 cm frame), 1.6 cm mesh (Gillespie, et al., 2007; Yamada & Gillespie, 2008; Zargarpour, et al., 2016), with a rigid plastic bait can (Figure 5). A plastic can was chosen as it allows sufficient bait plume, and allows for the prevention of bait depletion from scavengers and breakdown (Robertson, 1989; Zargarpour, et al., 2016). Fukui traps have two entrances, on either side, with two mesh panels forming a horizontal “V”. The slits remain closed until an animal (in this case, a green crab) enters the trap. Once trapped, it is difficult for them to escape due to the one-way entrance panels (Archdale et al., 2008).
Bait samples were prepared to roughly 100 g samples, as this is often the standard amount used when baiting Fukui traps (Archdale, et al., 2008). On each day we deployed two traps equipped with each bait type, for a total of eight traps per day. Trap deployments were conducted in Fox Harbour for a study period of 38 days, and for 8 days in North Harbour, Newfoundland and Labrador. Forty-four trap-hauls were completed for each bait type, 176 deployments in total. In each location, there were two blocks (A and B in Fox Harbour, and C and D in North Harbour), these were selected based on preliminary field work, ensuring that they were accessible by land and that green crab populations were high (Pers. Comm. Jonathan Bergsheoff).

Deployment and removal were completed at low tide, daily, resulting in a soak time of approximately 24 hours, though dependent upon logistical conditions. Traps were separated by at least 10 meters (Gillespie, et al., 2007; Yamada & Gillespie, 2008) to reduce trap and bait interactions (Cyr, & Sainte-Marie, 1995). When the traps were retrieved, organisms were collected, the bait was removed and replaced, and the trap was immediately deployed again (Zargarpour, et al., 2016). Retrieving and deploying traps occurred during low tides. Due to the semidiurnal tidal cycle in Placentia Bay (DFO, 2016), soak times sometimes shifted. Global positioning system (GPS), time of day, weather, and water temperature (recorded using data storage tags (DST)) were recorded, at each deployment (Cyr, & Sainte-Marie, 1995; Zargarpour, et al., 2016).
3.4. Data Recording – Measurements and Observations

Bycatch were sorted and identified to the lowest possible taxonomic level, and then immediately released back into the ocean. Green crab caught were collected in bags to be returned to the Marine Institute in St. John’s, Newfoundland, to be frozen. After 24 hours of freezing, sex and carapace width were recorded. Sex was determined by examining the abdominal shape of the crab. A female’s abdomen has a rounded shape, while the male’s abdomen is more triangular (Figure 7). For further clarification, under the abdominal flap, the male will have two gonopods (Miza, 2015). Carapace width was measured at the fifth tooth/spine, using a digital caliper (Figure 8). Once data was retrieved, the crabs were returned to the freezer to ensure they were deceased before they were properly disposed of.

![Figure 6: Comparison of female (left) and male (right) abdominal shape for sex determination](image)

![Figure 7: Measuring the carapace width of a green crab at the fifth spine/tooth of the anterolateral margin, using digital calipers](image)
3.5. Analysis

R 3.3.2 and RStudio 1.0.44 was used to explore and plot all data collected from the field (R Core Team, 2016) and to evaluate the study’s hypotheses (Table 1). Each green crab caught were sexed and had their carapace measured. Graphs were created using the ggplot2 package (Wickham, 2009). Additional labels were added to graphs using the ggrepel package (Slowikowski, 2016). The dplyr package was used for data manipulation (Wickham & Francois, 2016). Maps of North Harbour and Fox Harbour were created with ggmap (Kahle & Wickham, 2013), and labels were added with the package ggrepel (Slowikowski, 2016). Visual exploration of all data was conducted to validate main results. Statistical analysis on total catch as the dependent variable as described by the independent variables of bait and location was conducted through a generalized linear model through RStudio, glm(Total.Catch~Bait.x*Location, family=poisson, data=AllData). Another generalized linear model, glm(Total.Catch~Bait.x*Block, family=poisson, data=AllData), was used to determine block effectiveness and bait with R 3.3.2 and RStudio 1.0.44. A generalized linear model was used as the data in this study is nonnormal data, with random effects (e.g. through individual crabs, environmental factors, and space and time), typical of data gathered in the field of ecology. Poisson distribution is used for count data; counts of events that occur randomly at a certain time or space. Poisson distribution has no limit of counts, as opposed to binomial (Bolker et al., 2009).
**Table 1**: Alternative hypothesis in regards to this optimal bait selection study

<table>
<thead>
<tr>
<th>Hypothesis 1</th>
<th>Hypothesis 2</th>
<th>Hypothesis 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1: Baits will differ in attractiveness for green crabs</td>
<td>H1: Higher proportion of larger (mature) green crabs than smaller (juvenile)</td>
<td>HO: Baits will not differ in attractiveness for green crabs</td>
</tr>
<tr>
<td>HO: Baits will not differ in attractiveness for green crabs</td>
<td>H2: Higher proportion of smaller (juvenile) green crabs caught than larger (mature) ones</td>
<td>HO: There is no significant difference between catch and size (CW)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1: Higher proportion of males caught</td>
<td>H1: Higher proportion of brooding females caught</td>
<td></td>
</tr>
<tr>
<td>H2: Higher proportion of females caught</td>
<td>H2: Higher proportion of non-brooding females caught</td>
<td></td>
</tr>
<tr>
<td>HO: No significant difference between gender</td>
<td>H0: No significant difference between brooding and non-brooding females caught</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1: Intense trapping will decrease green crab populations</td>
<td>H1: Higher proportion of brooding females caught</td>
<td></td>
</tr>
<tr>
<td>H2: Intense trapping will increase green crab populations</td>
<td>H2: Higher proportion of non-brooding females caught</td>
<td></td>
</tr>
<tr>
<td>H0: Intense trapping will not affect green crab populations</td>
<td>H0: No significant difference between brooding and non-brooding females caught</td>
<td></td>
</tr>
</tbody>
</table>
4. Results

4.1. Data Exploration

As this study was completed in the field, it is important to explore the data, to understand the ecological and logistical interactions, to allow the summarization of the main findings of this study; bait choice. Firstly, soak time duration (whether longer or shorter than the regular 24 hours in this study) did not affect total catch. As seen in Figure 8, CPUE remains quite consistent with a soak time of 15 to 30 hours. In Figure 9, CPUE and blocks are compared to determine if blocks performed similarly. The results illustrated show Atlantic cod had the highest CPUE when in Block D, followed by A, B, then C. It also performed better than the other three species, in each block. Short-fin squid had the second highest CPUE, followed by Atlantic herring, then blue mussels. CPUE bait results showed the same pattern in both Fox Harbour and North Harbour. From Table 2, which was produced using a generalized linear model, all p-values have a value of <2e-16, this determines that there is a significant difference between each block location and each bait that was used. Change of catch rates over time were explored to determine if CPUE of all traps, using the different baits, all demonstrated similar trends throughout the study period (Figure 10). In Fox Harbour the trend is very apparent; CPUE decreases during continuous trapping at the beginning of the study period. There is an eight-day period where no trapping was conducting in Fox Harbour (as trapping was occurring in North Harbour at the time). When returning to Fox Harbour, we see a continuous increase in CPUE. This trend is seen with all of four bait species. Unfortunately, it is more difficult to see such trends in North Harbour, perhaps due to the trapping period being too short for a trend to be seen, though we do see a decrease occurring around day 8 of continuous trapping, like what occurred in Fox Harbour. Water temperature trends, shown in Figure 11, show a continuous increase in water temperature in both sites as the study period enters more into the warmer August month. There is seen to be a cold dip between day 20 and 30 (end of July). Each data point on the graph represents an average of temperature readings (one every 30 minutes) throughout the duration of the soak time, in this case, 24 hours.
**Figure 8:** Total catch of green crabs per fukui trap in relation to soak time in Fox Harbour and North Harbour, Newfoundland. Linear model smooth line function with a 95% confidence interval is used to better visualize trends.
Figure 9: Violin plot of total number of crabs per fukui trap in relation to block and bait type in Fox Harbour and North Harbour, Newfoundland. Median represented by points.
Table 2 Generalized linear model results from glm(Total.Catch~Bait.x*Block, family=poisson, data=AllData) to determine Block and Bait effectiveness. One coefficient not defined because of singularities.

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>SE</th>
<th>Z Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4.092808</td>
<td>0.005288</td>
<td>774.02</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Location North Harbour</td>
<td>0.521268</td>
<td>0.006517</td>
<td>79.98</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Herring</td>
<td>-0.270445</td>
<td>0.008720</td>
<td>-31.01</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Mussels</td>
<td>-0.942272</td>
<td>0.016514</td>
<td>-57.06</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Squid</td>
<td>0.345884</td>
<td>0.006770</td>
<td>51.09</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Block B</td>
<td>0.749573</td>
<td>0.006113</td>
<td>122.61</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Block C</td>
<td>-0.896673</td>
<td>0.009704</td>
<td>-92.40</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Block D</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Bait Herring : Block B</td>
<td>-0.607194</td>
<td>0.011766</td>
<td>-51.60</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Mussels : Block B</td>
<td>-0.656511</td>
<td>0.022837</td>
<td>-28.75</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Squid : Block B</td>
<td>-0.923100</td>
<td>0.008714</td>
<td>-105.93</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Herring : Block C</td>
<td>-0.347601</td>
<td>0.021502</td>
<td>-16.17</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Mussels : Block C</td>
<td>0.661973</td>
<td>0.022918</td>
<td>28.88</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Squid : Block C</td>
<td>-0.297922</td>
<td>0.014132</td>
<td>-21.08</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Herring : Block D</td>
<td>-0.420140</td>
<td>0.012296</td>
<td>-34.17</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Mussels : Block D</td>
<td>-0.704774</td>
<td>0.026193</td>
<td>-26.91</td>
<td>&lt;2e-16 ***</td>
</tr>
<tr>
<td>Bait Squid : Block D</td>
<td>-0.771566</td>
<td>0.009817</td>
<td>-78.59</td>
<td>&lt;2e-16 ***</td>
</tr>
</tbody>
</table>
Figure 10: Change of catch rates over time in Fox Harbour and North Harbour, Newfoundland, throughout the study period of June 16 to August 11, 2017. Smooth line function with a 95% confidence interval is used to better visualize trends.

Figure 11: Water temperature trends in Fox Harbour and North Harbour, Newfoundland, throughout the study period of June 16 to August 11, 2017. Smooth line function with a 95% confidence interval is used to better visualize trends.
4.2. Bait Choice Findings

The key question to this study was will green crabs prefer one bait, providing a higher CPUE? Figure 12 illustrates that in both locations, Fox Harbour and North Harbour, Atlantic cod resulted in a higher CPUE, followed by short-fin squid, Atlantic herring, and lastly blue mussels. Producing a generalized linear model from the data (Table 3), a p-value of <2e-16 determines that there is a significant difference between bait used. Figure 13 shows some pattern of brooding females catch throughout the study. Though there is limited information provided for North Harbour, Fox Harbour illustrates that there is no difference in bait type used regarding brooding female catch (Figure 13), expect blue mussels in Fox Harbour does show to catch the least. Figure 14 visualizes that all four baits are catching juvenile (smaller) and adult (larger) size green crabs, equally, based on carapace width measurements (Figure 14). Both Fox Harbour and North Harbour represent a broad range catch of green crabs. Figure 15 shows more visualization of carapace width of trapped green crabs by dividing females and males. The same trend is shown as in Figure 13; all bait species catch crabs of similar body sizes. Lastly, in Figure 16 brooding and non-brooding females are plotted against carapace width. The figure illustrates that in Fox Harbour, all baits catch non-brooding females of similar sizes. Blue mussels caught a smaller range of brooding females than did the other three baits. In North Harbour, similar sized non-brooding females were caught with all four baits, but only short-fin squid caught brooding females.
Figure 12: Violin plot of the total number of crabs per fukui trap in relation to bait type in Fox Harbour and North Harbour, Newfoundland. Median is represented by points.
Table 3: Generalized linear model results from glm(Total.Catch~Bait.x*Location, family=poisson, data=AllData) to determine Bait effectiveness.

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>SE</th>
<th>X-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4.594655</td>
<td>0.002654</td>
<td>1731.393</td>
<td>&lt; 2e-16 ***</td>
</tr>
<tr>
<td>Bait Herring</td>
<td>-0.707086</td>
<td>0.005679</td>
<td>-124.508</td>
<td>&lt; 2e-16 ***</td>
</tr>
<tr>
<td>Bait Mussels</td>
<td>-1.398158</td>
<td>0.011317</td>
<td>-123.550</td>
<td>&lt; 2e-16 ***</td>
</tr>
<tr>
<td>Bait Squid</td>
<td>-0.240130</td>
<td>0.004078</td>
<td>-58.883</td>
<td>&lt; 2e-16 ***</td>
</tr>
<tr>
<td>Location North</td>
<td>-0.182421</td>
<td>0.004395</td>
<td>-41.505</td>
<td>&lt; 2e-16 ***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bait Herring</td>
<td>0.026615</td>
<td>0.009755</td>
<td>2.728</td>
<td>0.00637 **</td>
</tr>
<tr>
<td>Location North</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bait Mussels</td>
<td>0.256278</td>
<td>0.016154</td>
<td>15.865</td>
<td>&lt; 2e-16 ***</td>
</tr>
<tr>
<td>Location North</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bait Squid</td>
<td>-0.142498</td>
<td>0.007291</td>
<td>-19.543</td>
<td>&lt; 2e-16 ***</td>
</tr>
</tbody>
</table>
Figure 13: Segmented bar chart of the number of female green crabs per trap (brooding – Y, non-brooding – N), in relation to bait type in Fox Harbour and North Harbour, Newfoundland.
Figure 14: Violin plot of carapace width of total catch of green crabs in relation to bait type in Fox Harbour (FH) and North Harbour (NH), Newfoundland. Boxplots (line – median, boxes – upper and lower quartiles) added for statistical clarity.
Figure 15: Violin plots of carapace width of male (M) and female (F) green crabs in relation to bait in Fox Harbour and North Harbour, Newfoundland. Boxplots (line – median, boxes – upper and lower quartiles) are added for statistical clarity.
Figure 16: Violin plots of carapace width of brooding (Y) and non-brooding (N) female green crabs in relation to bait type in Fox Harbour and North Harbour, Newfoundland. Boxplots (line – median, boxes – upper and lower quartiles) are added for statistical clarity.
5. Discussion

5.1. Hypothesis Evaluation

As presented above, green crabs are shown to prefer one bait over another (Figure 11). Atlantic cod provides the highest CPUE in both Fox Harbour and North Harbour, followed by short-fin squid, Atlantic herring, and blue mussels, respectively. A total catch of 6436 crabs were caught throughout this study, with 83% being male. Of the 934 females caught, only 20% were brooding. Figure 13 illustrated that there was not a significant difference between CPUE and CW, though juvenile to adult crabs were caught. Each bait tested caught crabs of similar size. Lastly, Figure 9 illustrates that with intense trapping, catch declines. However, when trapping stops, population levels rise, causing CPUE to increase during the next trap deployment. Therefore, the following hypothesis (Table 4) are supported: baits will differ attractiveness for green crabs, there is no significant difference between catch and size (CW), higher proportions of males are caught, higher proportion of non-brooding females are caught, and intense trapping will decrease green crab populations.
### Table 4: Hypothesis evaluation based on results. Bolded text indicates the hypothesis that is accepted for this study, based on results.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Accepted Hypothesis</th>
<th>Alternative Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1: Baits will differ in attractiveness for green crabs</td>
<td>Higher proportion of larger (mature) green crabs than smaller (juvenile)</td>
<td>Higher proportion of smaller (juvenile) green crabs caught than larger (mature) ones</td>
</tr>
<tr>
<td>HO: Baits will not differ in attractiveness for green crabs</td>
<td>Higher proportion of larger (mature) green crabs than smaller (juvenile)</td>
<td>There is no significant difference between catch and size (CW)</td>
</tr>
<tr>
<td>H1: Higher proportion of males caught</td>
<td>Higher proportion of brooding females caught</td>
<td>Higher proportion of non-brooding females caught</td>
</tr>
<tr>
<td>H2: Higher proportion of females caught</td>
<td>Higher proportion of brooding females caught</td>
<td>Higher proportion of non-brooding females caught</td>
</tr>
<tr>
<td>H0: No significant difference between gender</td>
<td>No significant difference between brooding and non-brooding females caught</td>
<td></td>
</tr>
<tr>
<td>H1: Intense trapping will decrease green crab populations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2: Intense trapping will increase green crab populations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H0: Intense trapping will not affect green crab populations</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 5.2. Data Exploration Discussion

As previously mentioned, ecological field studies often contain both ecological and logistical variables which require their own analysis to ensure they do not disrupt the findings from the main study. Without proper exploration, an underlining disruption to the main findings may not be noticed. Here, the data exploration results will be discussed in full to reinforce the main findings of this field study.

Soak time is the length of time the trap is submerged in the water (Robertson, 1989), in this case, 24 hours. This length of time allows for catch to be completed both during night and day to compensate whether the crabs are more active at night or day. Research suggests
that green crabs are nocturnal, emerging at night when their predators are inactive. They search for food via chemical cues rather than visual stimuli (Hayden et al., 2007). Figure 8 visually illustrates that there was no relationship between soak time and CPUE across all bait types.

Each location had two blocks to allow a comparison of habitat; rocky and sandy. Within these blocks, CPUE showed similar trends though located in different locations (Fox Harbour versus North Harbour) and habitats (Figure 9). Through statistical analysis there was a significant difference between block and bait. Position was looked at in regards to whether the baits were represented equally amongst all four positions. Figure 17 shows that all baits were used in each position, more than once. Therefore, a bias cannot be concluded that one position with one bait works better, causing an increase in catch, or vice versa.

**Figure 17:** Scatterplot of total green crab catch per fukui trap and the location (block and position) of baited traps in Fox Harbour (A-B) and North Harbour (C-D), Newfoundland

Figure 10 shows that Fox Harbour showed a decrease in catch over time, whereas North Harbour did not. This can be presumed because the study time in North Harbour was not long enough to achieve a decrease in green crab populations. Interestingly, after a period of time without catching green crabs in Fox Harbour, when returning, catch increased, and CPUE was higher than the initial study days. This unveils more questions about mitigation
strategies; to reduce green crab populations continuous eradication must be completed, or efforts will be futile, as the population with bounce back.

In Figure 11 the temperature data for each study day is shown as the average of all temperature readings (one every 30 minutes) for the 24-hour soak time. In Fox Harbour, the temperature climbs (as expected as summer temperatures were increasing), but then there is a large drop in July. Because the traps were very close inshore, there is a possibility that the DSTs could not have been fully submerged in the water during low tide. A stationary DST should have been placed deeper in the water at the same location, throughout the entire study period, for more accurate readings.

In conclusion, exploring these outside factors resolved that there was no reason environmental or logistical data collected disrupted or swayed the main findings of the optimal bait choice. Soak time did not affect total catch, as catch remained consistent with a soak time of 15 to 30 hours, blocks performed similarly with CPUE and bait, and each position was used more than once with each bait to provide non-biased information on CPUE in the block and location.

5.3. The Effect of Bait Choice and Green Crab Catch
Atlantic herring is a common bait used for the eradication of green crabs in Newfoundland (Gillespie, et al., 2007; Zargarpour, et al., 2016), perhaps simply due to its low cost ($0.50/pd) (Pers. Comm. Beothuk Fish Processors Ltd, Valleyfield, NL). However, is this the best bait to achieve the highest CPUE of green crabs? The data depicted in Figure 12 suggests that green crabs are attracted to specific baits over others. Even though gut analysis show that green crabs predominately forage on bivalves, like blue mussels (Best et al., 2013; Sungail et al., 2013), they are preferring something else, in this case, Atlantic cod. Very close behind, short-fin squid also caught significantly more crabs than the Atlantic herring and blue mussels. This trend is shown in both Fox Harbour and North Harbour. Furthermore, we see this trend mimicked when looking at catch of brooding females (Figure 13). This is vital for picking the proper bait, as you want to use a bait that not only has a high CPUE, but one that is effective in catching females, especially brooding ones, to decrease future recruitment.
Carapace width of crabs provides an estimate of their age (juveniles or adults) (Souza et al., 2011), which can be important when dealing with invasive species and eradication. Using a bait that can catch a wide size range of crabs is the best, as it is not size selective. Visual inspection of crab size by bait (Figure 14) indicates that bait did not affect catch size. This pattern was consistent for both males and females (Figure 15), determining that one bait is not highly size selective. Interestingly however, when we further analyze and compare male and females caught, it is shown that these traps are catching the entire range of the females in this area, as they fit within the wider range of carapace size shown with the male crabs. This also means that the traps are effective in catching brooding females (Figure 16). This is important to note for eradication efforts, as catching the most females is vital to reduce their population.

Managing this invasive species in the province of Newfoundland and Labrador is being conducted through eradication efforts; reducing population levels below sustainable levels (Gherardi & Angiolini, 2004). However, effective management requires more than just eradication, but other factors as well, such as prevention and control of the species (Klassen & Locke, 2007). To prevent, it is imperative to understand how the species got here; cutting off that entrance (e.g. stronger enforcement on ballast water regulations), and to prevent further dispersal throughout the province (e.g. in the Northern Peninsula of Newfoundland). Controlling the species (either controlling its dispersal and/or controlling population increase) requires knowledge of the species’ life history. Green crabs prolonged larvae stage allows for great dispersal capabilities (Best et al., 2013). Furthermore, females can carry up to 200,000 eggs, making them highly fecund (Klassen & Locke, 2007). Gonadogenesis can also occur up to twice a year (Auget et al., 2008). These characteristics makes it nearly impossible to completely control their distribution. However, knowing this information is crucial to understanding what needs to be done to manage the population. For these reasons, female, especially brooding female, green crabs should be targeted for eradication, as this will be the most effective method to reduce population and recruitment of this invasive species.

5.4. Bycatch

Using a Fukui trap resulted to be highly beneficial to this study. As seen again in Figures 14 and 15, a broad range of green crabs were collected, including the entire range of
females (both brooding and non-brooding). Moreover, the traps were impressively selective with catching green crabs, as bycatch was very low: 0.34% of total catch. Five different species were caught in total: American Eel (*Anguilla rostrata*), Cancer/Rock Crab (*Cancer Irroratus*), Rock Gunnel (*Pholis gunnellus*), Cunner (*Tautogolabrus adspersus*), and Winter Flounder (*Pseudopleuronectes americanus*) (Figure 18).

![Figure 18: Bar graph of total bycatch (AE: American Eel (Anguilla rostrate), CU: Cunner (Tautogolabrus adspersus), RC: Rock Crab (Cancer Irroratus), RG: Rock Gunnel (Pholis gunnellus), WF: Winter Flounder (Pseudopleuronectes americanus)) caught with each bait type in North Harbour and Fox Harbour, Newfoundland.](image)

5.5. Limitations

Completing a field study is both logistically challenging and expensive. This project had a short window of opportunity because of the “crab season”, the time when they are highly active and more readily available to catch. Furthermore, it is very expensive for the fuel to drive in and out of the locations, causing the time frame to be stricter. These two issues caused a limitation to the number of locations we trapped. Having only two people...
(Jonathon Bergeoff and myself) also played a factor, as we did not have the bodies to do this study at the same time, in different locations. Therefore, we completed this study in two locations.

The Newfoundland and Labrador recreational groundfish fishery was opened between July 1st to September 5, 2016 for their summer season (DFO, 2016). This happened to be exactly when this project was taking place. This was of concern because there would be an increase in groundfish carcasses in the area (such as Atlantic Cod) that could attract green crabs to these locations as opposed to traps, or they would get used to eating Atlantic Cod and would not be as attracted to the bait as it is something they are used to. To attempt to overcome this limitation, blocks were chosen away from used docks to minimize such interactions.

5.6. Further Research

This bait choice study on green crabs can be expanded through testing more locations, provincially, or even nationally and by testing more bait species. By testing more locations, it will help determine if all green crabs have the same food preference or not. If so, this will be a huge step in facing this invasion and understanding the species. This study revealed that Atlantic cod provides the highest CPUE in regards to bait choice, but expanding the tested baits may unveil that there is something that works more effectively.

The list provided by the locals was quite long with unique bait selections (e.g. chicken and canned tuna). Furthermore, when discussing bait selection amongst fishermen and locals prior to this study, it was suggested to dip the bait into fish oil, thereby attracting more green crabs into the trap due to an intensification of bait plume, increasing CPUE. This is another layer of research which could help expand bait selection research in green crabs.

Having a more complete data set of bait preference and tested locations will further backup that bait choice is indeed a significant field of study in regards to fishing and eradication efforts.

As previously mentioned, to reduce green crab populations brooding female green crabs should be targeted. Though my results showed that brooding females prefer the same bait as non-brooding females and males, further research can determine if this indeed the case, or not by expanding research to new locations. As life history is an important part of
managing a species, and brooding females is key to reduce population and recruitment, more research should be done on brooding females in the area of eradication interest, e.g. Placentia Bay. During trapping, I caught brooding females of different stages, as suggested by the colour of the eggs (brown versus orange) (Figure 1), it would beneficial to have more research into the life stages of the eggs, when they are about to hatch, what water temperature and time of year hatching occurs, as this could be the foundation of when eradication efforts should be at its maximum.

5.7. Can Green Crab Become Economically Useful?

Newfoundland and Labrador is not the only province that is experiencing an invasion of green crabs. Prince Edward Island, Canada, is also having the same issue, but instead of eradicating and discarding, they are creating a green crab fishery from it. Depending on the trap used, it takes between 10 to 305 crabs to break-even: costs equaling the benefits (i.e. an optimal cost-benefit analysis) (Naidoo & Ricketts, 2006). This is very easy to achieve, as areas in Newfoundland have been observed to host hundreds of thousands of green crabs (DFO, 2011). Therefore, it is possible to assume that when using an optimal trap and bait a the high CPUE, a green crab fishery can become very profitable. Maine, U.S.A., has also been invaded by green crabs, and have been researching ways to make better use of the species. Though the government says it does not make sense to attempt a sustainable fishery with an invasive species, which they are trying to eliminate, there are still markets in which they can make of value, such as exporting it for pet food, aquaculture feed, and fishing bait (DMR, 2014). A green crab fishery could indeed be worthwhile for Newfoundland and Labrador, to use the crabs into something useful and economically valuable for the people of the province. Not only will the environmental benefits out way the costs, but the economic benefits gained will surely be higher than the cost of the eradication process.

In their native region, green crab harvesting has always been a successful part of the European fishing sector, as they are seen as a delicacy (Klassen & Locke, 2007). Natively, they are also being used as a cleaning species in aquaculture. They have been noted to remove 3.4 kg/m2/7d in dry weight of fish feed pellets, that are found underneath marine fish farms. Cleaning species removes excess nutrients in the water, decreasing the chance of an anoxic environment (Klassen & Locke, 2007).
6. Conclusion

Green crabs are an ecosystem engineer due to their advanced resiliency to environmental factors. They can tolerant a wide range of salinity (Penney et al, 2016) and temperature (Rodrigues et al, 2015), and have great dispersal capabilities (Best et al., 2013; Lyons et al., 2012; Roman & Palumbi, 2004). As opportunistic scavengers (Cohen 2011; Klassen & Locke, 2007) and with low preference to habitat (Amarala et al., 2009), green crabs have become successful invasive species (Klassen, & Locke, 2007; Leignel et al., 2014; Rey et al., 2015).

As a province that is historically reliant on fisheries, and recently aquaculture, the costs associated with the eradication of green crabs are diminishing the economic success in the province of Newfoundland and Labrador. This province has been struggling with ecological fluctuations for centuries, with overfishing, moratoriums, and now with aquatic invaders (Mather, 2013).

This study has allowed a better understanding of green crabs, how they interact when provided multiple choices of bait and what occurs to population levels with continuous trapping. It is clear they do indeed prefer a specific bait. Though Atlantic herring is most commonly used in DFO green crab removal programs (Gillespie et al., 2007), this study has shown the using Atlantic cod provided a higher CPUE, followed by short-fin squid. An important part of total catch were the catch dynamics discovered. Carapace width and sex landings were consistence throughout all baits tested. Lastly, continuous mitigation efforts demonstrated a decrease in catch, until there was a period of no trapping. After a break, green crab population increased as CPUE increased. In conclusion, if there is a switch from Atlantic herring to a more effective bait, like Atlantic cod, and having a continuous mitigation effort, a significant decrease of green crabs will be noticed.
References


DFO. (2009). Does eelgrass (Zostera marina) meet the criteria as an ecologically significant species? DFO Can Advis Sec Sci Advis Rep 2009/018 Fisheries and Oceans Canada, Moncton.


