Comparison of the green crab (*Carcinus maenas*) population trends of different Nova Scotian sites and comparison of green crab management strategies from Atlantic Canada and the U.S.

by

Krish Thapar

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Approved: ________________________

Dr. Tony Charles
Supervisor

Approved: ________________________

Dr. Jeremy Lundholm
Examiner

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Abstract

Despite the green crabs (*Carcinus maenas*) devastating ecological impacts, there have been few studies that have done a green crab population comparison between N.S sites. This study will aim to do a comparison analysis between various sites by analysing the number of crabs caught, the sex ratio changes, and the carapace width changes over time. This study will also compare the different management strategies (eradication, prevention, and control) practised in both Atlantic Canada and the U.S.

Data of the green crabs from Kejimkujik Seaside and Malagash Wharf were collected by Parks Canada manager Gabrielle Beaulieu (Kejimkujik Seaside) and Dalhousie Professor Scott Jefferey (Malagash Wharf). Both sites used standard procedures for capturing and collecting the data from the crabs. A regression analysis was conducted to determine the significance of the time trends for each individual site, and a comparison of two regressions was used to compare and determine the significance between the time trends of two sites. In this study, three comparisons of the various time trends were made: Little Port Joli sub-sites (lagoon, basin, river), Little Port Joli and St Catherine's River, and Kejimkujik Seaside (Little Port Joli + St Catherine's River) and Malagash Wharf.

The majority of the sites, with the exception of the basin (from Little Port Joli) and Malagash Wharf, showed a decrease in the number of crabs over time. The sample of green crabs caught at all sites showed a increased proportion of males captured compared to females over time. Lastly, all sites (with the exception of Malagash Wharf) experienced an increase in the average carapace size over time. Both Atlantic Canada and the U.S have similar management strategies in dealing with green crabs (prevention, eradication, and control), however both countries are currently trying to establish a fishery market for this species.

Introduction

The European green crab, shore crab, or scientific name *Carcinus maenas* is considered to be globally in the top 100 world's worst invaders according to the International Union for Conservation of Nature (IUCN) (Elliott and Young 2019). Its success as an invasive species is partly due to the fact that it has wide ranges of tolerances in temperature, salinity, and oxygen, larvae is quite resilient, has a huge selection of diet, and huge population potential (Elliott and Young 2019). This crab is native to North Western Europe down to North Africa and has invaded both sides of North America, as well as in Australia, Argentina, and South Africa (Elliott and Young 2019). Nova Scotia in particular has been heavily invaded by this crab species, in which the first invasion took place in the 1950's in the Bay of Fundy (Government of Canada 2021). A second invasion occurred in the 1980's and 1990's off of the Northern shore of Halifax and in the Gulf of St Lawrence which introduced a genetically distinct green crab population that was colder resilient (Government of Canada 2021). It was found that the second invasion were not only colder tolerant but noticeably more aggressive of the two populations which in turn created a highly problematic hybrid green crab found in all parts of Nova Scotia (Deese and Arnold 2014).

Invasive species are a type of non-native species that once introduced to a new environment, can spread/increase rapidly and negatively impact the new region of habitat by outcompeting and/or preying on native species and can physically cause damages to the native environment. Invasive species also has the potential to impact humans as well such as increased rates in food shortages, and economical damages (Ehrenfeld 2010).

1.0 Biological traits and characteristics of the green crab

1.1 Physical appearance

Contrary to its name, green crabs are not all green and can in fact come in many color variations such as pure white, black, blotchy, and have various striping patterns which is especially prevalent among juveniles for camouflage and hiding and can also be a vibrant red and orange for adults as well (Grason 2018). Green crabs are not particularly unique in their physical appearance either and are often confused with local crab species (Grason 2018). The size of mature adults ranges from 60 to 100mm across the longest width of its carapace, being quite smaller compared to other native crabs such as rock crabs and lady crabs (DFO 2019). However, one of the key features to single out a green crab from natives is that there are five marginal teeth that run behind the eyes, with three small ridges between the eyes as well (Grason 2018). Other distinctive features of this crab are that the overall shape of the carapace is diamond/trapezoidal in design as well as the majority of the body being smooth and hairless (Grason 2018).

1.2 Mating and maturity specifications in Nova Scotia

It has been recorded that females, were most numerous during spring compared to the rest of the year (Audet et al. 2008). Egg bearing females recordings were at its peak in early July. Mature males molted from June to December, but the majority of them matured in July. Size at maturity fell into the ranges of 28.66-41.43mm for females and 21.30 to 34.49mm for males (Audet et al. 2008). The reproductive strategy of the green crabs is dependent on both latitudinal and regional temperature variations in the water. Water temperatures in the Maritimes are less than 10°C for about eight months of the year. This would suggest that the crabs adapted to a fixed narrow breeding time during the warmer parts of the year (Audet et al. 2008).

1.3 Temperature

Carcinus maenas has a wide range of temperature tolerances where it can survive short term exposures to temperatures between 0 and 33-35°C due to its eurythermal nature (Drolet et al. 2018). To cope against extreme heat, green crabs possess high levels of shock proteins that are integral to their cellular defense against protein degradation from extreme temperatures (Diniz et al. 2012). In cold environmental circumstances, it has been reported that sampled adult crabs from Vancouver Island, British Colombia, survived an 18-week duration exposure to temperatures below or equal to 5°C (Buckley et al. 2013). The minimum temperature required for molting and growth is 10°C, and the minimum for feeding for the majority of recorded crabs is 7°C (Behrens 2001). Most populations of adult green crabs will migrate offshore in search for warmer waters if temperatures drop below 8°C, however crab populations from Northern Europe, such as Sweden, have been able to feed at temperatures lower than 7°C but ceases at 3-4°C. In fact, the second green crab population (origins from Scandinavian lineage) introduction into Nova Scotia created hybridized green crab populations more tolerant to cold temperatures (Eriksson et al 1975). There are no successful populations of *C. maenas* in tropical or subtropical environments and the green crabs are restricted to subpolar and temperate coasts in order to maintain sustainable populations (Carlton and Cohen 2003). This is partly due to the fact that maximum temperatures for breeding is 26°C and 18°C for egg incubation (Elliott and Young 2019).

1.4 Salinity

Green crabs also possess a wide range of salinity tolerances with the minimum salinity concentration needed for long term adult survival reported as being as low as 4% salt concentration to high of, assuming short term exposure to adults, 54% salt concentrations

(Elliott and Young 2019). However, temperature is a key variable that is heavily correlated with salinity of the water and both of these variables combined determines the survival of theses crabs. It was tested that crabs died when in an environment set to 15% salinity and a temperature of 0.6°C in 30 days, while same salt concentrations and a temperature of 9.7°C led to no deaths (Broekhuysen 1936). In comparing salt tolerances among sexes, it was found that males are more tolerant to low salt concentrations compared to females. In terms of salinity preferences, it was tested with the Isle of Man green crabs that their preferences were in the ranges between 27-40% concentration (Elliott and Young 2019).

1.5 Oxygen

Adults crabs, assuming they are kept relatively moist and at an ideal temperature, can survive out of the water for at least 10 days (Darbyson 2006). They are able to cope with this change through a process called "bubbling"-an alternative respiratory process for crabs when out of the water. Based, on this adaptation, it was suggested as a possibility that crabs were able to be transported from New England to California in shipments of wet seaweed (Elliott and Young 2019). However, adults do tend to consume oxygen more quickly compared to earlier life stages due to being more active and larger body mass overall (Aldrich 1986). It was found in Helgoland, Germany that adults increased respiration with temperature increase, yet at low Q10 values, in which the assumption was made that green crabs has the ability to stabilize their metabolic rates under a broad range of habitats (Boos et al. 2018).

1.6 Larvae

The larval stage can stand up to 80 to 90 days getting washed around with the current, and because of this stage it has been able to make great expansions especially up the west coast of the United States in 1997/1998 due to the El Niño events which allowed it to spread from San Francisco Bay all the way up to the coast of British Columbia (Grason 2018).

Green crab larvae have higher tolerances to temperatures than adults, as well as juveniles being more tolerant to temperature fluctuations than both adults and older crabs (Elliott and Young 2019). Rate of development from early stages to adults is dependent on environmental temperatures, where it takes 62 days to develop at 12°C, whereas it takes only 32 days at 18°C (Dawirs 1985).

Salinity ranges for larvae are more restricted compared to juveniles. At low salinities it was shown that early larvae from the North Sea reduced their respiration, suggesting a low or not yet developed osmoregulatory capacity. However, as larval stages develop, salinity tolerances are relatively small until it reaches the juvenile stage, where in this stage green crabs can tolerate a wide range of salinities (Elliott and Young 2019).

1.7 Population potential

Mature female green crabs tend to mate once to two times per year. A green crab female can reproduce more than 185,000 eggs per reproductive event. Assuming two reproductive events per year, a single female may produce as many as 370,000 eggs per year (Green Crab Control Committee 2002). Another report, however, has recorded smaller reproductive rate values, ranging from 185,000 to 200,000 eggs per year for mature female adults (Cohen et al. 1995).

1.8 Native range and regions of invasion

Carcinus maenas is native to the European and North African coasts, extending as far as Iceland and Central Norway and all the way south to Morocco (Williams 1984).

Its non-native distribution in North America was first recorded in Massachusetts in 1887 with both the East and West coasts of North America inhabited with green crabs extending all the way up to British Columbia on the west coast, and furthest in Newfoundland on the east coast (Klassen and Locke 2007). In Australia, *C. maenas* was first reported in Port Philip Bay, Victoria in the late 19th century. Ever since then the crabs have spread to the coast of Victoria, New South Wales, South Australia, and Tasmania being the latest invasion in 1993 (Klassen and Locke 2007). The invasion of South Africa was first observed near Cape Town in 1983 (LeRoux et al. 1990). Argentina was also invaded in 2003 off the coast off of Patagonia. Japan was the last recorded area to be invaded by either the green crab or its close relative, *C. aestuarii.* Some of the areas where the green crabs were introduced but failed to maintain populations were in the Red Sea, Brazil, Panama, Sri Lanka, Hawaii, Madagascar, Myanmar, Perth, and Pakistan (Klassen and Locke 2007).

1.9 Habitat

Green crabs are most commonly found in areas that are well sheltered/protected from tidal waves (Grosholz and Ruiz 1996). Their preferred habitats usually are composed of rocky and vegetated intertidal zones, mud and sandy subtidal zones, as well as saltmarshes and sea grasses (Ray 2005). Juveniles were most abundant in areas covered in eel grass beds and shell debris with their numbers highly increasing with the increased abundance of mussels. On average, it was found that crabs achieved maximum population sizes in the most sheltered shores (Klassen and Locke 2007).

In contrast, green crabs are less likely to be found in fast flowing open waters since it makes it more difficult and longer to locate, capture, and consume prey with their limited vision and their inability to hold onto rocks in relatively mobile currents (Robinson et al. 2011).

1.10 Predation

Although an omnivore, *Carcinus maenas* prefers to be a predator and has been proven multiple times to harm native organisms through predation or outcompeting. European green crabs have a wide range in its diet, essentially eating anything that it can manage reliably, which includes oysters, cockles, snails, mussels, smaller crabs (including their own juveniles), scallops, polychaete worms, clams and barnacles (Grason 2018). They have also been reported to prey on juvenile lobsters, juvenile winter flounder, stickle back eggs, hermit crabs, and barnacles (Klassen and Locke 2007). Given that they are not strictly predators, they will also consume seaweed and the shoots and seeds of eel grass as well (Grason 2018). In fact, they can alter their diet to feed selectively on plant material or algae in the presence of strong competition such as the Asian shore crab, *Hemigrapsus sanguineus* (Armstrong et al. 2002). In general, it was found that green crabs have relatively fixed preferences in diet, no matter the location of a certain population (Klassen and Locke 2007).

A study in the southern Gulf of ~~the~~ Saint Lawrence in Atlantic Canada suggested that green crab predation could potentially be affected by injuries of its claws specifically its crusher claw. It was found that about 12.4% of the crabs collected were missing a claw and it was also demonstrated that compared to non-injured crabs, the loss of the crusher claw led to an increased survival rate for oysters between 93% to 100% (Flynn et al 2015). The loss of the crusher claw also had led to a slightly lower feeding rate on soft shell clams (Flynn et al 2015).

1.11 Economic and ecological impacts of the green crab

Green crabs have had a huge impact on many commercially important marine species, especially bivalves. It was estimated that the potential loss from green cab predation on commercial fisheries could be close to $44 million dollars per year in the US (Elliott and Young 2019). In the east side of North America, green crabs have been recorded to reduce populations of commercially viable species such as soft-shell clams, scallops, and hard clams. In fact, the lowest clam harvest years in Massachusetts and Maine were correlated with high densities of green crab, while the highest clam yields also had considerably smaller crab populations most likely due to environmental pressures (Elliott and Young 2019). Specifically, adult crabs feed on juvenile and adult clams, while both post larval and juvenile crabs feed on clam larvae. Other global areas in which commercially important species are impacted includes blue mussels, quahogs, and pacific oysters in Britain, flat oysters from France, and palourdes from Portugal (Elliott and Young 2019). However, in Tasmania both Pacific oyster and blue mussels, while commercially important, are in relatively little danger to these crabs due to them being located deep in the ocean, but their cockle industry is still at risk (Elliott and Young 2019). Another economically important species that is preyed upon by green crabs are juvenile American lobsters. Green crabs have also taken a huge toll on eelgrass beds (which acts as a nursery/shelter for many marine species) due to extensive foraging and digging off the coast of New England (Elliott and Young 2019). In summary, it was found that green crab presence has led to high mortality rates and reduced yields of commercially important species resulting in huge economic losses.

1.12 Sex ratio trends of green crabs

Understanding the sex ratios of green crabs is of high importance as it aides in estimating the functional population size of the green crabs in a particular area (an imbalance of one sex over the other could heavily impact the size of the next generation) (Beaulieu 2021).

The sex ratio of green crabs is greatly influenced by the characteristics of its surrounding environment. These environmental factors include water depth, temperature, salinity, as well as timing and location of capture because of migratory flow and location preferences (Elliott and Young 2019). Specifically, an abundance of males over females has been found mostly in colder regions such as PEI, whereas female numbers are predominant in warmer regions such as Southern Maine. In terms of salinity preferences, males are more tolerant in lower salinity concentrations compared to females which require higher salt concentrations to survive (Elliott and Young 2019). These concentration preferences from both sexes allows males to move in and out of intertidal zones, while females are mostly found in subtidal zones. Another factor that might influence sex ratios as mentioned above is migratory behaviour as female green crabs most likely migrate during mating periods when mature, moving downstream where salt concentrations are higher, resulting in a larger abundance of males upstream (Elliott and Young 2019). Behavioural differences between both sexes have also been a factor in sex ratios as males are often more active than females and have been recorded to be in more abundance when captured in the traps. In comparison, egg bearing females are much less active and have been observed to burrow into loose sediment so that they are less susceptible to be preyed upon (Elliott and Young 2019). Taking into account these variables, it is quite possible that the actual sex ratio of the entire green crab population in a certain site may be completely different to the sex ratio values calculated from the crabs caught in the traps.

1.13 Carapace size trends of green crabs

Measuring the carapace sizes of the green crabs is equally as critical as the average sizes of the crabs can determine the number of resources within the site available to the crabs and the level of control of the population size as well (larger green crabs will often feed on the smaller ones keeping the population size stable) (Lohan 2021). The carapace size of green crabs can be determined by different types of factors, which includes temperature, region, sex, and population dynamics. Specifically, green crab being an endothermic species relies upon the surrounding external temperature in order to perform physiological functions such as growth (Elliott and Young 2019). It has been discovered from a couple of studies from the Pacific north east that the average carapace widths of green crabs are bigger farther north, such as the maximum range limit in British Columbia, compared to the Southward range of California, which suggests a negative correlation pattern to the temperature-size rule (Elliott and Young 2019). However, the Atlantic green crab population on the North American coastline does not have a clear temperature-size correlation as both the largest recorded crab was located off of the north coast of Nova Scotia and far south in New Hampshire. Furthermore, the smallest maximum size for males was caught on the East coast, also from Nova Scotia and in Maine for females. Despite the inconsistent size-temperature relationship, it is generally found that green crabs are on average smaller in their native region (Europe) compared to the non-native populations (Elliott and Young 2019). In terms of size differences between sexes, males are mostly larger than females (Elliott and Young 2019). Carapace size in relation to population dynamics have been recorded in Bodega Bay, California in which the site had a steady decrease in both number of crabs caught and size of the crabs caught as well. It was suggested that initially the biggest and more aggressive crabs from the population were entering the traps before the smaller crabs could get a chance until the numbers and size started to decrease over time (Rivera et al. 2007). The subsequent crabs not caught then started to increase in size as time progressed, implying that there was less intraspecies competition and more resources for the remaining crabs that weren't originally caught and therefore grow further (Rivera et al. 2007).

1.14 Objectives

The main objectives of this study are as follows.

The 1st objective was to compare the time trends of different characteristics of the green crab populations within different Nova Scotian sites which includes: comparing Little Port Joli Bay's subsites with each other (lagoon, basin river), comparing Kejimkujik Seaside National Park major sites (Little Port Joli Bay and St Catherine's River Bay), and comparing Kejimkujik Seaside National Park green crab population with Malagash Wharf over time.

The 2nd objective of this study was to test the significance of the time trends for each site individually as well. The population characteristics that were analyzed in this study were the time trends of the number of crabs caught, the changes in sex ratios, crabs caught per month (Little Port Joli Bay only), and the carapace width changes over time. Previous studies have compared the population characteristics within different Nova Scotian sites however, most of the studies that have done these comparisons were conducted after quite a while (in which there could have been some significant population changes when the studies ceased) and not compared the sites listed above. Thus, it would be important to give an up-to-date comparison of the new sites so that this study can provide information about the population characteristics and trends of these sites and possibly lead into new methods for dealing with Nova Scotian green crab populations.

The 3rd objective was to interview local fishermen about their opinions and experiences with green crabs. Few studies have interviewed fishermen on their experiences with green crabs, let alone in Nova scotia. These interviews may give new information about the green crabs in Nova Scotia and how to best manage them.

The 4th objective was to examine, through a comparative literature review analysis, of what is being done in the Canadian Maritimes to manage the green crabs in comparison to what is being done in the U.S and if any different management techniques practiced in the U.S can also be applied here. There have been no studies that did a comparative analysis between the two countries in terms of their methods of managing the impacts of green crab populations. This literature analysis may find distinct methods practised in the U.S that are not done in Atlantic Canada and vice versa, that could be applied in the other country in order to better manage the green crabs overall. The literature analysis review will be done in the discussion section.

Materials and Methods

2.0 Malagash Wharf Site Data

Data collections for Malagash Wharf green crabs was conducted by Dalhousie Professor Scott Jeffrey along with his class. The crabs were processed from assigned trap ID's (numbered) at each one of the two sites of the wharf to determine the species, sex, carapace width, site letter (A or B), and abundance of the crab species caught (Jeffrey 2020). Green crabs (*Carcinus maenas*) were caught at the Malagash Wharf, Nova Scotia by the Dalhousie class led by Professor Scott Jeffrey. Data collections for the green crab abundances at this wharf first started in 2015 proceeding until 2019. There were no collections in 2016 due to bad weather, and 2020 was skipped due to the recent COVID-19 restrictions (Jeffrey 2020). All collections occurred in mid October, and took place between 11-2pm. Green crabs were caught at two different sites at the wharf; in which site B was relatively protected from wave and tidal interference, whereas site A was completely exposed and subjected to the full tidal interference (Jeffrey 2020). Over the years this annual data collection took place, there were different baits used to lure and capture the green and rock crabs (*Cancer irroratus*). In 2015 rainbow trout, mackerel, flounder and herring mixture were used to lure the crabs. Mackerel, Arctic charr and herring mixture were used in 2017. Mackerel, artificial bait, and herring mixture were used in 2018. Lastly, mackerel and striped bass were used as crab bait for the latest capture of 2019 (Jeffrey 2020).

Preparation of the traps was conducted solely by Professor Scott Jeffrey where each trap was baited accordingly, every trap had an educational permit and trap ID number attached to the ropes holding the traps (Jeffrey 2020). Each of the traps were soaked for 24 hours; a day before the student collections. A total of 12 collapsible crab traps was used per collection with six of the traps placed in site A with full tidal exposure, and the other six in site B being sheltered from tidal waves (Jeffrey 2020).

On the day of sampling, the class was divided into groups and assigned associated trap ID's to later collect. They were then taught how to properly ID all the crab species (to differentiate between green and rock crabs), determine the sex, and measure the carapace widths of all crabs caught. The groups then went to locate and retrieve their assigned ID's and brought them back to the meeting zone (Jeffrey 2020). The groups then started collecting the data from the traps using datasheets, pencils, and calipers. After all data recordings were done, all of the groups data was compiled into one Masterfile (excel spreadsheet). Rock crabs that were caught in the traps were carefully released back along the wharf's side, while all green crabs were taken back to the lab and euthanized as per the Department of Fisheries and Oceans Canada (DFO) permit (Jeffrey 2020).

Figure 1. Overhead view of Malagash wharf and both sites used to capture and collect green crabs. Photo by: Professor Scott Jefferey.

Figure 2. A sample of the collapsible crab trap used to capture the crabs from Malagash wharf. Photo by: Professor Scott Jefferey.

Figure 3. Top specimen is male green crab depicted by its ventral triangular tail, with the bottom crab specimen being female depicted by its more ovular ventral tail. Photo by: Professor Scott Jefferey.

2.1 Kejimkujik Seaside Data

Data collections were conducted from Little Port Joli and Saint Catherine's river beach and data was collected by members of Parks Canada. Similar to Malagash data collections, Keji Seaside National Park members collected the date, sex, carapace length (mm), abundance, and site location from the captured green crabs. The methods for this data collection were acquired from *The European Green Crab Protocol: Kejimkujik National Park Seaside* from project manager Gabrielle Beaulieu. Data collections for the green crab abundances at these sites first started in 2009 till 2019 being the latest data collection.

In order to access the trap locations, set, bait, empty traps, and move monitoring equipment, a canoe or Jon boat is required (Parks Canada 2014). To ensure maximum safety and protection, appropriate gear must be worn at all times, which is explained in detail in *The European Green Crab Protocol.*

The monitoring of green crabs is done through randomly selected locations of different habitat types from the Little Port Joli Estuary. All locations that were selected by Parks Canada were ensured that it was submerged throughout the daily tidal cycle as well (Parks Canada 2014). A total of 14 traps locations are used permanently in which seven are randomly positioned in the northern half of the estuary and the remainder seven are randomly positioned in the south as well. Traps were also kept at a minimum of 50m apart from each other to minimize cross-trapping influence (Parks Canada 2014).

In order to capture the green crabs effectively, Parks Canada have been using modified eel traps to catch the crabs (details of the dimensions and characteristics of the traps can be found in *The European Green Crab Protocol*). Pieces of herring were used as bait for the trap by placing it in a perforated 250ml Nalgene bottle and attaching it (to the opposite side of the entrance) inside the traps (Parks Canada 2014). Enough rope (tidal cycle accounting) is attached with a buoy for simplified identification. The trap is then deployed at the site for a 24 ± 2 hr period and is retrieved during daytime hours in which all of the data is recorded on one standardized spread sheet. The spread sheet categories included species identification, sex, location of site, and width across the carapace in millimetres (Parks Canada 2014). The equipment that was necessary to conduct the recordings were modified eel traps, ropes, buoys, bait bottles (250 mL Nalgene), herring chunks (bait), datasheets, GPS (NAD 83), watch, field ID sheets, collection buckets/crates, Vernier Callipers, water proof camera, and sample bags (Parks Canada 2014).

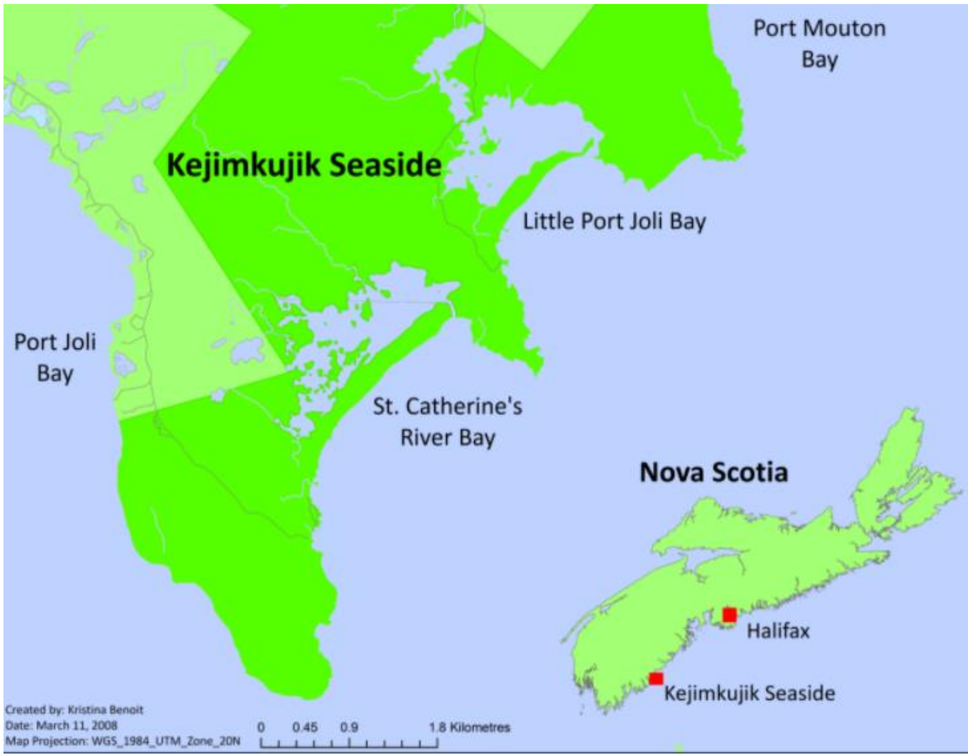

Figure 4. Map above depicts the locations used to capture and collect green crab data from Kejimkujik Seaside, Little Port Joli and St. Catherine's River Bay. Map by: Parks Canada.

Figure 5. Depiction of the three sub-sites (lagoon, basin, river) used to capture and collect green crab data from Little Port Joli Bay, Kejimkujik Seaside. Photo by Parks Canada.

2.2 Comparisons between sites

Restrictions were made to Little Port Joli's Bay data series when making comparisons to St Catherine's River Bay and Malagash Wharf. Specifically, Little Port Joli site collected data from August to October per year, whereas St Catherine's River collection only occurred during August. In order to properly compare between the two Kejimkujik sites, Little Port Joli data was filtered to just August recordings to match the data with St Catherine's and to also to establish variable control. Restrictions were also made to Kejimkujik Seaside data (Little Port Joli and St Catherine's River bay) with Malagash

Wharf as data collections in Malagash Wharf started significantly later than Kejimkujik Seaside data collections (2015 as opposed to 2009). Thus, data collected from 2009 to 2014 from Kejimkujik Seaside was omitted when comparing the data collections with Malagash Wharf. Months were not restricted in this comparison since both St Catherine's and Malagash Wharf collected green crabs from different months (August and October) and would have completely omitted St Catherine's data from this comparison.

2.3 Ethics approval and interviews

The main objectives in conducting an interview are to obtain primary data independently, and to be able to communicate with local fisherman and experts of their experience and potential data on green crabs. Before the interviews take place, it was mandatory for the SMU Research Ethics Board (REB) to review the main application (Form 1c), followed by the informed consent form, recruitment letter, and thank you letter in order to be approved to invite participants in the study. The participants that took part in study were three fishermen from Nova Scotia, in which they were all interviewed via recorded phone calls. Before each interview was conducted, all participants were required to read the documents sent to them via email (recruitment letter and a consent form) and they all emailed back stating that they agree to participate in this study. The participants were given a choice whether or not they wished to be voice recorded, wish to have their name kept private, and the liberty to skip questions that they did not feel comfortable answering or did not know. The interviews lasted between 15 to 20 minutes.

The list of all of the questions asked in the interviews included:

Personal questions

What is your name? Where do you fish? How long have you been working in this field? How have you contributed to helping DFO data collection in the past? Where have you been collecting data?

Lobster-related questions

On average, when you are fishing, how many lobsters do you catch each day? How does that change over the course of a fishing season? Has the size or quality of lobster changed over time? When is the lobster season for you? When is there the breeding/mating season? Is there a particular time of year when lobsters are noticeably more abundant? Less abundant?

Green crab questions

How have green crabs affected your work broadly and specifically? Have green crabs impacted your catches of lobsters to a significant degree? Has your job, or your revenues, been impacted due to the presence of green crabs? How many green crabs do you catch on average, per day, month, year? When was the highest green crab catch per day, month, year? When was the lowest? On average, how many green crabs would you catch in each lobster trap, for each haul? If you fish intentionally for other than lobster, has anything else been impacted by green crab presence? If so, to what extent? What are the interactions between lobsters and green crabs? Do you feel that they are unaffected, negatively impacted, or act as an alternative food attraction for lobsters? Is there a particular time of year when green crabs are noticeably more abundant? Less abundant? Are green crabs more abundant when sea temperatures are higher in Nova Scotia? What do you do with captured green crabs? Do you do anything to reduce the impacts of green crabs? Is there any economic benefit from green crab harvesting? (bait, fertilizer, bioplastic, food source) What is the future for green crabs in Nova Scotia, and do you think this invasive species will have more economic value in the future?

2.4 Literature review analysis

A literature review was conducted in the discussion section to answer the second research question regarding on similarities and differences between Atlantic Canada and the U. S's management strategies to cope against the green crabs. The comparison analysis was organized into three main strategies: prevention, eradication, and control. All information compiled and used were from government web sources and research articles as well.

2.5 Statistical analysis

A regression analysis was conducted to determine the P-value for each individual site and test if there was a significant time trend or not. The null hypothesis for the regression analysis for an individual site would state that the regression coefficient (slope) of the time trends close to or equal to zero in which there is no significance in the time trend. However, if the null hypothesis is rejected it would imply that the regression coefficient is not equal to zero in which there is a significance in the time trend for the individual site. R^2 was analyzed to determine the correlation strength of the regressions for each of the individual sites. Specifically, the closer the R^2 value is to one, the stronger the correlation of the regression as the individual points are closer to the slope of the line of best fit.

The residuals for each individual regression were checked to ensure that the vertical error points displayed on the residual plot showed no patterns (unpredictable) as it would suggest that the regression model needs to be adjusted. Such adjustments may include adding another variable that could be influencing the dependant variable, or adding a polynomial term to model a curved pattern (Frost 2019).

A comparison of two regression lines was used to test the significance of trends over time between the two sites. Essentially, the null hypothesis for the comparison of two regression lines would state that there is little to zero difference between the two regression coefficients and therefore no significant difference in time trends between the two sites. However, if the null hypothesis is rejected it would imply that difference between the two regression coefficients is not equal to zero and therefore have a significance in time trends between the two regressions.

The P-critical value used in all statistical tests was 0.10 instead of the more common 0.05 to reflect the relatively low consequences of incorrect hypothesis rejection, together with the limited extent and greater variability in the data for this study. In addition, the annual sex ratios for each site were calculated by dividing the number of males caught in a particular year by the total number of crabs caught in the same year. All statistical tests were performed using Microsoft Excel 2016 data analysis tool package.

2.6 Hypothesis testing

Individual regression test:

H_0: Null hypothesis states that the slope of the regression line is equal to zero. (If the P-value is greater than the P-critical value, cannot reject null hypothesis).

H_a: Alternative hypothesis states that the slope of the regression is not equal to zero. (Reject null hypothesis if the P-value is less than the P-critical value).

Comparison of two-regression lines test:

H_0: Null hypothesis states that there is <u>no difference</u> between the slopes of two regressions. (If the P-value is greater than the P-critical value, cannot reject null hypothesis).

H_a: Alternative hypothesis states that there is a difference between the slopes of two regressions. (Reject null hypothesis if the P-value is less than the P-critical value).

Results

3.0 Little Port Joli Bay individual sites (lagoon, basin, river) time trends

Catches per year

A total of 27,035 crabs were caught at the lagoon site, 7,668 from the basin, and 8,484 at the river site from 2009 to 2019. Both the lagoon and river sub-sites (with the exception of the basin) had a negative line of best fit for the number of crabs caught per year, with the lagoon site having the steepest slope. Individually, the lagoon sub-site was the only data set that had a significant P-value of 0.058, while the basin and river sub-sites had no significant regressions (>0.10).

All sites had a relatively small correlational values with lagoon having the highest R^2 value and basin having the smallest R^2 value (**Figure 6**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between each site for the number of crabs caught per year, lagoon and basin displayed a significance in the P-value between the two slopes of 0.088. However, there was no significance in the comparison of two slopes between lagoon and river (0.17), and between river and basin (0.56).

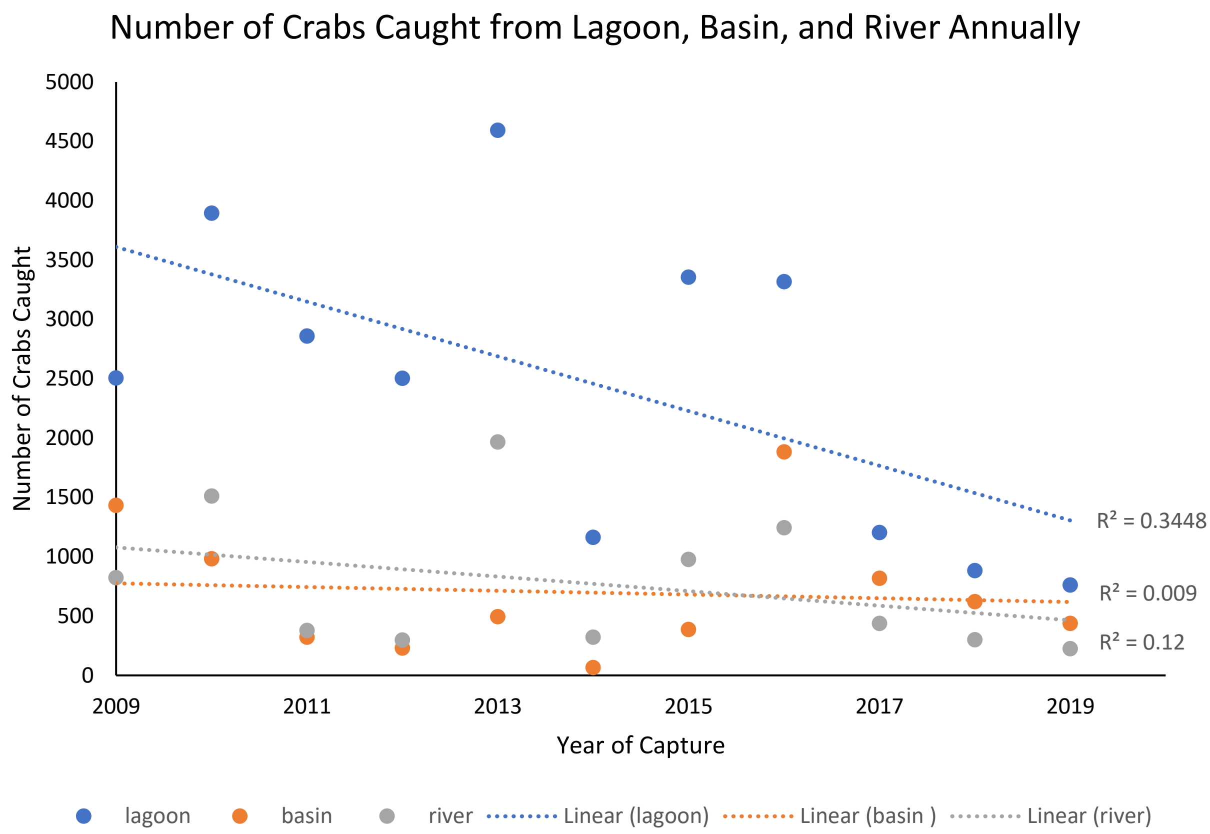

Figure 6. Number of crabs caught at the lagoon (blue), basin (orange), and river (grey) sub-sites from 2009-2019.

Sex ratio changes over time

*Sex ratios were calculated by taking the number of male crabs caught in a specific year divided by the total number of crabs caught of the same year.

Little Port Joli's lagoon, basin and river sub-sites all had a positive line of best fit for the male abundance of sex ratios per year, with the river having the steepest slope. Individually, both the lagoon and river sub-sites had significant P-values of 0.048 and 0.025.

All three sub-sites had a relatively small correlational value with river having the highest R^2 value and basin having the smallest R^2 value (**Figure 7**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between each site for the male abundance of sex ratios caught per year, there was no significance in the comparison of two slopes between any of the sites (>0.10).

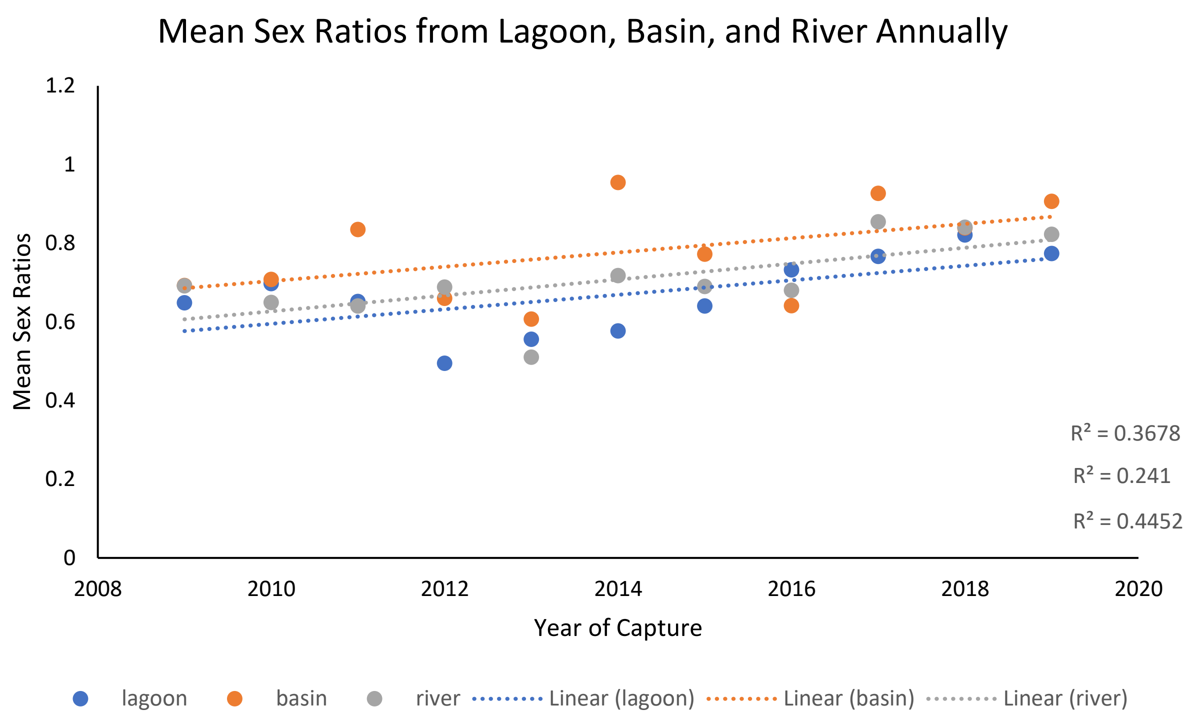

Figure 7. Sex ratio changes from the lagoon (blue), basin (orange), and river (grey) sub-sites from 2009-2019. (Positive regression lines indicates a higher ratio of males caught)

Carapace width changes over time

All sub-sites had a positive line of best fit for the carapace width changes per year, with the basin sub-site having the steepest slope. Individually, both the lagoon and basin sub-sites had significant P-values of 0.090 and 0.095.

All sites had a relatively small correlational value with lagoon having the highest R^2 value and river having the smallest R^2 value (**Figure 8**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between each of the three sites for the average carapace width size per year, there was no significance in the comparison of two slopes between any of the sites (>0.10).

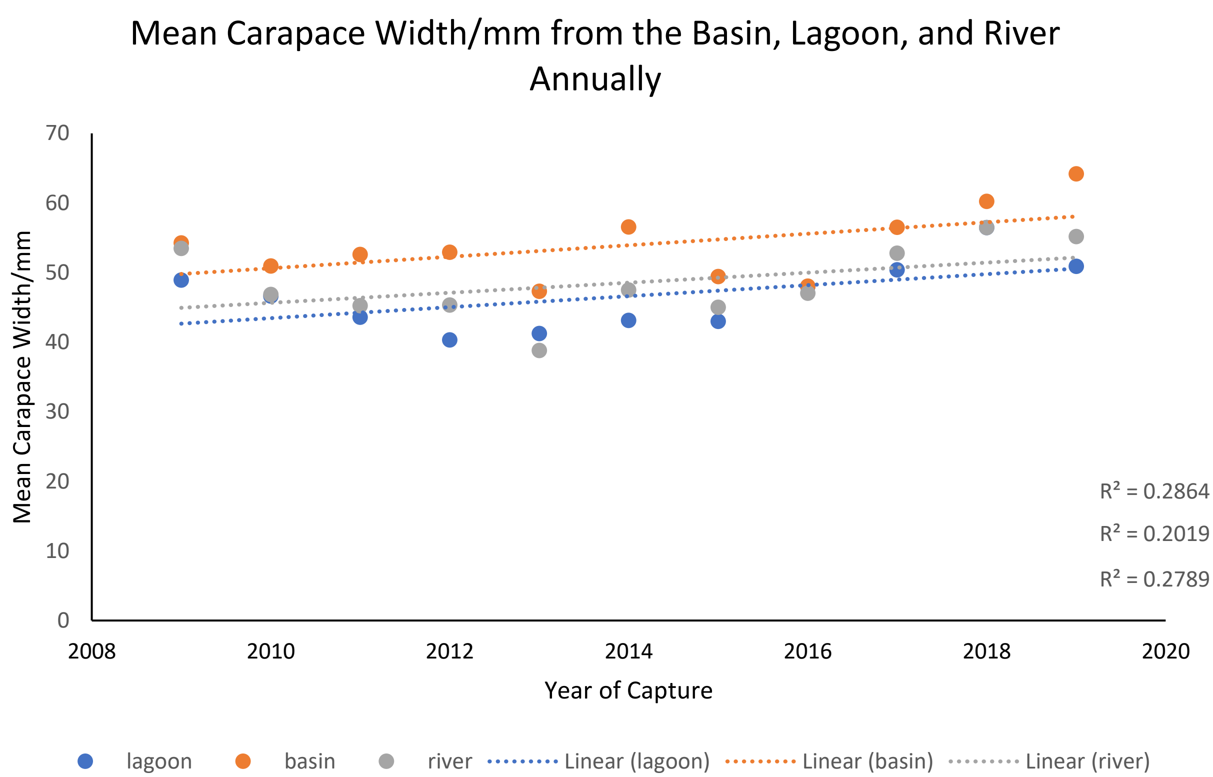

Figure 8. Carapace size changes from the lagoon (blue), basin (orange), and river (grey) sub-sites from 2009-2019.

Catches per month of Little Port Joli Bay

A total of 16,410 crabs were caught during August, 12,694 September, and 14,089 in October from 2009 to 2019 at Little Port Joli Bay. All months had a negative line of best fit for the number of crabs caught per year, with October having the steepest slope and September having the shallowest slope. All sites had a relatively small correlational value with August having the highest R^2 value and September having the smallest R^2 value (**Figure 9**). The residual plots for each site were random and displayed no signs of patterns in the errors. There was no significance in the comparison of two slopes between any of the months (>0.10). Individually, none of the months had a significant P-value (<0.10).

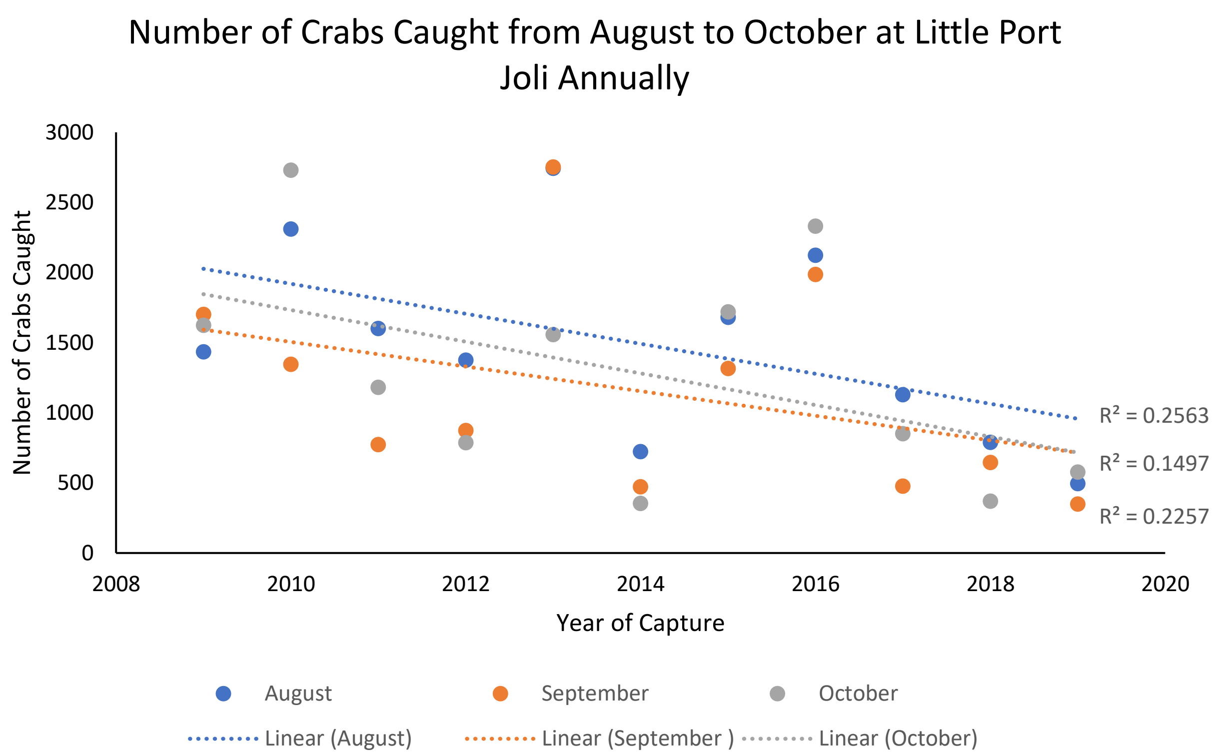

Figure 9. Number of crabs caught in August (blue), September (orange), and October (grey) from 2009-2019 at Little Port Joli Bay (lagoon, basin, and river values combined).

3.1 Little Port Joli and St Catherine's River Bay time trends

Catches per year

A total of 16,410 crabs were caught at Little Port Joli Bay (August) from 2009 to 2019, and 3,586 at St Catherine's River Bay from 2012 to 2019. Both Little Port Joli and St

Catherine's River Bay had a negative line of best fit for the number of crabs caught per year. Individually, both sites had no significant regressions (0.11 for Little Port Joli and 0.74 for St Catherine's River).

Both areas had a relatively small correlational value with Little Port Joli having the highest R^2 value in relation to St Catherine's River Bay as well (**Figure 10**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between each site for the number of crabs caught per year, there was no significance in the comparison of two slopes between Little Port Joli and St Catherine's River bay (0.24).

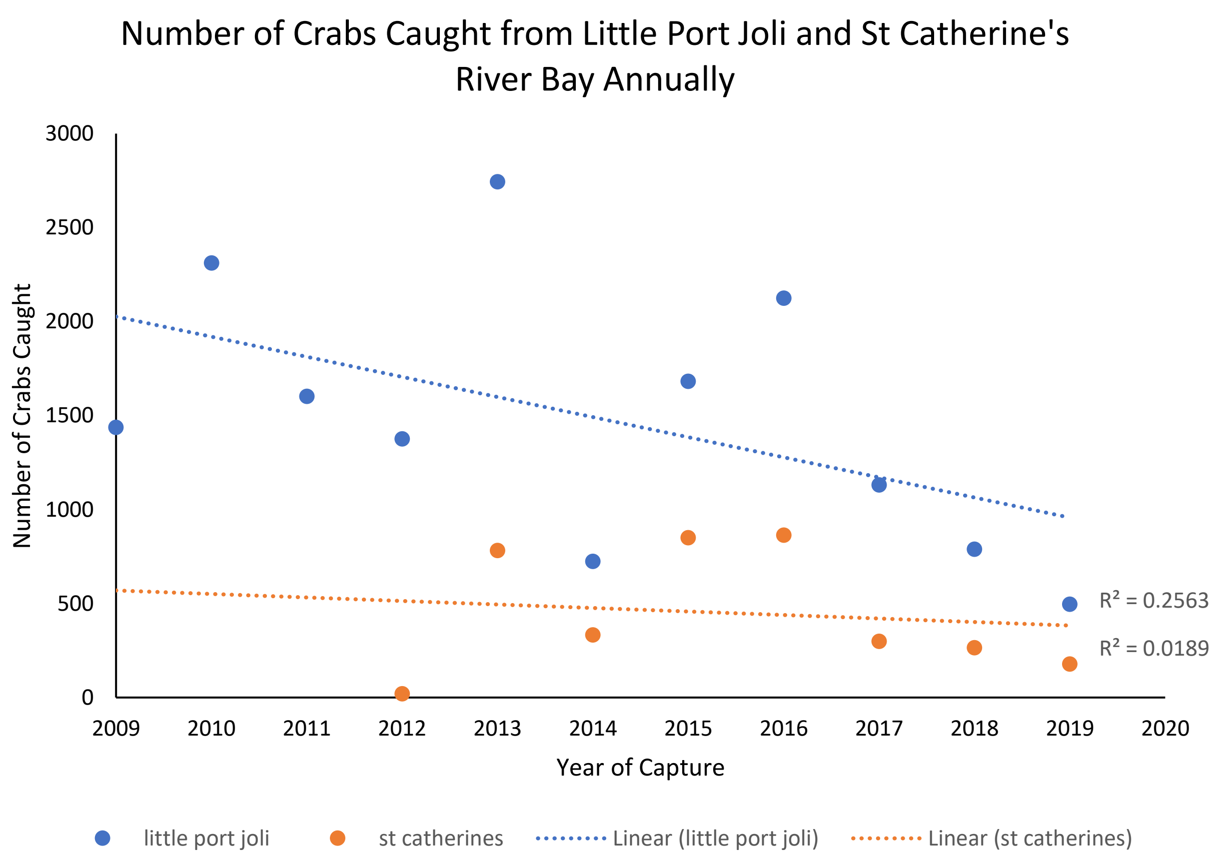

Figure 10. Number of crabs caught at Little Port Joli Bay (blue) from 2009-2019, and St Catherine's River Bay (orange) from 2012-2019. Little Port Joli data was restricted to October since St Catherine's data was collected in just October.

Sex ratio changes over time

*Sex ratios were calculated by taking the number of male crabs caught in a specific year divided by the total number of crabs caught of the same year.

Both Little Port Joli and St Catherine's River Bay had a positive line of best fit for the male abundance of sex ratios per year, with St Catherine's River having the steepest slope compared to Little Port Joli. Individually, both Little Port Joli and St Catherine's River Bay areas had significant P-values of 0.019 and 0.07.

Both areas had a relatively high correlational value with Little Port Joli having the highest R^2 value compared to St Catherine's River (**Figure 11**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between each site for the male abundance of sex ratios caught per year, there was no significance in the comparison of two slopes between any of the sites (0.41).

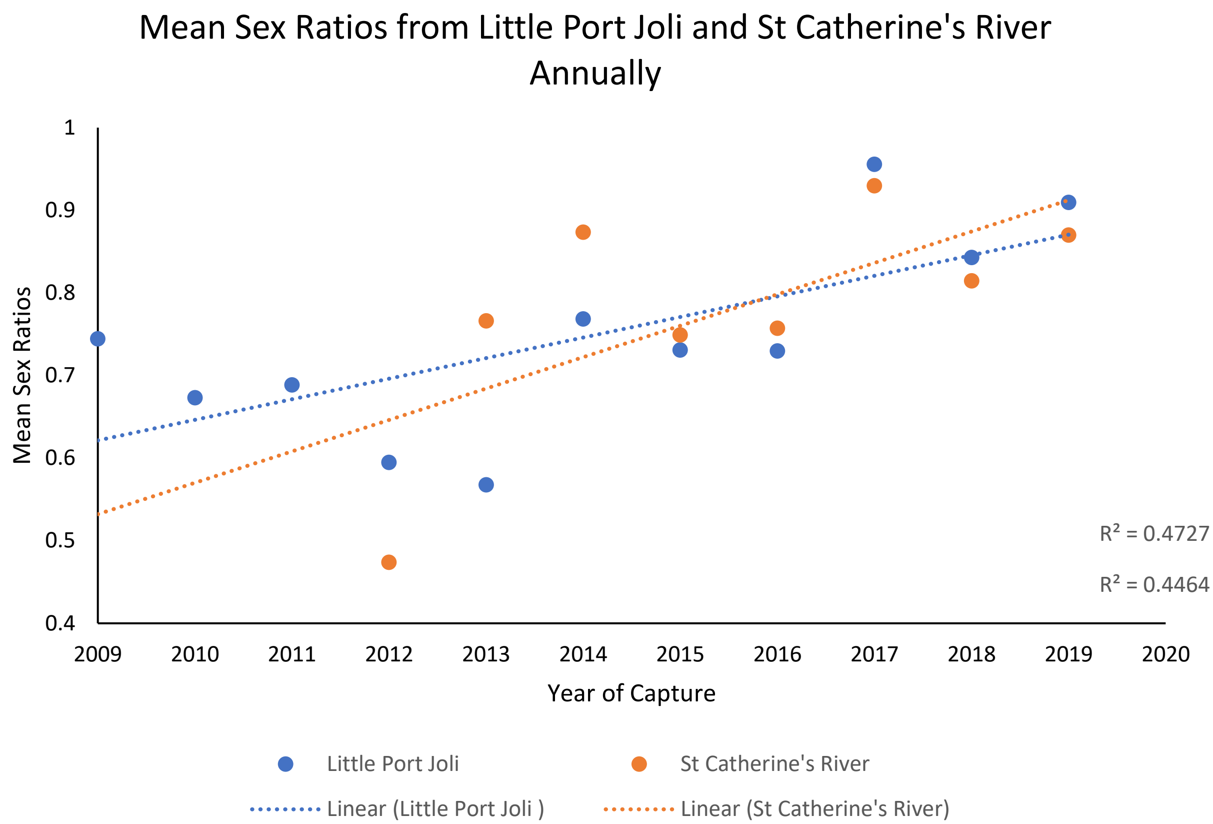

Figure 11. Sex ratio changes at Little Port Joli Bay (blue) from 2009-2019, and St Catherine's River Bay (orange) from 2012-2019. Little Port Joli data was restricted to October since St Catherine's data was collected in just October. (Positive regression lines indicates a higher ratio of males caught)

Carapace width changes over time

Both Little Port Joli and St Catherine's River Bay had a positive line of best for the carapace width changes per year, with St Catherine's River having the steepest slope compared to Little Port Joli. Individually, both Little Port Joli and St Catherine's River Bay had significant P-values of 0.010 and 0.090.

St Catherine's River had a relatively high correlational R^2 value compared to Little Port Joli (**Figure 12**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between both sites for the average carapace width size per year, there was no significance in the comparison of two slopes between both areas (0.47).

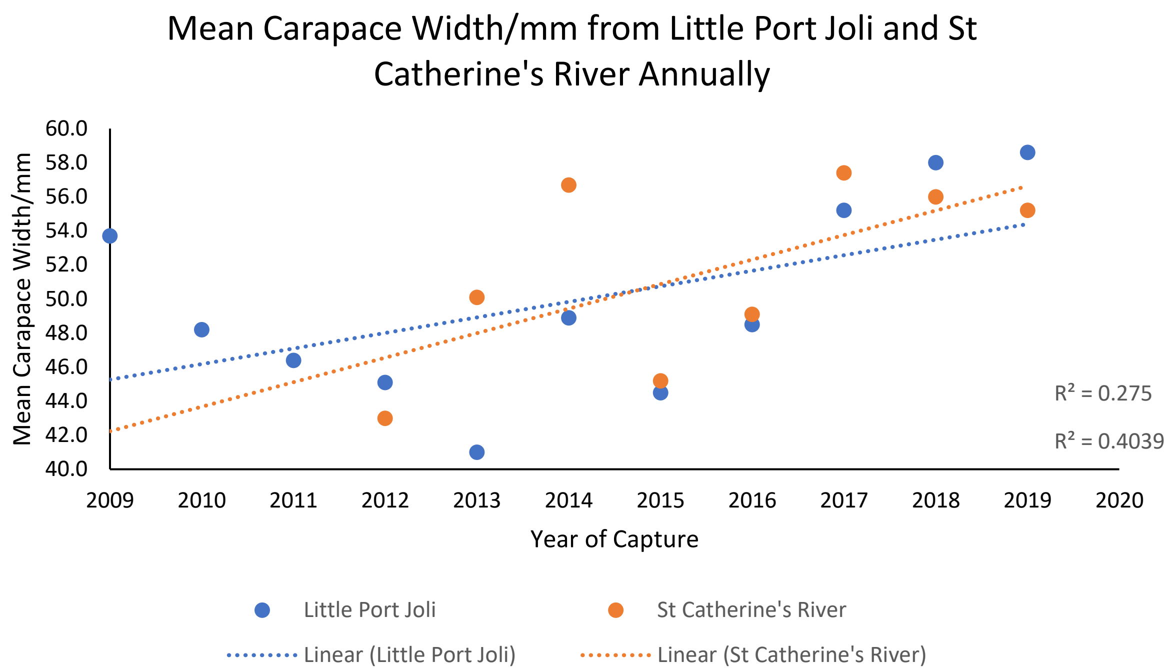

Figure 12. Carapace size changes at Little Port Joli Bay (blue) from 2009-2019, and St Catherine's River Bay (orange) from 2012-2019. Little Port Joli data was restricted to October since St Catherine's data was collected in just October.

3.2 Kejimkujik Seaside National Park and Malagash Wharf time trends

Catches per year

A total of 19,301 crabs were caught at Kejimkujik Seaside (including all months) and 379 at Malagash Wharf from 2015 to 2019. Kejimkujik Seaside had a negative line of best fit for the number of crabs caught per year **(Figure 13)**, while Malagash Wharf had a small positive line of best fit **(Figure 14)**. Individually, Kejimkujik Seaside National Park was the only data set that had a significant P-value of 0.072, while Malagash Wharf had an insignificant regression of 0.97.

Kejimkujik Seaside had a relatively high correlational R^2 value **(Figure 13)** in comparison to Malagash Wharf **(Figure 14)**. The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between each site for the number of crabs caught per year, Kejimkujik Seaside and Malagash Wharf both displayed a significance in the P-value between the two slopes of $8.8*10^{-9}$.

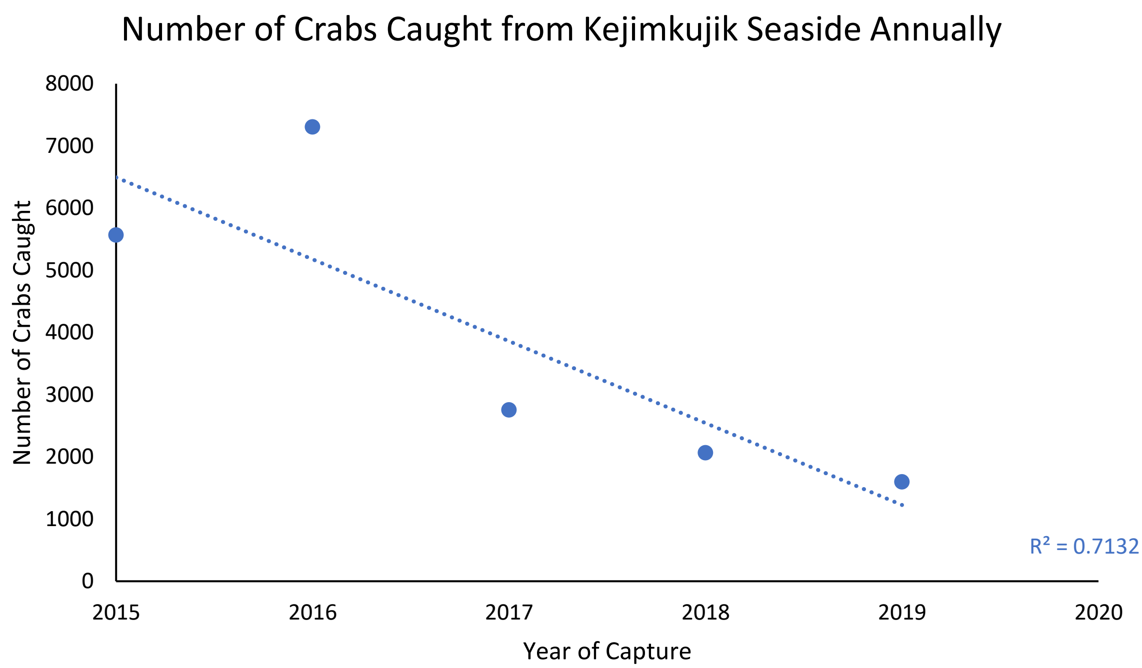

Figure 13. Number of crabs caught at Kejimkujik Seaside National Park (Little Port Joli and St Catherine's River Bay combined) from 2015-2019.

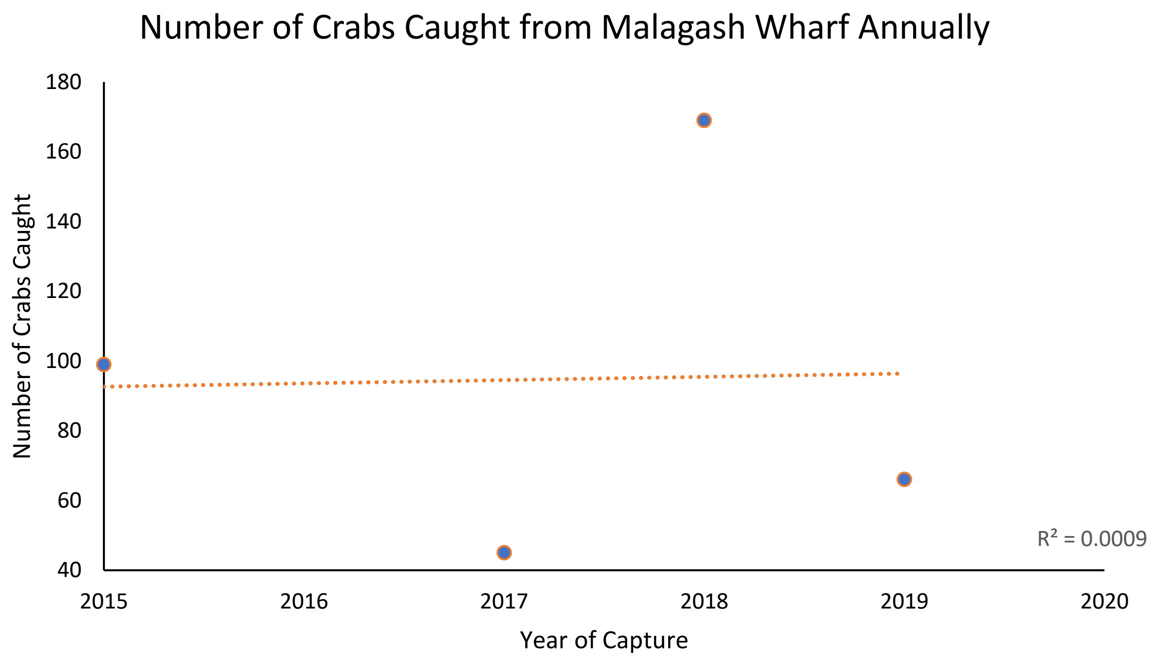

Figure 14. Number of crabs caught at Malagash Wharf from 2015-2019. Catches at this site only occurred in October.

Sex ratio changes over time

*Sex ratios were calculated by taking the number of male crabs caught in a specific year divided by the total number of crabs caught of the same year.

Both Kejimkujik Seaside and Malagash Wharf had a positive line of best fit for the male abundance of sex ratios per year, with Malagash Wharf having the steepest slope compared to Kejimkujik Seaside. Individually, both Kejimkujik Seaside and Malagash Wharf areas had significant P-values of 0.069 and 0.0090.

Both areas had a relatively high correlational value with Malagash Wharf having the highest R^2 value compared to Kejimkujik Seaside (**Figure 15**). In comparing the time trends between each site for the male abundance of sex ratios caught per year, there was no significance in the comparison of two slopes between any of the sites (0.65).

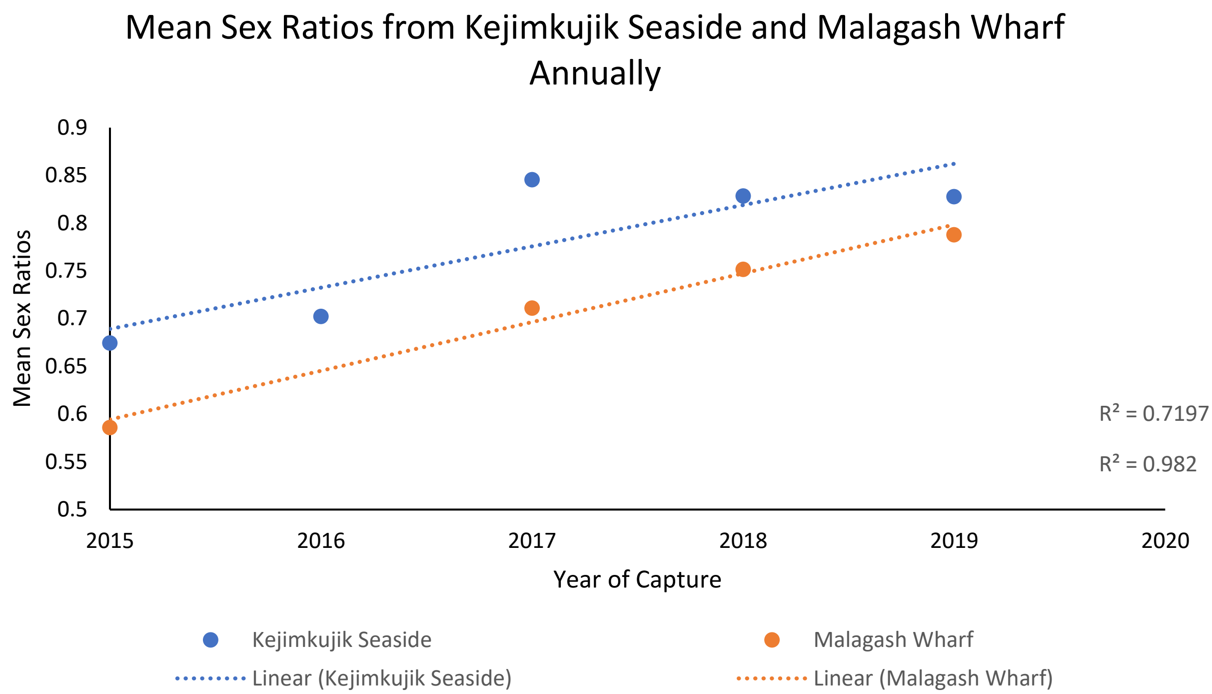

Figure 15. Sex ratio changes at Kejimkujik Seaside (blue), and Malagash Wharf (orange) from 2015-2019. (Positive regression lines indicates a higher ratio of males caught)

Carapace width changes over time

Kejimkujik Seaside had a positive line of best fit for the carapace width changes per year, while Malagash Wharf had a negative line of best fit. Individually, both Kejimkujik Seaside and Malagash Wharf had significant P-values of 0.038 and 0.011.

Both areas had a relatively high correlational value with Malagash Wharf having the highest R^2 value compared to Kejimkujik Seaside (**Figure 16**). The residual plots for each site were random and displayed no signs of patterns in the errors. In comparing the time trends between both sites for the average carapace width size per year, there was a significance in the comparison of two slopes between both areas (0.0046).

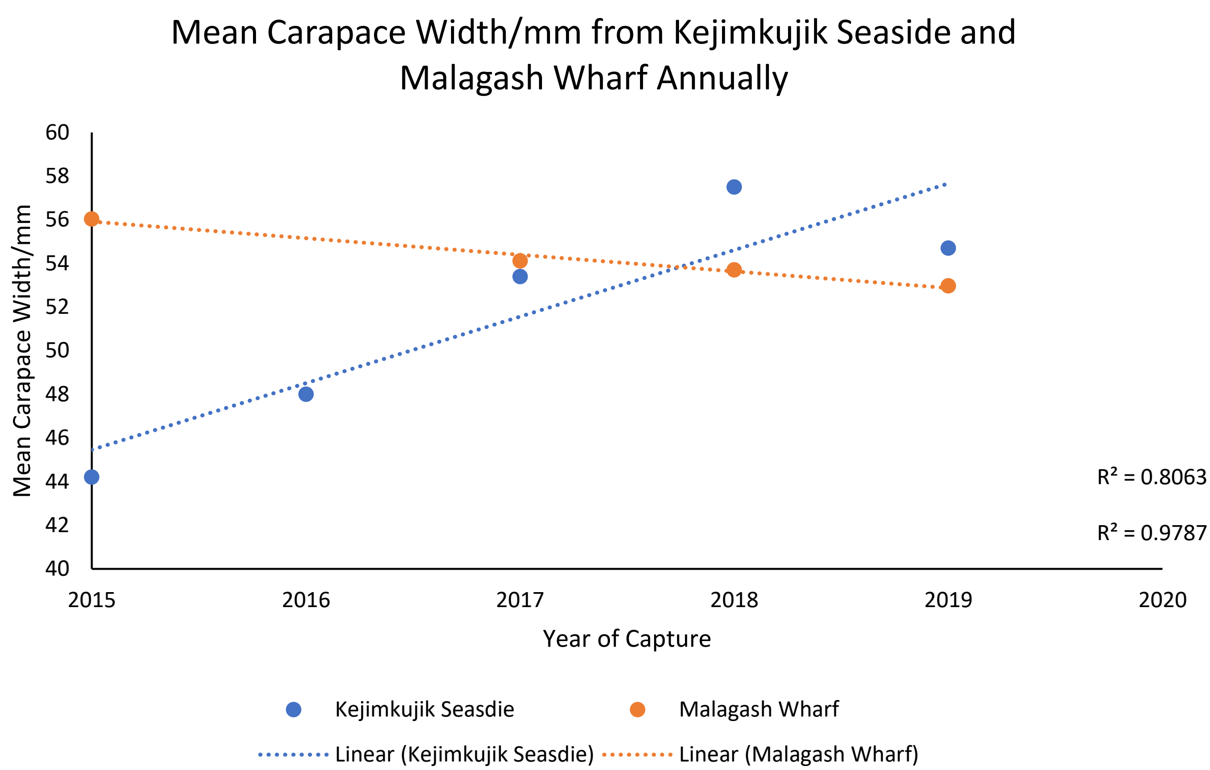

Figure 16. Carapace size changes at Kejimkujik Seaside (blue), and Malagash Wharf (orange) from 2015-2019.

3.3 Interviews

The results obtained from three interviews with fishermen are presented in the Appendix.

Discussion

4.0 Number of catches per year

Little Port Joli sub-sites (lagoon, basin, river)

The lagoon was the only sub-site from Little Port Joli Bay that showed a significant decrease in the number of crabs caught per year based on the line of best fit and the P-value being less than 0.10. This would suggest that the difference in the number of crabs caught per year at the lagoon is significant, implying that the trapping efforts are indeed helping control and reduce the green crab populations located in this sub-site.

However, the other two sub-sites, the basin and river, showed no significant regression for the changes in the number of crabs caught over time. This could suggest there is either no clear trend over time (slope is close to zero) or the data is not sufficient enough to show a distinct relationship.

The comparison of two regression lines between the lagoon and basin sub-sites displayed a P-value that was less than 0.10. This P-value implies that there is a significant difference in the trend of abundance between the two sub-sites. Specifically, the lagoon sub-site had a significant decreasing regression line that had a P-value less than 0.10 (implying that the number of crabs caught per year is decreasing), while the basin sub-site had no significant regression line as the P-value was greater than 0.10 (this would suggest that there is no distinct trend in the number of crabs caught per time at this sub-site).

A possible cause for the lack of a significant trend over time in the basin population was explained by another study conducted by Californian researchers at the Seadrift Lagoon. At this site similar mass efforts were conducted in removing the crab population located there from 2009 to 2014, in which the population was reduced from 250,000 to 10,000 crabs (Lohan 2021). However, by 2015 the population grew to about 300,000. It was suggested that the adult crabs were controlling the population by preying on the smaller crabs, and once the adults started getting removed by the traps it possibly off-set the balance within the population leaving many smaller crabs behind (Lohan 2021). The remaining smaller crabs were possibly given a greater chance to mature and consequently led to a lot of mature females becoming fertile and therefore greatly expanding the population size than before. This study might also explain the lack of a significant trend over time in the other sites as well, especially Malagash Wharf.

Comparison of the change in the number of crabs caught per month at Little Port Joli:

The results of the number of crabs caught in each month at Little Port Joli Bay showed no significance in the difference in number of crabs caught in a particular month, whether it be August, September, or October. In addition, the P-values that represented the number of crabs caught for each individual month showed no significance for any of the three months. This would suggest that the number of crabs caught per year within each month was highly varied and that there were no significance in the time trends for any of the months. However, all three months showed a general decrease of the number of crabs caught per year.

Little Port Joli and St Catherine's River Bay

Little Port Joli and St Catherine's River Bay both showed a decrease in the number of crabs caught per year based on the line of best fit. The results support the original prediction in that the number of green crabs caught should decrease per year based on the removal efforts by Parks Canada**.** However, the comparison of two slopes showed that there was no significance between the two Kejimkujik sites having a P-value greater than 0.10. The P-value implies that there is no sizeable difference in terms of the change in the number of crabs caught per year with both sites decreasing relatively at the same rate over time. These results also demonstrates that Parks Canada's removal and trapping efforts are consistent with both sites.

However, individually, both Little Port Joli and St Catherine's River Bay had no significance in the change in number of crabs caught per year based on the p-values being greater than 0.10. This would suggest that the difference between sites in the trend over time of the number of crabs caught per year is not significant, implying that the trapping efforts are indeed helping control and reduce the green crab populations located in this sub-site. This would also imply that the number of crabs caught per year within each site was highly varied and that there is no significant difference in the number of crabs caught despite the trapping efforts from both sites.

Kejimkujik Seaside National Park and Malagash Wharf

Kejimkujik Seaside site showed an overall decrease in the number of crabs caught per year based on the line of best fit. The results again support the original prediction in that the number of green crabs caught should decrease per year based on Parks Canada's removal efforts**.** However, the Malagash Wharf showed very little to zero difference in the number of crabs caught per year based on the line of best fit. This might suggest that the efforts that went towards removing the green crabs from Malagash site were not as impactful as the efforts down south at the Kejimkujik Seaside site. It is quite possible that the crab population at Malagash Wharf could be following the same trend as the basin sub-site from Little Port Joli Bay and Seadrift Lagoon from California.

The comparison of two regression lines between Kejimkujik Seaside and Malagash Wharf displayed a P-value that was less than 0.10. The P-value implies that there is a significant difference in the trend of abundance between the two sites. Specifically, Kejimkujik Seaside site decreasing over time and surprisingly, despite the removal efforts, the Malagash Wharf population appears to have no significant trend over time.

Individually, the Kejimkujik Seaside site had a significance in the change of the number of crabs caught per year based on its P-value being smaller than 0.10. This would suggest that the difference in the number of crabs caught per year at Kejimkujik Seaside is significant, implying that the trapping efforts are indeed helping control and reduce the green crab populations located at this site. However, the Malagash has a P-value greater than 0.10 which suggests that the number of catches varied considerably between each year and there was no distinct trend over time similar to what's occurring in the crab population at the basin sub-site.

4.1 Sex ratios

Little Port Joli sub-sites (lagoon, basin, river)

In comparing the green crab sex ratios between the Little Port Joli sub-sites, the lagoon, basin and river, contrary to the original prediction of there being no difference over time, all showed an increasing proportion of male crabs over females during the entire collection time indicated by the line of best fit. This could suggest that there might be environmental factors that could be influencing the shift in sex ratio over time such as a decrease in water temperature, reduced salinity concentrations of the water in the sites which would decrease the area of suitable habitats for required for female green crabs. It might also suggest that there is a shift in mating season over time which might lead to more females migrating and hiding more frequently (especially when they are oviparous) before the annual capture (August-October) by the Parks Canada team at Kejimkujik Seaside National Park. It was also mentioned by Park's manager, Gabrielle Beaulieu, that the greater reduction of females in comparison to males could also be due to the fact that males are generally larger than females (more competitive success and entering the traps more frequently) and have also been frequently observed to eat females as green crabs in general are known to be cannibalistic (Beaulieu 2021).

The comparison of two regression lines between the three sub-sites produced no P-values that were less than 0.10. The P-values implies that there is no significant difference in the trend of the sex ratios between the three sub-sites. This would suggest that all three sub-sites have similar sex ratio time trends in which there seems to be a greater proportion of male green crabs caught over time.

Little Port Joli and St Catherine's River Bay

In comparing the green crab sex ratios between Little Port Joli and St Catherine's River, contrary to the original prediction of there being no difference over time, both sites displayed an increasing proportion of male crabs over females during the entire collection time indicated by the lines of best fit. This could suggest as mentioned above, that there might be environmental factors, a shift in the mating season, or predation of females by males that could be influencing the shift in sex ratio over time.

The comparison of two regression lines between Little Port Joli and St Catherine's River Bay displayed a P-value that was greater than 0.10. The P-value implies that there is no significant difference in the trend of the sex ratios between the two Kejimkujik Seaside sites. This would suggest that both sites have similar sex ratio time trends in which there seems to be a greater proportion of male green crabs caught over time.

Kejimkujik Seaside National Park and Malagash Wharf

In comparing the green crab sex ratios between Kejimkujik Seaside and Malagash Wharf, contrary to the original prediction of there being no difference over time, both sites displayed an increasing proportion of male crabs over females during the entire collection time indicated by the lines of best fit. This again could suggest that there might be environmental factors, a shift in the mating season, or predation of females by males that could be influencing the shift in sex ratio over time.

The comparison of two regression lines between Kejimkujik Seaside and Malagash Wharf displayed a P-value that was greater than 0.10. The P-value implies that there is no significant difference in the trend of the sex ratios between the two Kejimkujik Seaside sites. This would suggest that both sites have similar sex ratio time trends in which there seems to be a greater proportion of male green crabs caught over time.

4.2 Carapace sizes

Little Port Joli sub-sites (lagoon, basin, river)

In comparing the mean carapace width changes between the Little Port Joli sub-sites (lagoon, basin, river), all of them displayed an increase in mean carapace width during the entire collection time indicated by the lines of best fit. These results support the original prediction in that the green crabs, on average, would increase in their carapace width as intraspecies competition is decreased and thus more food and other resources are made more available to remaining crab population based on the results from the Bodega Bay study (Rivera et al. 2007). Despite all sub-sites seemingly experiencing an increase in carapace size over time, the river population had a P-value greater than 0.10. This would imply that there was high variability in the average carapace sizes of the crabs caught at the river per year with no significant trend of carapace widths over time.

The comparison of two regression lines between all of Little Port Joli's sub-sites (lagoon, basin, and river) displayed a P-value that was greater than 0.10. The P-value implies that there is no significant difference in the trend of the mean carapace width sizes between the three sub-sites. This would suggest that both sites have similar sex ratio time trends in which there seems to be a greater proportion of male green crabs caught over time. This would be expected as all three sub-sites are quite close together and therefore should experience little to no significant difference in environmental factors that could possibly influence carapace width growth over time.

Little Port Joli and St Catherine's River Bay

In plotting the mean carapace width changes between Little Port Joli and St Catherine's River Bay, both sites showed an increase in mean carapace width during the entire collection time indicated by the lines of best fit. These results support the original prediction in that the green crabs, on average, would increase in their carapace width over time as more resources are available to the remaining crab population.

The comparison of two regression lines between Little Port Joli and St Catherine's River Bay displayed a P-value that was greater than 0.10. The P-value implies that there is no significant is no significant difference in the trend of the mean carapace width sizes between the two Kejimkujik Seaside sites. This would suggest that both sites have similar sex ratio time trends in which there seems to be a greater proportion of male green crabs caught over time. Similar to the close carapace trends between Little Port Joli Bay's sub-sites, both Little Port Joli and St Catherine's River Bay carapace time trends are likely influenced by approximately identical environmental factors that could be influencing carapace growth over time, despite St Catherine's River Bay being located directly south to Little Port Joli Bay.

Kejimkujik Seaside National Park and Malagash Wharf

In comparing the mean carapace width changes between Kejimkujik Seaside National Park and Malagash Wharf, Kejimkujik Seaside showed an increase in mean carapace width, while Malagash population had a decrease in average carapace width during the entire collection time indicated by the lines of best fit.

The results of Kejimkujik Seaside again support the original prediction that the carapace size of green crabs should increase over time as the competition within the population is decreased. It would also seem that Malagash population has supported the original prediction in that the crab carapace size would initially decrease for a certain period of time. This could have been due to the initial green crabs that were caught were most likely the biggest as the smaller crabs would have a more difficult time in competing with the bigger crabs to enter the traps to consume the bait. Consequently, the mean crab size could have been getting smaller as each of the next biggest crabs from the Malagash population were entering the traps during each year of capture. In fact, the Kejimkujik Seaside data of average carapace widths before 2015 was decreasing from 2009 to 2014, similar to what was happening to the Malagash population from 2015 to 2019. This might indicate that future trappings at the Malagash Wharf may possibly experience an increase in the mean carapace widths as well, again based on the trend results from the Bodega Bay study.

The comparison of two slopes, for Kejimkujik Seaside and Malagash Wharf regressions over time, showed a significant result, with a P-value lower than 0.10. The P-value indicates that there is a significant difference in terms of the carapace width changes among Kejimkujik Seaside and Malagash Wharf populations. It is possible as mentioned above, that Malagash Wharf was going through a phase of decrease in average carapace size as larger crabs were mostly likely filling up the traps in contrast to the smaller crabs. This might lead to a gradual increase in crab size among the current population as there is less competition for the remaining crabs which would lead to more food and other resources available, similar to what might be occurring with Kejimkujik Seaside's population.

4.3 Interviews

Generally, it was agreed upon by all fishermen that green crabs are an abundant invasive species that has caused significant damage and disturbances to its surrounding ecosystems especially commercially important marine species. Specifically, a couple of the fishermen had replaced their eel license for a green crab license due to the green crabs destroying significant amounts of their habitat which primarily consists of eel grass beds, which led to a huge eel decline. However, despite these problems, all of the participants have coped with the impacts of this crab species and in fact made either a partial livelihood by selling the crabs as lobster bait or using them as alternative personal resources such as enriched fertilizer. Some of the fishermen have even given free samples to local restaurants, and other citizens to be eaten as soft-shelled crabs. All participants have agreed that they are now well established here and the best way to minimize the impacts caused by the crabs is by trapping them as a means of controlling the green crab populations. The first two fishermen have expressed that it would be good to see the crabs turn into an official market so that they can sell them for a higher value, while the third fisherman expressed concerns of establishing a market of this crab and the potential risks.

4.4 Literature review analysis

This literature review compares the different management techniques practiced or at least theorized from both Atlantic Canada and the U.S. Specifically, the management techniques that are compared in this literature analysis are prevention of green crab invasions, eradication of green crab populations, and control strategies of the populations by both countries. In addition, specific locations in both Atlantic Canada and the U.S were used to highlight some of the key management techniques used against green crabs from selected case studies.

Prevention methods (overview)

Prevention is a management technique that aims to stop/minimize any future possible introductions of green crabs in a designated area. Prevention measures mostly aims to reduce the risks of crab dispersal caused primarily from anthropogenic activities (EPA 2008). Such activities that could potentially cause the dispersal of this crab species includes the exchange of ballast water, movement of commercial shellfish/aquaculture products, bait releasement, potential dispersal from traps and cages, research/education facilities, marine construction equipment, and movement of sediments (EPA 2008). According to the Green Crab Control Committee, most of these activities that could introduce green crabs have management options which mainly comprises of inspections, cleansings or both practises combined (EPA 2008).

Prevention methods (U.S)

In terms of prevention methods being practised in the U.S, the Washington Department of Fish and Wildlife created restrictions on the transfer of shellfish and aquaculture into Washington state. Shellfish that are imported from areas of known high green crab activity are subjected to one-hour chlorine dips (EPA 2008). Possessing or transporting of green crabs requires a special permit according to WAC 232-12-1701 Emergency Regulation. Lastly, Washington also introduced similar the Ballast Water Management Act in which vessels must "exchange ballast water at least 50 miles offshore and report the exchange" in which it is prohibited to release unexchanged ballast water into Washington waters. California has also followed similar preventative practises and regulations as well due to the recent green crab introductions on the West Coast (EPA 2008).

Prevention methods (Canada)

Preventing any possible future invasions from unwanted pests, especially green crabs, is also taken with seriousness in Canada. Specifically, Transport Canada has a detailed management process in dealing with ballast water. Currently, all vessels entering Canadian waters are required to exchange ballast water outside of the Exclusive Economic Zone (Government of Canada 2011). In the ballast water exchange, water from foreign waters is flushed out leading to remaining high salinity concentration (30 parts per million or greater) resulting in absolute or high mortality rates especially to fresh water organisms (Government of Canada 2011). Currently, there is further research being done to utilize different treatment technologies to better prevent foreign organism dispersal. This includes, inducing nitrogen gas to cause oxygen deprivation in the ballast water, application of concentrated UV light, and oxidants to neutralize any potential organisms in the water (Government of Canada 2011).

Eradication methods (overview)

Eradication is a management technique that aims to completely remove a green crab population from a designated area including possible traces of larvae. Once a population is identified, decision makers consider whether it is appropriate/possible to remove the entire crab population (eradication method) or to contain the population in low numbers annually (control method) (EPA 2008). Such factors that determine the action plan depends on the crab abundance, reproductive potential (since it can reproduce rapidly under optimal conditions), and available equipment. Eradication methods will most likely be successful in areas in which the crab population is newly established, still in low numbers, and located in small isolated bays or estuaries (EPA 2008). In terms of conducting this method, it has been agreed upon by the Green Crab Control Committee that concentrated trapping of the crabs would be most optimal as an eradication strategy since it minimizes the risks of harming native species. It was also mentioned by the committee that trapping would be best carried out by volunteers trained and supervised by resource managers and researchers (EPA 2008).

Eradication methods (U.S)

On the west coast of the U.S there was a study that aimed to conduct a local eradication management effort on adult green crabs in Bodega Bay, California. In order to determine the effectiveness of the anticipated eradication effort, the population size was estimated by using a mark-recapture method in which unmarked crabs were released back into the water and an estimated population size was recorded before the study took place (Rivera et al. 2007). The trapping efforts lasted from July 15th 2016 until December 31st 2016 with a total of 9,691 crabs removed from the bay. In terms of the impacts of the trapping efforts over time, the initial catch per effort started from 21.3 crabs per trap until late

November/early December in which only 1.4 crabs were being caught per trap (Rivera et al. 2007). It was concluded that crabs were in low enough numbers in Bodega Bay that, eradication efforts could be transferred to control efforts (less intense trapping). However, it was undetermined whether the crab population could be entirely removed or not in the distant future (Rivera et al. 2007).

Eradication methods (Canada)

Not many studies in Atlantic Canada have tried to conduct green crab management via eradication as most locations that are inhabited by green crabs have been well established for a long time and have become quite abundant. Thus, it is near impossible to eradicate green crab populations with these traits, but instead efforts are directed to controlling the populations (control management is similar to eradication methods except the efforts are less) (Beaulieu 2021).

Control methods (overview)

Control is a management technique that aims to limit and stabilize the targeted crab population in an area consistently overtime. Eradication methods as mentioned before is the most preferred management strategy over control as it aims to remove the entire crab population (EPA 2008). However, if the crab population in the designated area has been well-established for an extended amount of time, population size is abundant, and located in an area where it is non-isolated and open to larger bodies of water then control as a management method may be deemed as the most appropriate course of action (EPA 2008). The types of methods that have been introduced or at least proposed to help control existing populations of green crabs includes trapping/capturing, development of bounty/bait markets, development of non-commercial fisheries, chemical control, and biological control strategies (EPA 2008).

Control methods trapping/capturing (U.S)

Capturing of crabs is currently the most widely accepted mode of controlling the population sizes in the U.S. An example of this method coming to fruition was in Willapa Bay and Grays Harbor, Washington, where 1,100 crabs have been removed, which led to the number of crabs per unit of effort declining from 1999 to 2001 (EPA 2008).

Control methods trapping/capturing (Canada)

Similarly, to the U.S in terms of control efforts, Atlantic Canada's most common strategy to contain the populations of green crabs is through systematic trappings. In 2011, a pilot green crab fishery started in southwest Nova Scotia until 2014, where it was succeeded by a commercial fishery from then on. From 2011 to 2015, approximately 3 million crabs (~157 tonnes worth) were captured from 5-19 active licence holders (75 traps per licence) (Vercaemer and Sephton 2015). This effort has evidently led to a reduced number of crabs caught. Both Basin Head Marine Protected Area (Prince Edward Island) and Kejimkujik Seaside National Park (Nova Scotia) have also conducted trapping trials of similar efforts to determine the potential recovery of native species impacted by the presence of green crabs (Vercaemer and Sephton 2015). The efforts have led to a decrease in crabs caught per unit effort from both sites, but it was premature to determine the recovery of native species impacted by the crabs (Vercaemer and Sephton 2015). However, recent analysis has shown that the number of juvenile soft-shell clams are making a slow recovery from Little Port Joli Bay from Kejimkujik Seaside National Park, highlighting the success of capturing the crabs as a means of controlling the population (Government of Canada 2017).

Control methods bait and fishery (U.S)

In its native regions some green crab populations, such as those located in Portugal, are in decline due to harvesting the crabs in the fisheries. There was some incentive to try and establish a market as a fishery and bait in the U.S, however it has NOT? been fully developed yet due to the potential risk of reintroducing the crabs back into the water (EPA 2008) and the difficulty in establishing a monetary value for the crabs (the value must be high enough to motivate people to fish for it and low enough so that it will discourage new introductions for commercial purposes) (EPA 2008). Despite the potential risks, residents of Massachusetts are currently allowed to fish for green crabs without a permit as they are labelled as an edible invasive species, but are still required to hold an authorization from the Division of Marine Fisheries (DMF) according to state law in order to harvest this species of crab (Massachusetts 2021).

However, a recent study in New England studied the identifications and marketable values of soft-shelled green crabs in New Hampshire. Locals have been informed by Venetian fishermen that the best way to get the most out of the green crabs is to fry them whole when they have molted or are close to molting (pre molting stage) (Bradt and McMahan 2020). The members of this study also tried to figure out any patterns or noticeable signs of when a green crab is ready to molt (usually crabs that are about or close to molting have halo-like patches around the ventral side of their appendages and tail). The fishermen in the study caught the green crabs during their free time outside of their normal fishing time and were averaging 100 crabs per crate and selling each crab to restaurants for about 3 dollars a piece (Bradt and McMahan 2020). Some restaurants, were quite intrigued by the green crabs and were selling each crab for approximately $9.00 in which customers met with positive reviews and sold out each time. What makes the green crabs an ideal future main market fishery is that once they are molted and taken out of the water, they can last up to two weeks in refrigerators (without water), however the biggest problem that still remains is the average number of green crabs harvested that had just molted (soft-shelled) or in a pre-molt stage were only 15% with the remaining green crabs caught still being far from molting (Bradt and McMahan 2020).

Control methods bait and fishery (Canada):

There has been some examination of the potential for commercial fisheries in Atlantic Canada just like the U.S, however similar potential problems were discovered as well if a fishery were to be established. One of the potential problems is that the crab population may not be large enough to maintain commercial fisheries due to the DFO's current policy of unlimited green crab fishing for license holders only. Consequently, this could lead to another problem in which the green crab fisheries sustainability could take over the primary goal of managing the crab as an invasive species and might encourage intentional introductions of green crabs for more profits (Klassen and Young 2007). Lastly, North America in general does not have a developed "palate" yet for green crabs, and it may a take a long time in the distant future for a successful market to be established after more people are comfortable in trying out green crabs (Klassen and Young 2007).

However, in 2016 a study was done in PEI that aimed to determine the potential for establishing a sustainable commercialized green crab fishery that could in turn be used as a method of control. It was estimated that it would cost between $1365 and $5866 for fishing for 21 days (St-Hilaire et al. 2016). It was also concluded that selling crabs at a minimum of $0.50/lb would be deemed profitable. At the same time, between 70 and 74 crabs per trap would have to be caught in order to break even (assuming the monetary values listed above). Thus, it was concluded from the analysis that in order to sustain a green crab fishery in Canada, a high concentration of crabs would have to be caught daily with prices high enough for fishermen to make a profit (St-Hilaire et al. 2016). Though eradication would seem highly unlikely through sheer efforts from commercial fisheries, it is possible that green crab numbers can be brought down to just 10 caught per day (from harvesting), which in turn will help protect the ecosystem the crabs inhabit (St-Hilaire et al. 2016).

In addition, the Department of Fisheries and Oceans Canada (DFO) has granted permission for qualified individuals to fish green crabs for baiting purposes in accordance to Maritimes Region Commercial Fisheries Licensing Policy. Specifically, green crab licences are available to those who trade in their commercial eel licenses in southwest and eastern Nova Scotia (Government of Canada 2020). In addition, potential holders must also meet the requirements under the coastal sector which entails that the individual must be a Canadian citizen or permanent resident, the licence is issued in the name of the fish harvester, license holders are to personally fish the license given to them, and holders are permitted to hold one license for a given species (Government of Canada 2020). The season for catching green crabs is anytime of the year in which number of green crabs harvested is unlimited as it is labelled as an invasive species. In addition, green crab license holders can use a maximum of 75 traps (Government of Canada 2020).

The majority of green crabs that are caught in Atlantic Canada, are sold as lobster bait to other fishermen which has proven to help boost the lobster fishery and help reduce the green crab numbers as well (Deese and Arnold 2014). Fishermen on average sell green crabs for approximately $100 per crate in which they are sold at about $0.83 per pound. It is estimated that close to 600 crabs caught would yield a marketable value of $100 (Deese and Arnold 2014).

Chemical control methods (U.S):

The Green Crab Control Committee had suggested using aerial pesticide and poisoned baits as a source of chemical control to cope against the green crabs as the pesticide carbonyl was being used to control burrowing shrimp on oyster beds in Willapa Bay and Grays Harbor, Washington (EPA 2008). However, it was banned by other states and Washington soon after discontinued using this parasite due to the minimal impacts on the crabs (EPA 2008).

Furthermore, it was found that carbonyl also affected non-targeted species including fish, other aquatic invertebrates, bees and even humans (EPA 2008).

Thus, more research is necessary to determine the specific impacts on non-targeted species and to find alternative pesticides that are more effective.

Chemical control methods (Canada):

There have been no reports of using any types of chemicals and/or pesticides as a means for controlling green crab populations in Atlantic Canada. However, it was suggested that if poisoning were to be introduced in Atlantic Canada as a method to control an invasive species population, this strategy would most likely be introduced at Basin Head, PEI

(Beaulieu 2021). This Marine Protected Area (MPA) is a very closed system which is home to an endemic species of Irish moss (*Chondrus crispus*) which is actively foraged by green crabs. Out of the priority to protect this endemic species, the DFO could introduce poison control to reduce or possibly eradicate the green crab population resided there (Beaulieu 2021).

Biological control methods (U.S):

Biological control is a practise that involves using either natural predators or parasites to rid of or at least reduce the numbers of invasive species. For example, *Sacculini carcini* (parasite) was initially tested to determine it effectiveness in controlling green crab populations on the Western Coast of the U.S (EPA 2008). However, efforts ceased once it was discovered that this parasite was attacking native organisms as well (EPA 2008). Similar to chemical control, the use of parasites needs further research and testing in order to minimize the risks of non-targeted species. It has also been suggested by the U.S Environmental Protection Agency (EPA) that it may be possible to increase the populations of native crabs (ex: Dungeness crabs) by breeding and releasing them (EPA 2008).

Biological control methods (Canada):

In Parks Canada, substantial efforts have been made to reduce the invasive crab population, however the remaining numbers still pose a threat to Kejimkujik Seaside's marine ecosystem. Despite this, there is a potential for the introduction of a native crab species as a biological control, *Callinectes sapidus* (blue crab) (Williams 2014). Blue crabs are approximately four times bigger than green crabs and have been reported to prey on them as well. Blue crabs compete with the same food resources as with green crabs; but critically they do not rip up eel grass beds in the process of foraging (Williams 2014). The blue crabs, however are not commonly found in Nova Scotian waters due to being less cold tolerant than green crabs. Despite this, a recent observation in Basin Lake, Kejimkujik Seaside found them in concentrated numbers (approximately 200) (Williams 2014). It was suggested that their numbers will continue to increase in Nova Scotian waters as the temperature increases over time. Blue crabs could potentially act as a natural biological asset in controlling green crab populations while at the same time leading to less eel grass bed being destroyed as well as their numbers increase over time (Williams 2014).

Comparison of management methods between Atlantic Canada and U.S (summary):

Overall, it would seem that both the U.S and Atlantic Canada follow similar, yet strict and effective management methods to cope against the impacts of the invaded green crab populations on their coast lines. In terms of prevention methods, ballast water is the primary vector in which green crabs, especially their larvae, can travel great distances an invade newly uninhabited areas, in which both countries have established effective ballast program in which minimizes risk of spread (ballast displacement before entering the Exclusive Economic Zone, and various ballast treatments no potential organisms transported are still alive).

Eradication methods for both countries seems to be the most unlikely effective management strategy out of the three due to nature of green crabs (small sizes, hard to reach habitat, large population, robust larvae…) and the extra time and effort applied in order to eradicate the population. Some areas have tried to fully eradicate green crab populations by using intense trappings, but no areas have seemed to completely eradicate a green crab population. The optimal scenario (applies to both countries) for an eradication to be most effective is during the early detection of a recently invaded green crab population in a certain area that is small in population and is immediately dealt with. Control methods for both Atlantic Canada and the U.S seems to be the most effective and common strategy employed in dealing with pre-existing green crab populations. Both countries primary method of controlling established green crab populations is through systematic trappings, as it is currently the cheapest, and safest (minimal damage to native organisms) method in dealing with this invasive species. However, there has been other tested and hypothetical control methods used by both countries, with the U.S having the most variation. There were supposed tests done in the U.S to see if green crab populations could be more effectively controlled by either introducing chemical or biological control, however both methods are at a standstill due to the potential risk of inflicting damage on native marine species. Atlantic Canada, in comparison has not tested these types control methods for similar reasons, but may introduce chemical control methods if an endemic species is at high risk of being impacted by green crabs based on the DFO (Beaulieu 2021). The other control method that might soon become active is the establishment of a green crab fisheries. Both countries have conducted various of studies determining the profitability and practicality of turning green crab into a food product just like in its native countries Portugal, Spain and Italy (Beaulieu, 2021). Despite the potential in opening a market for the green crabs, there is currently no official fisheries for them in both Atlantic Canada and the U.S.

Conclusion

Based on the overall study, it would seem that the green crab removal efforts from the majority of the Nova Scotian sites had no significant difference in the time trends as some years would yield low number of crabs caught while often subsequent years yielded high numbers. The majority of sites studied experienced a shift in a higher proportion of males caught compared to females over the span of the collection time. Carapace widths of the green crabs also showed to be steadily increasing as the years progressed for the majority of the Nova Scotian sites as well.

The interviewed fishermen have all had negative experiences with green crabs mostly due to its ecological destructive capabilities and impacts on commercial fisheries. However, all fishermen were able to successfully cope with this invasive species by means as selling them as bait or for personal usage as enriched composite fertilizer. Most of the fishermen are waiting for an established green crab fishery in order to make a higher profit off of these crabs.

Both Atlantic Canada and the U.S appear to have the same management techniques currently with strict ballast regulations as the main prevention method, and periodic trappings of green crabs as a control method for both countries. However, both countries have tested and conducted research on the potential probability and consequences that may arise if a green crab commercial fishery was established.

The significance of this study is with the observations of the green crabs caught over time along with the time trends (number of crabs caught, the sex ratios, and the average carapace width of the green crabs caught per year) may offer an insight for more effective management methods to cope against these crabs in the future. The associated patterns found from the various sample sites, such as the increasing proportion of males caught, and an average increase in carapace widths may also aide in predicting the overall population dynamics at the given site. This study also displayed significant differences in time trends among geographically distinct sites. This could suggest that there are environmental factors that may impact the nature and dynamics of green crab populations of which conservationists and other members of society should take into account when planning strategies to deal with this invasive species. This study has proved that green crabs, from various literature sources and personal accounts, do not necessarily have to be treated as a complete nuisance species as there is large potential in utilizing these crabs as a resource. Such resources include using the green crabs as bait, enriched fertilizer, or even as an official green crab fishery in Nova Scotia which may happen in the distant future.

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Appendix: Interviews

First participant

Q1. What is your name?
A1. Name provided but withheld here.

Q2. Where do you fish?
A2. Lobster Fishing Area (LFA) 29

Q3. How long have you been working in this field?
A3. Since 2015-2016, started fishing for green crabs three years ago.

Q4. How have you contributed to helping DFO data collection in the past/currently?
A4. Through daily loggings of each green crab caught during fishing.

Q5. Where have you been collecting data?
A5. Lobster Fishing Area (LFA) 29

Q6. On average, when you are fishing, how many lobsters do you catch each day?
A6. On average throughout the season, approximately 800 lbs.

Q7. How does that change over the course of a fishing season?
A7. At the start of the season lobsters are more abundant compared to the end of the season where there is considerably less.

Q8. Has the size or quality of lobster changed over time?
A8. No significant changes in size or quality of lobsters over time, at least when I first started fishing for them.

Q9. When is the lobster season for you?
A9. May 1st to June 29th

Q10. When is their breeding/mating season?
A10. Assuming during the summer time when the water gets warmer and when they start to molt.

Q11. Is there a particular time of year when lobsters are noticeably more abundant? Less abundant?

A12. At the start of the season lobsters are more abundant compared to the end of the season where there is considerably less.

Q12. How have green crabs affected your work broadly and specifically?
A12. Green crabs have been quite beneficial as I fish for them regularly and make considerable amounts of money off of them. Green crabs that are caught are mostly sold for lobster bait. Price for green crab bait is widespread where I have sold them individually up to $2.00 and bought green crabs for under $1.00.

Q13. Have green crabs impacted your catches of lobsters to a significant degree?
A13. I have fished for lobsters using green crabs as bait and the yields were pretty good. There not much benefits of green crabs other than economic factors.

Q14. Has your job, or your revenues, been impacted due to the presence of green crabs?
A14. Green crabs have been quite beneficial for my job as I fish for them regularly and make considerable amounts of money off of them. Green crabs that are caught are mostly sold for lobster bait. Price for green crab bait is widespread where I have sold them individually up to $2.00 and bought green crabs for under $1.00.

Q15. How many green crabs do you catch on average, per day, month, year?
A15. Answer to this question was requested to be kept private by the participant.

Q16. When was the highest green crab catch per day, month, year? When was the lowest?
A16. Last year (2020) yielded the highest yield of green crabs on average, in which 1,350 lbs was caught in one day using 75 crab pots. The lowest catch is mostly at the start of the season when the water is still relatively cold and the last week of June from my experience they go and molt, where there is none caught at that point in which they come back out in which point they are soft shelled.

Q17. On average, how many green crabs would you catch in each lobster trap, for each haul?
A17. I have never seen a green crab enter/be caught in a lobster trap. I have talked to others who have set lobster pots and caught no lobsters but be completely filled with green crabs.

Q18. If you fish intentionally for other than lobster, has anything else been impacted by green crab presence? If so, to what extent?
A18. I used to eel fish for a year and caught nothing but green crabs. I switched my eel license over to get a green crab license-my grandfather had the license before me and he said that 20 years ago the eels were gone and caught nothing but green crabs. The crabs destroyed the habitats for the eels by ripping out the eel grass from the roots leaving nothing but mud. I have seen eels get captured in the crab pots in which they are attacked immediately by the crabs. I also catch other species of crabs as well such as rock crabs in which they are found to be in different locations to green crabs as they are highly competitive and are a nuisance to the rock crabs. I have set traps purposefully to catch rock crabs and the green crabs were taking over them. We used to able to set traps in coves and catch all kinds of rock crabs but now there is nothing but green crabs. They are negatively impacting the rock crabs because of their aggressive nature and being far greater in numbers.

Q19. What are the interactions between lobsters and green crabs?
A19. In my career so far I have only caught three lobsters when fishing for the green crabs. The restrictions on the traps keep out the lobster.

Q20. Do you feel that they are unaffected, negatively impacted, or act as an alternative food attraction for lobsters?
A20. Question not answered.

Q21. Is there a particular time of year when green crabs are noticeably more abundant? Less abundant?
A21. They are most abundant in warm waters. Spring summer and fall is when they are active; there are none during the winter.

Q22. Are green crabs more abundant when sea temperatures are higher in Nova Scotia? **A22. Answered above.**

Q23. What do you do with captured green crabs?
A23. I Sell it all for lobster baits.

Q24. Do you do anything to reduce the impacts of green crabs?
A24.I pretty much fish for just green crabs; I fish for green crabs everyday throughout the lobster season.

Q25. Is there any economic benefit from green crab harvesting? (bait, fertilizer, bioplastic, food source)?
A25. I have sold some crabs to those who were willing to prepare the crabs as a food source; about 20lbs. The customers that bought the crabs as food always cooked it by deep frying it whole with shell intact when they have just molted (soft shelled).

Q26. What is the future for green crabs in Nova Scotia, and do you think this invasive species will have more economic value in the future?

Q27. Hopefully the economic value is that people will start eating them. It would allow me to sell the crabs at a higher price per pound. I know in the past few years that the green crabs have started to disappear in Yarmouth and Liverpool; I think they are starting to disappear down the line which isn't a bad thing. Trapping the crabs so far have seemed to be the best way to control the crab population.

Second participant

Q1. What is your name?
A1. Name provided but withheld here.

Q2. Where do you fish?
A2. I fish in the Port Medway Harbour

Q3. How long have you been working in this field?
A3. I have been fishing there for green crabs since 2013. And since then, made my own business out of it.

Q4. How have you contributed to helping DFO data collection in the past/currently?
A4. We fill out a log sheet and turn it in at the end of my season. The log sheet gives them the area that I fished and how many crates I used to fish/catch (catch limit). The log sheet is submitted twice a year once during the spring fishery and one in the fall.

Q5. Where have you been collecting data?
A5. This fall I fished in the Liverpool Harbor (the main lower part of the river) now I'm down fishing in the Medway River.

Q12. How have green crabs affected your work broadly and specifically?
A12. It is boosting my work considerably. I am making a livelihood from catching green crabs. In some spots the green crabs are starting to dwindle off, but other spots have been taken over again by the crabs.

Q13. Have green crabs impacted your catches of lobsters to a significant degree?
A13. Not applicable.

Q14. Has your job, or your revenues, been impacted due to the presence of green crabs?
A14. It is boosting my work considerably. I am making a livelihood from catching green crabs. In some spots the green crabs are starting to dwindle off, but other spots have been taken over again by the crabs. I sell green crabs $120 per crate as bait (approximately 110lbs of crabs in a crate). I do not sell the crabs for anything else other than for bait, however there is the odd restaurant that will pick up a few crabs but I don't charge them for those not until we start getting a good commercial fisheries market for the green crab.

There was a restaurant out in Lunenburg in which the chef got a few of the crabs from me last year. Around here, they are a hard crab to judge for molt and when they are in the molting stage is the period to cook them when they are soft shelled and be able to do more with them.

Q15. How many green crabs do you catch on average, per day, month, year?
A15. On average, per week, I haul approximately 3,000 lbs of crab (using the maximum number of crates during fishing allowed by the DFO which is 75 traps).

Q16. When was the highest green crab catch per day, month, year? When was the lowest?
A16. One day I caught over 1,200 lbs (in 2017). Last spring, I was only getting a crate every few days (in which the water temperature fell; it was considerably cold last year). We find that the lobsters follow the same trend in which at 42°F they are active, at 38°F you can see a little bit of movement but 42°F the lobsters are on the crawl.

Q17. On average, how many green crabs would you catch in each lobster trap, for each haul?
A17. Not applicable.

Q18. If you fish intentionally for any species other than lobster, has anything else been impacted by green crab presence? If so, to what extent?
A18. I started out with an eel fishing license for Port Medway Harbor and I found that there were hardly any eels, due to the eel grass gone, and more green crabs so I switched my eel license to a green crab license. I took 3 months and one winter in 2013, and talked to whole bunch of fishermen online and convinced them to take a green crab to try for lobster bait and if they wanted

Q19. What are the interactions between lobsters and green crabs?
A19. Not applicable.

Q20. Do you feel that they are unaffected, negatively impacted, or act as an alternative food attraction for lobsters?
A20. Not applicable.

Q21. Is there a particular time of year when green crabs are noticeably more abundant? Less abundant?
A21. They are most likely at their highest numbers during April 1st until the water starts cooling off. When the water gets 42F and above the crabs are quite plentiful and active as well.

Q22. Are green crabs more abundant when sea temperatures are higher in Nova Scotia?
A22. Mentioned above.

Q23. What do you do with captured green crabs?
A23. I sell them as lobster bait.

Q24. Do you do anything to reduce the impacts of green crabs?
A24. I have made a livelihood out of fishing for green crabs on a regular basis so I am helping to control the green crab populations.

Q25. Is there any economic benefit from green crab harvesting? (bait, fertilizer, bioplastic, food source)
A25. I sell the green crabs currently for lobster bait. Hopefully there will be a fisheries market for the green crabs in the future will increase their economic value.

Q26. What is the future for green crabs in Nova Scotia, and do you think this invasive species will have more economic value in the future?
A26. The green crabs are not going anywhere and there are not enough people fishing for them. They have been well established here about 20-25 years now in which they have settled in and adapted well (they can go up into a river into fresh waters and can still get the percentage of salt they need to survive). Establishing a food market is the next step. I am mostly fishing the green crabs as a control management so that the populations are low enough so that they are not destroying everything. It has only been approximately the last ten years that anybody started catching them, and now there are fishermen all along the shore catching the green crabs. I don’t think we will be able to completely get rid of them by just catching them (not with the number of licences out there), I think they are here to stay we are just keeping the population down. I don’t even know if we are keeping the population down at a safe level because we had eight crates today in one little spot. I haven’t even moved my crab pots; usually I’m moving my pots around quite a bit but now I’m hauling and dumping on the spot.

Third participant

Q1. What is your name?
A1. Participant wished to keep their name private.

Q2. Where do you fish?
A2. Mainly around Nova Scotia, mostly Eastern Shore at any harbour. For lobster fishing specifically, I fish at Musquodoboit Harbour area.

Q3. How long have you been working in this field?
A3. Commercially, this will be my first-year fishing.

Q4. How have you contributed to helping DFO data collection in the past/currently?

A4. No contributions yet for the DFO. When I am recreation fishing there is surveys that they want me to fill out.

Q5. Where have you been collecting data?
A5. Not applicable.

Q6. On average, when you are fishing, how many lobsters do you catch each day?
A6. At the end of the season between 300 to 400 lbs of lobster on a good day.

Q7. How does that change over the course of a fishing season?
A7. I've heard from other fishermen it really depends on the weather if the water is warm early in the season usually you'll catch a higher amount of lobsters. Last year was a relatively cold season, the catch was spread out over the whole season.

Q8. Has the size or quality of lobster changed over time?
A8. Not for our season; usually after the winter their shells are still good and hard-they don't get soft until the summer time (when they start to molt).

Q9. When is the lobster season for you?
A9. April 20th this year up until two months (April 19th-June 20th).

Q10. When is their breeding/mating season?
A10. We often catch females that spawn; I'm not sure when they eggs are fertilized. They do carry spawns throughout the entire season. When the water warms up there is definitely more females. We always throw all spawning lobsters back; you'll often catch the same lobster throughout the season.

Q11. Is there a particular time of year when lobsters are noticeably more abundant? Less abundant?

Not Applicable.

Q12. How have green crabs affected your work broadly and specifically?
A12. It's hasn't affected my work. More recreationally-I dig clams and hunt. The birds feed off of eel grass; the green crabs eat eel grass and have taken a huge toll on the grass beds which consequently affected the other species. The green crabs will pull out the snouts of clams so there is a bit of conflict there which could have led to a scarcity of clams in some areas they have been over-digged by the crabs who knows if the clams will be able to make a replenish every year in the clam beds. Sand worms are another thing we use them to catch smelts-the worms now seem harder to find year after year (implied by the cause of green crabs or pollutants possibly global warming).

Q13. Have green crabs impacted your catches of lobsters to a significant degree?
A13. In the harbours we typically catch a lot of red crabs; but in different harbours there is definitely more green crabs because later in the season you move into the harbour and when the water is cold you fish out further and then you work your way in to the harbour as the lobsters move in. You catch more in the season when you move in (crab wise). Seems that the green crabs are living in inlets within harbours more so than the ocean floor. I grew up on one of the inlets in which front of the property is all marsh and they are all full of green crabs; the gullies and channels are especially full of them when they dry out because they are full of clam beds and mussels-it's a perfect place for the green crabs to be because the current holds them around but the current doesn't pull them out to the harbour or the main channel.

Q14. Has your job, or your revenues, been impacted due to the presence of green crabs? A14. Some guys might put them on the spike, but a lot of times they'll just let them sit out for a day or two so that the smell is extra concentrated for crabs in general; I don't anything about green crabs specifically. When we catch green crabs by ourselves off the wharf, we use them as fertilizer- they make great fertilizer. The crabs make the soil turn quite dark and rich along with other compost materials (lobster shells, clam shells...etc); it enriches the soil with nitrogen and phosphate compounds.

Q15. How many green crabs do you catch on average, per day, month, year?
A15. Not answered.

Q16. When was the highest green crab catch per day, month, year? When was the lowest? A16. At my parents wharf you can catch at least a hundred of green crabs in one of the small crab traps. Depending on the size there is little ones and big ones; if you pull the traps up quick enough you can capture a lot of green crabs. It depends on the bait used as well (they seem to have a preference for some baits). Specifically, green crabs are quite attracted to mackerel due to its oily meat and concentrated smell, a cod skeleton will occasionally be thrown after it's been fileted and the crabs will go for it, but not as much compared to a mackerel.

Q17.On average, how many green crabs would you catch in each lobster trap, for each haul?
A17. Not applicable.

Q18. If you fish intentionally for other than lobster, has anything else been impacted by green crab presence? If so, to what extent?
A18. I don't hear too many complaints about the green crabs; a lot more people care about the seals actually (they seem to be a big issue).

Q19.What are the interactions between lobsters and green crabs?
A19. From what I can tell, number-wise, is that lobster fishing has boomed for a while now; I'm not sure if I can contribute that to the green crab presence now; but I do know my grandfather when he fished, he was lucky to get a quarter of what they are fishing for now (there was probably no green crab back then). I can't say that it has had a negative effect on lobsters. My grandfather could barely make bait-he was selling the lobsters $4.50 a pound and were only catching between 100-200lbs which was considered a big day. Now some fishermen are able to haul up much bigger catches.

Q20. Do you feel that they are unaffected, negatively impacted, or act as an alternative food attraction for lobsters?
A20. I don't know if lobsters would actually eat green cabs. I'm not sure. I do know that lobsters like items that have a potent smell-some guys will actually salt their bait before they put it in the water. There so many different ways to prepare the lobster bait. I don't know if they would just eat a green crab.

Q21. Is there a particular time of year when green crabs are noticeably more abundant? Less abundant?
A21. They similar throughout the season compared to a lobster in terms of activeness. At the start of the season, they are a lot slower because they are in cold water and as you are banding them throughout the season you got to get faster at banding them because the water starts to warm up and they start to speed up as well. Green crabs are definitely busier in the summer times, we don't really bother with them during the winter time.

Q22. Are green crabs more abundant when sea temperatures are higher in Nova Scotia? A22. Answered above.

Q23. What do you do with captured green crabs?
A23. I mostly use them as fertilizer.

Q24. Do you do anything to reduce the impacts of green crabs?
A24. Trapping seems to be the best way to get them; I'll walk on one if I see them.

Q25. Is there any economic benefit from green crab harvesting? (bait, fertilizer, bioplastic, food source)
A25. Unless if you made compost out of it, I couldn't see the benefit of it. You have to have some supply and kind of farm them to make it worth while.

Q26. What is the future for green crabs in Nova Scotia, and do you think this invasive species will have more economic value in the future?
A26. If I'm being honest with you probably not. I don't see any benefits from having the green crabs here. The future of green crabs all depends on the efforts from conservation if

there are people willing to go out and cull them and get rid of the population in that way because they believe it shouldn't be there. It's sort of a grey area because they ae invasive-some places you can kill any invasive species. If there is market for them they will need a habitat to sustain a fishery for these crabs and therefore regulate the population to keep it around.

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