Keeping Arctic fisheries as Happy as a Clam: Assessing the life history and density of truncated soft-shell clams (*Mya truncata*) of southern Baffin Island, Nunavut, to promote sustainable fishery development

Submitted by
Jessica Marie Wood

A thesis submitted to
School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in Fisheries Science and Technology

School of Fisheries
Marine Institute of the Memorial University of Newfoundland

August 2020

St. John's Newfoundland and Labrador

This thesis is dedicated to my nephews Carter and Noah- future marine biologists.

Abstract

Fishery development is a priority for Arctic governments, Indigenous organizations, and communities to promote Arctic economic development and food security. The recreational truncated soft-shell clam (*Mya truncata*) fishery of southern Baffin Island, Nunavut, is expected to undergo increased fishing pressure with northern population expansion and potential commercial development in Frobisher Bay and on the north shore of the Hudson Strait. Understanding aspects of the life history and population density of *M. truncata* of southern Baffin Island is key to sustainable fishery development. I first found the shell length at 50% sexual maturity to be 31 and 32mm in male and female *M. truncata*, respectively. Based on the stage of gonadal development observed in sexually mature clams collected from inner Frobisher Bay in late August 2018 and Hudson Strait in early September 2018, I suspect a late-summer or fall spawning event may have taken place in 2018. I identified strong length-bias in calculated condition indices for these populations, and so I used dry-body weight to shell length relationships to gauge population condition over small and large spatial scales. I then implemented a drop-camera set-up using the frame of a snow crab trap, a GoPro, lasers and a weight strung on a monofilament line for scale to assess *M. truncata* density in the intertidal zone. By comparing drop-camera density estimates with those obtained by manual excavations, I determined that drop-camera deployments within the intertidal zone estimate significantly less clams than excavation estimates across all sites. This difference was attributed to smaller clam siphons not being visible in video, the retraction of siphons at low tide, and fine sediment displacement with tidal flow covering siphons. This research is expected to

help with community-based resource harvest plans and conservation measures and to inform policy at regional, territorial, and national levels.

General Summary

The truncated soft-shell clam (*Mya truncata*) is recreationally harvested in southern Baffin Island, Nunavut, within Frobisher Bay and on the north shore of Hudson Strait. Increasing fishing pressure and potential commercial fishery development creates the need to understand the biology of clams to inform sustainable fishery management decisions, the condition of clams to monitor population health with climate change and estimating the density of clam populations to gauge the effects of harvesting. I studied aspects of the life history, body condition, and density of *M. truncata* of southern Baffin Island and established the size at sexual maturity of clams, developed a reliable method to assess body condition, and tested the accuracy of underwater video to assess clam density in the intertidal zone. My results will help inform fishery management decisions and conservation measures for *M. truncata* of southern Baffin Island.

Acknowledgements

I would like to sincerely thank Dr. Scott Grant for his exceptional support as my supervisor, and mentorship throughout my Master's degree. I am forever grateful for Dr. Paul Winger granting me a summer student position with the Centre for Sustainable Aquatic Resources in 2017 and 2018, two summers that fostered my interest in fisheries science and provided me with a foundation from which to build my skills. Many thanks to my third committee member, Dr. David Deslauriers, for valued input and support throughout the past two years. I would like to thank my co-author of my manuscripts, Meghan Donovan, for helping me collect the data necessary to put together my two research chapters. My work would not be possible without the tireless help and invaluable knowledge of the local Inuit of Iqaluit and Kimmirut including Matthew Akavak, Sandy Akavak, and Jamie Akavak. I am grateful for my lab mate Maggie Folkins, as well as Phil Walsh and Kirk Regular for field work help in 2018 and 2019. Many thanks to the Ocean Frontier Institute, the Government of Nunavut, Fisheries and Oceans Canada, the Canadian Northern Development Agency, Memorial University of Newfoundland, and the Fisheries and Marine Institute of Memorial University of Newfoundland for the funding of my research and stipend. Finally, my family's support has meant the world to me throughout my Master's degree. I would not have been as successful without their love and support.

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Chapter 1. General Introduction

Northern economic development is a priority for the Canadian government to ensure Nunavummiut attain a high quality of life through food security and economic opportunities, as these are often challenges faced due to harsh Arctic environments and isolation. Often, the food security of Inuit communities is correlated with how many hunters, harvesters, or fishers there are to bring natural food home to their families or share with their community, as high store prices may deter from purchasing non-local food (Wakegijig et al. 2013). The best solution to these issues may be to promote an activity that could not only make natural food available year-round to Arctic communities, but also bring financial benefits to community members. In 2005, the Government of Nunavut introduced the Nunavut Fisheries Strategy: a document that reflects the priorities and objectives of fishery development within the territory of Nunavut (Government of Nunavut 2005). These objectives include expanding recreational food fisheries and where suitable numbers of individuals of a species exist, developing sustainable fisheries to increase opportunities for employment of Inuit within the fisheries sector and ultimately increase food security for northern communities.

In Qikiqtarjuaq, a community located on the east coast of Baffin Island, Nunavut, Siferd (1997) estimated that there was 35.4 million pounds of truncated soft-shell clam (*Mya truncata*) in the subtidal zone. At a potential harvest of 2-3% at $2.50/lb USD, a truncated soft-shell clam fishery in the area would equate to $1.8-2.7 million in USD to fishers alone. In the year 2000, an experimental fishery was opened in Qikiqtarjuaq based in part on these estimations. Clams were harvested from the subtidal zone via SCUBA diving, and clams were sold Nunavut-wide in Northern Stores. However, by April 2003, Fisheries and Oceans Canada (DFO) halted all commercial harvests until the Canadian Food Inspection Agency and Nunavut Department of Sustainable Development agreed upon the testing protocol required to meet Canadian Shellfish Sanitation Program certification (Maurel 2003). Nevertheless, this pilot fishery proved that from sea to table, a truncated soft-shell clam fishery could produce jobs in the fishing and processing sectors and make natural food available in stores for Nunavut communities.

The above pilot fishery for truncated soft-shell clams in Qikiqtarjuaq sparked questions regarding whether recreational truncated soft-shell clam fisheries in communities in the southern region of Baffin Island could support commercial fisheries. Although it is not required for recreational clam harvesters to report the number of clams they harvest, estimations from the intertidal zone have been made for the communities of Iqaluit and Kimmirut: Priest and Usher (2004) estimated that from June 1996 to May 1997, 3,870$^{\pm}$882 clams were collected across 15 harvesters near Iqaluit, and 11,312$^{\pm}$882 clams across 25 harvesters near Kimmirut. The number of clams harvested has no doubt increased in recent years due to human population expansion in Iqaluit (StatsCan 2019), earlier ice break-up, and later ice formation due to climate change making clams available for more of the year. The intertidal truncated soft-shell clam resource has supported recreational subsistence harvests in these communities for decades but there is little known about the subtidal component apart from observations at low tide of several clam siphons or siphon holes/depressions that are just out of reach of beach harvesters. The high numbers of truncated soft-shell clams that were found to occur in the subtidal zone in Qikiqtarjuaq have raised questions as to whether there is suitable resource in the deep subtidal zone in Frobisher Bay and on the north shore of Hudson Strait to support commercial development.

The Nunavut Fisheries Strategy promotes sustainable fishing attained through "evidence-based decision making" (Government of Nunavut 2005). Put differently, the truncated soft-shell clam populations on the south coast of Baffin Island must be thoroughly understood to develop the most sustainable fishery possible. This means the biology (e.g., life history and condition), density, and recruitment of the clam populations must be understood enough to be able to make sound decisions related to fishing capacity (e.g., number of harvesters), quotas, and how, where, and when fishers should harvest this resource. In addition, it is important to gather the same information to monitor the effects of increased recreational fishing pressure with expanding Iqaluit and Kimmirut populations. Following these principles, this thesis will investigate the maturity, condition, spawning season and methods of assessing population density of *M. truncata* near the communities of Iqaluit and Kimmirut to help provide a foundation of information to ensure that if recreational fisheries are developed into commercial fisheries, it can be done sustainably.

1.2. Overview of *M. truncata* life history

The first record of *M. truncata* in the eastern Canadian Arctic was by Hancock (1846), and in the Hudson Strait by Whiteaves (1881). *M. truncata* is known as a common bivalve in the Canadian Arctic and other parts of the north-west Atlantic, such as Greenland and Norway, with its most southern boundary in North America designated as Massachusetts Bay (Lubinsky 1980). Clams are generally found in the intertidal and upper subtidal zone, with a maximum density around 15 m in depth, exponentially decaying until roughly 80 m (Lubinsky 1980). In Arctic waters, they were found to be distributed to greater depths being most abundant in the 20-30 m depth strata and most common within the 5-60 m depth range (Sifred 1997). Truncated soft-shell clams can be distinguished from other clams by the gape of the shell at the posterior end and projecting chondrophore from the left valve with a siphon that is not entirely retractable (Bernard 1979).

In the Canadian Arctic, studies of *M. truncata* are sparse. Existing published studies have focused on estimating abundance, aging, or growth analyses, rather than maturity, spawning, and biological condition (Andrews 1972; Welch et al. 1992; Siferd 1997; Siferd 2005). In North America, the life-history of its sister species, *Mya arenaria*, is far more studied, and can help to infer biological parameters of *M. truncata*. Bivalves are broadcast spawners, releasing eggs and sperm into the environment during a spawning event, where fertilized eggs will morph to pelagic larvae before settling as juveniles. Abraham and Dillon (1986) reviewed the life-history of *M. arenaria* of the north-eastern United States. They noted that pelagic trochophore larvae will filter feed on suspended particles for 24 to 96 hours until they pass to the late veliger stage, where they will settle to the bottom within 2 to 10 days and are then considered juveniles. Juveniles possess byssal threads and can move to a desired location using their foot and will then settle and shallowly burrow. Once older, it becomes harder for larger clams to uproot themselves to move. At southern latitudes, after 1 to 2 years of age they remain burrowed in one location and some members of the population commence spawning at this age. In New Brunswick, the settlement of *M. arenaria* larvae usually occurs in the lower intertidal or shallow subtidal zone, but juveniles that have not yet burrowed will be pushed to the upper intertidal zone by waves (Chandler et al. 2001). Adult *Mya* filter feed by drawing in water via the inhalant siphon and expelling waste through the exhalent siphon (Abraham and Dillon

1986). *M. arenaria* of the Canadian Maritimes recruit from spawning to harvestable shell-lengths of about 50 mm in 6 to 8 years, and animals have been found to spawn when as small as 40 mm (Abraham and Dillon 1986).

The life history of members of the genus *Mya* can vary in both time and space. For example, Appeldoorn (1995) found that in Nova Scotia, *M. arenaria* only spawn once per year, but more southern populations near Chesapeake Bay have been found to spawn twice per year. They also observed that maturation occurs at an earlier age in the south, as growth was faster at the warmer temperatures that occurred there. Thus, it is important to assess the life-history of southern Baffin Island *M. truncata*, rather than infer life-history traits from southern populations of *M. arenaria* or *M. truncata*. Life-history parameters important to truncated soft-shell clam fisheries include size at maturity to determine minimum harvestable sizes (Gwinn et al. 2013) and spawning season to determine fishing season, but body condition to assess population health is also of significance for conservation measures. Therefore, in chapter 2 of this thesis, I address questions regarding the maturity, spawning, and condition of *M. truncata* near two communities located in the southern region of Baffin Island, Iqaluit and Kimmirut.

1.3. Overview of techniques used to estimate bivalve density

The success of animal populations, including bivalves, depends on density to support essential processes such as reproduction and recruitment, as these processes may fluctuate with population density (reviewed by Rose et al. 2001). For example, Zimmermann et al. (2018) showed that recruitment is density dependent in a large proportion of fish and bivalve populations in the Northeast Atlantic and some populations also exhibited density dependence in somatic growth, which can affect productivity and biomass of fish available for harvest. To be able to understand factors affecting bivalve density, or what effects density has on the population (e.g. growth), a method that accurately estimates density must first be developed.

Traditionally, within the intertidal zone, the density or abundance of burrowing bivalves has been determined by using manual excavations and/or sediment cores. For example, to assess the intertidal zone density of Baltic clams (*Macoma balthica)*, Azouzi et al. (2002) used excavations 30 cm × 30 cm × 10 cm (length × width × depth). Similarly, a study by Seitz et al. (2001) used sediment cores to sieve out *M. arenaria* and Defeo (1996) also used sediment cores to sieve and estimate density of yellow clams (*Mesodesma mactroides*). For juvenile clams, Hunt et al. (2020) used a known trap size to collect settling *M. arenaria*. These examples of density-estimation can be time consuming and require substantial human labour, such that the need for other density estimation techniques that make field work faster and easier are typically welcome.

An alternative to manual excavation or sediment cores to assess the density of burrowing bivalves is the use of video observations or still photography, which has become more and more popular in recent years. For example, a study estimating the density of *M. arenaria* along a beach used siphon counts and excavated quadrants, but also used a towed video sled to estimate density beyond the intertidal zone, where excavations could not be completed (Smith 2002). Towed video sleds have also been used to estimate razor clam (S*iliqua patula*) density by converting counts per tow to area-based densities (Fox 2018). The extra calculations and potential error involved in converting siphon counts from towed video sleds to an area-based density estimate may be conquered by use of a drop-camera system, wherein the camera is on a frame and remains still to allow the number of clams in a known area within the field of view of the camera to be counted. For example, Faggetter (2011) developed a frame on which an under-water video camera could sit to observe the benthic environment. A similar set-up was developed to estimate commercial scallop (*Placopecten magellanicus*) abundance on George's Bank (Stokesbury et al. 2004). In Qikitarjuaq, Nunavut, underwater photography and the use of still images was used to assess *M. truncata* density (Siferd 1997; Misiuk et al. 2019).

While drop-camera surveys may expedite estimating *M. truncata* density, it is important to ensure these estimates are accurate. Verifying the accuracy of drop-camera density estimates for *M. truncata* populations within the subtidal zone requires the use of SCUBA divers or dredges which can be cost prohibitive and were beyond the scope of the current study. To gain a better understanding of the utility of drop-cameras when assessing the density of burrowing bivalves in the intertidal zone, in chapter 3 of my thesis, I compared manual excavations of *M. truncata* density within the lower intertidal zone at high tidal amplitude sites within Frobisher Bay and on the north shore of Hudson Strait to drop-camera density estimates.

1.4 Thesis overview

This thesis details the results of two field studies, one within Frobisher Bay, near the community of Iqaluit and the second on the north shore of Hudson Strait, near the community of Kimmirut, during the summers of 2018 and 2019. In the first study, I collected clams from two sites within Frobisher Bay and two sites within the Hudson Strait in August and September of 2018. I dissected a subsample of clams collected from each site across a wide range of sizes to determine their sex, stage of gonadal development, and body condition. I then used these results to infer the spawning season of clams collected, compare body condition between sites, and construct a maturity ogive. I then applied my findings to aspects of the development of a sustainable northern truncated soft-shell clam fishery, and implications for biological monitoring for future conservation purposes.

In the second study, I compared the use of manual excavations and drop-camera video to estimate *M. truncata* density within the intertidal zone at two sites within Frobisher Bay and two sites within the Hudson Strait in August and September of 2019. I estimated the mean density of truncated soft-shell clams for each method and compared the results both qualitatively through density maps and quantitatively via statistical analyses. In addition, I examined the sediment composition at the study sites to provide information on the dominant sediment classes and their potential to impact the density assessments in the intertidal zone.

The overall objective of this thesis is to characterize some of the key life-history parameters and measures to assess condition of Nunavut populations of *M. truncata* and determine whether drop-camera surveys are a viable method of assessing truncated soft-shell clam densities within the intertidal zone of coastal communities where there is a high tidal amplitude and where recreational fisheries exist. Information provided by my research is expected to aid in establishing a conservation-minded and biologically-based minimum legal size for harvesting *M. truncata*, the most suitable measure for assessing spatial-temporal trends in condition, and preliminary information of spawning season. As the capital city of Nunavut, Iqaluit faces a population increase of roughly 17% every five years (StatsCan, 2019) and with the development of a new deep water port, the opportunity for growth is likely to increase and lead to greater pressure on existing sources of natural food including truncated soft-shell clams. This study introduces an inexpensive drop-camera system that can be readily deployed from community vessels in an effort to support community-based assessment and management of the truncated soft-shell clam recreational fishery. The aim was to provide a quick and easy method to assess clam densities within the intertidal zone and subsequently the effects of a potential increase in harvesting pressure with an increase in the human population. On a broader scale, my research will contribute to the fields of Arctic and bivalve biology, and supply evidence needed to determine the suitability of drop-cameras to estimate the density of burrowing bivalves within the intertidal zone.

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Co-Authorship Statement

Dr. Scott Grant brought forth the premise of the two field studies within this thesis, while I, Jessica Wood, was the main executioner of field work, data analysis, and preparation of manuscripts. I, Jessica Wood, and Dr. Scott Grant reviewed drafts of each chapter and have prepared them for publication. Meghan Donovan aided with data collection in the field and with laboratory analysis. I, Jessica Wood, Dr. Scott Grant, and Meghan Donovan are listed as co-authors on both data chapters within this thesis.

Chapter 2. Aspects of the life history of the truncated soft-shell clam, *Mya truncata,* of southern Baffin Island, Nunavut

2.1 Abstract

The truncated soft-shell clam (*Mya truncata)* is an important source of natural food for Indigenous communities across the territory of Nunavut, Canada. *M. truncata* also plays an important role in marine ecosystems, yet there is little understanding of their life-history and overall health or condition in Canadian Arctic waters. To provide a foundation on which aspects of the life-history and body condition of *M. truncata* of Baffin Island can be monitored in the future, this study investigated the size at maturity, spawning, and indices of condition of clams from inner Frobisher Bay and the north shore of the Hudson Strait. Male and female *M. truncata* exhibited similar lengths at 50% attainment of sexual maturity, 31 mm and 32 mm shell length (SL), respectively. Most of the sexually mature *M. truncata* collected from inner Frobisher Bay in late August and Hudson Strait in early September were in the ripe stage of gonadal development; 87.2% and 50.4%, respectively. These results lead me to conclude a late September-early November spawning event. Indices of condition based on some measure of *M. truncata* body weight divided by SL were positively correlated with SL and thereby deemed unsuitable for spatio-temporal comparisons of condition. This study then used dry body weight-SL relationships to demonstrate *M. truncata* condition can differ significantly over small and large spatial scales. Because water content varies with condition, this study concludes that dry body weight is a more accurate index of energy reserves than wet body weight.

2.2 Introduction

The Inuit of the Canadian Arctic have traditionally depended upon harvesting natural foods for nourishment (NCRI 2005; Chan et al. 2006). A popular source of natural food for communities across Nunavut is the truncated soft-shell clam (*Mya truncata*). Because the Arctic marine environment is increasingly affected by climate change (Hinzman et al. 2005), marine species, including *M. truncata*, may be impacted in ways that alter their physiology and subsequent life-history. For example, rising temperatures and earlier ice break-up may increase growth rates and advance spawning times (Philippart et al. 2003; Steeves et al. 2018). In addition, increases in freshwater runoff and a reduction in the geographic extent and duration of ice cover in marine environments is expected to increase the ratio of phytoplankton to ice algae over the course of a year and alter phytoplankton species and size composition (Smyth et al. 2004; Park et al. 2015; Blais et al. 2017; Makela et al. 2017). Changes in planktonic algae attributes with climate change could affect the body condition of *M. truncata*, as they depend on phytoplankton for nutrition by rapidly consuming influxes in organic matter (Sun et al., 2007; Makela et al., 2017). Changes in the life-history and condition of clams could influence existing recreational subsistence fisheries and the potential for commercial development with markets at local and national/ international scales. In a rapidly changing Arctic environment, it is important to provide baseline information on population health and life-history traits of *M. truncata* that could be affected by both harvesting and climate change.

In North America, *M. truncata* is typically found in coastal intertidal and subtidal waters of the Arctic, with its southern boundary designated as Massachusetts Bay, Massachusetts, U.S.A. (Lubinsky 1980). *M. truncata* is an integral part of the Arctic ecosystem providing a means of energy transfer from primary producers to bearded seals and walrus, two of the primary consumers of bivalve molluscs in Canada's Arctic (Banfield 1977; Welch et al. 1992). Despite its ecological importance, the life-history and indices of condition of *M. truncata* in the Canadian Arctic are poorly understood. To date, studies of *M. truncata* have focused on aging, growth, and developing methods to estimate abundance through siphon counts (Andrews 1972; Welch et al. 1992; Siferd 1997; Siferd 2005). From a sustainable fishery development, conservation, and environmental monitoring perspective it is also important to establish size at attainment of sexual maturity, spawning events, and an effective method to evaluate the health or condition of populations of *M. truncata*.

This study examines the sex and stage of gonadal maturity of male and female *M. truncata* from two sites in inner Frobisher Bay and two sites on the north shore of the Hudson Strait to establish the size at sexual maturity and information on when spawning occurs in Canadian Arctic waters. In addition, the body condition of *M. truncata* was examined to gauge population health and the merits of techniques used here to assess body condition are discussed.

2.3 Materials and Methods

2.3.1 Study sites

Mya truncata were collected at low tide from the intertidal zone at two sites within inner Frobisher Bay (hereafter FB), near the community of Iqaluit and two sites on the north shore of the Hudson Strait (hereafter HS) (i.e., south coast of Baffin Island), near the community of Kimmirut (Figure 2.1). One site near Iqaluit was accessible by road (Site I1), while the other was roughly 15 km across FB and only accessible by boat (Site I2). Similarly, one site near Kimmirut was accessible by road (Site K1), and the other was located roughly 15 km from the community (Site K2). The substrate type of the intertidal zone at all sites was sand with sparsely distributed small and large rocks (10-30 cm diameter) often with attached fucoid macroalgae. In FB, clams were collected from 28-30 August and on 12 September from HS. Clams were collected using garden trowels and were buried roughly 2-30cm in depth in the sediment. All clams in the sediment were collected, with no discrimination for size. All clams were kept in cool sea water on the way back to the laboratory, and then immediately frozen and maintained at -20°C until analysis.

2.3.2 Sex determination and gonadal staging

In the laboratory, frozen clams were thawed, blotted, and weighed (±0.01 g). A Vernier caliper was used to measure shell length (SL; ±1.0mm) from the anterior tip of the shell to the posterior edge. Clams were gently pried open and a scalpel was used to sever the adductor muscles at the point of attachment to the shell. The entire animal, including the adductor muscles, was then removed from the shell, blotted, and weighed (±0.01 g).

When present, tweezers were used to sample a pinch of the gonadal tissue to determine sex and stage of gonadal development. Subsequently, the body of each clam was individually dried to constant weight (±0.0001 g) at 60ºC, which took from 2-5 days depending on clam size. This analysis provided the following three weight measures for each clam: 1) wet body shell-on weight (WWSON), 2) wet body shell-off weight (WWSOFF), and 3) dry body shell-off weight (DWSOFF).

Clams that did not exhibit gonadal development could not be sexed and were classified as undifferentiated and considered immature. Gonadal smears were examined at 10-40× magnification and used to assign each clam to one of five stages of gonadal development based on the scale defined by Brousseau (1987): 1) indifferent, 2) developing, 3) ripe, 4) spawning (partially spent), and 5) spent. To aid in classification, gonadal smears of *M. truncata* were also compared to photographs of histological preparations of gonadal tissue of *Mya arenaria* from Ireland (Cross et al., 2011). In the current study, *M. truncata* classified as indifferent possessed gonadal follicles, but no lumen or cavity was present and no developing egg or sperm cells were found in several gonadal smears examined for each clam. As such, clams classified as indifferent were considered to be immature and lumped with clams classified as undifferentiated. Clams with gonads that exhibited follicular lumen and possessed egg or sperm cells developing on the periphery of the lumen were classified as developing. Ripe clams displayed more fully developed egg or sperm cells with tails and many of these gametes were free within the follicular lumen. Although many of the egg and sperm cells had been discharged in clams classified as spawning, there were still some free gametes within the follicle lumen. In spent clams, the follicular lumen is empty and there are no developing eggs or sperm on the periphery of the lumen. None of the clams examined during this study were classified as spent.

2.3.3 Length-based condition indices

I calculated three different condition factor (CF) indices for *M. truncata*:

$$CF_{WWSON} = WWSON/SL \times 100, \quad (1)$$

$$CF_{WWSOFF} = WWSOFF/SL \times 100, \text{ and} \quad (2)$$

$$CF_{DWSOFF} = DWSOFF/SL \times 1000. \quad (3)$$

These condition indices were chosen because of their appearance in previous mollusc condition studies (e.g. Eckblad et al. 1971; Ellis et al. 2002; Pillay et al. 2007). Fulton's condition factor (Ricker 1975) was not used in this study because it is known to be length biased in the estimation of average condition in fish (Rennie and Verdon 2008). Length-based condition indices for fish need to be free from length-related bias, or else a change in condition across size within or between populations could just be the result of a change in average size of the population, therefore misrepresenting condition (Gerow et al. 2004). To evaluate SL-related bias in condition factors, data from FB and HS were pooled for each condition factor index and plotted against SL. The most suitable regression model for each condition factor-SL relationship was selected using Akaike's second order information criterion (AIC_c; Burnham and Anderson 2002), where models tested included linear, quadratic, exponential, and cubic distributions, and model parameters and level of significance were calculated.

Length-related bias precludes comparing average condition factors between populations (Gerow et al. 2004). When length-related bias was detected via a significant p-value, ANCOVAs were performed to test between site differences in condition factor-SL relationships for FB and HS. When an ANCOVA indicated a significant difference in condition factor-SL relationships between sites, the data was plotted with the 95% CIs to identify where the difference occurred.

2.3.4 Weight-shell length relationships and moisture content

Weight-SL relationships were developed for *M. truncata* collected from each site in FB and HS using the three measures of body weight obtained (i.e., WWSON, WWSOFF, and DWSOFF). The most suitable regression model for each relationship was selected using AIC_c, where models tested included linear, quadratic, exponential, and cubic distributions. ANCOVAs were performed between populations in FB and HS to test for differences in relationships. When an ANCOVA indicated a significant difference in weight-SL relationships between populations, the data were plotted with the 95% CIs to identify where the difference occurred. Sites were compared within communities, i.e. sites I1 vs. I2 and K1 vs. K2, and between communities, i.e. I1 vs. K2 and I2 vs. K2 restricting the within and between community comparisons to populations that exhibited similar size ranges to avoid length-biased results (i.e., K1 clams did not exceed 47 mm SL and were removed from the between community comparisons).

Moisture, or water, content of clams was calculated using the following equation:

$$\text{Moisture (\%)} = \frac{(\text{WWSOFF} - \text{DWSOFF})}{\text{WWSOFF}} \times 100 \tag{4}$$

Differences in moisture content between sites and stage of gonadal development were evaluated using one-way ANOVAs. Tests of normality and equality of variance were performed using the Shapiro-Wilk's normality test. When assumptions of normality and equality of variance could not be met by transformation, the non-parametric Kruskal-Wallis ANOVA on ranks was used and Dunn's post-hoc test if the result was significant.

2.3.5 Shell length analysis by site, sex, and maturity

One-way ANOVAs were used to examine variation in *M. truncata* SL among all four sample sites (i.e., two in each of FB and HS) and among immature clams and mature male and mature female clams by region (i.e. FB and HS) using linear models in R Studio. Tests of normality and equality of variance were performed using the Shapiro-Wilk's normality test and the Levene median test, respectively. When assumptions of normality and equality of variance were not valid, non-parametric tests were performed as described for moisture content analyses. Tukey's HSD post-hoc test was used when parametric analysis indicated significant differences via the linear model.

2.3.6 Maturity Ogive

Maturity ogives calculate and visually display the size at which 50% of a population is sexually mature. Separate male and female size at maturity ogives were constructed for clams collected across all sites by quantifying the proportion of male or female clams that were sexually mature within each 5 mm SL class. The sex ratio of sexually mature clams was used to estimate the sex of immature clams (i.e., undifferentiated and indifferent stages combined). Specifically, the 1.14:1 female:male sex ratio was used wherein 53% of all immature clams within each 5 mm SL class were deemed female and 47% were deemed male. The best fit model for each maturity ogive was selected using AICc, where models tested included logit, probit, Gompertz, and Weibull distributions.

2.3.7 Data cleaning and software

A total of 8 outliers, 1 from site I1 (34mm in SL, ripe female), 4 from site K1 (all<17mm SL and undifferentiated), and 3 from site K2 (all<24mm SL and undifferentiated), all with weights outside the normal range of clams collected, were removed from the data set by testing linear regressions of WWSON, WWSOFF, and DWSOFF vs. log SL using the Bonferroni Outlier Test, which detects outliers that have the ability to shift the mean (Doornbos 1981). One clam collected from Iqaluit was removed from analysis as it was 80 mm, and outside the normal SL range of clams collected. All statistical analyses were performed in R Studio version 3.5.1 for windows (2018) and the significance level was set to $\alpha=0.05$.

2.4 Results

2.4.1 Shell length-based analyses

In the current study, 337 truncated soft-shell clams were examined: 115 male, 131 female, and 91 immature (i.e., undifferentiated and indifferent stages combined). There were more female truncated soft-shell clams collected at sites I1 and K1 while the sex ratios were equal or nearly equal at sites I2 and K2 (Table 2.1). Analysis indicated the sex of animals examined was independent of site, justifying the use of an averaged sex ratio of all sites for the allocation of immatures to be either male or female for the purpose of crafting maturity ogives (χ^2=3.77, df=3, p=0.29). Shell length differed significantly between sites (χ^2=67.43, df=3, p<0.001), and post hoc analysis showed that clams from site K1 had a significantly smaller mean shell length than all other sites (p<0.001)(Figure 2.2).

The mean SL of immature clams from FB did not differ significantly from HS (p=0.09; Figure 2.3). However, the mean SL of immature clams from each community was significantly lower than males and females from each community (p<0.01). The SL of females from FB did not differ significantly from females or males from HS (p=0.8, p=1.0, respectively). Males from FB were significantly smaller than females from FB, and males and females from HS (p=0.02, p<0.01, p<0.01, respectively; Figure 2.3).

2.4.2 Stage of Gonadal Development

In Frobisher Bay, 11.3% of the truncated soft-shell clams examined were undifferentiated, 2.1% were in the indifferent phase of gonadal development, 8.2% were developing, 77.3% were ripe, 1.0% were spawning, and 0% were spent. In the Hudson

Strait, 30.5% of clams were undifferentiated, 4.1% indifferent, 30.0% developing, 34.9% ripe, 0.4% spawning, and 0% were spent.

2.4.3 Maturity ogive

The logit model provided the best fit to both the male and female maturity data based on AICc scores (Table 2.2). This model is represented by the formula $\log(p/1-p)=\alpha+\beta X$ where p represents the probability of being mature, and α and β are constants.

The majority (90.1%) of the 91 truncated soft-shell clams classified as immature in the maturity assessment did not possess gonads while 9.9% possessed gonads in the early stage of differentiation (i.e., indifferent). The immature clams exhibited a range in SL of 11-40 mm. In females, the SL at first attainment of sexual maturity was 28 mm, SL at 50% attainment of sexual maturity (L_{50}) was 32 mm, and all females exhibiting a SL ≥42 mm were sexually mature (Figure 2.4). For the males, SL at first attainment of sexual maturity was 23 mm, SL at 50% attainment of sexual maturity (L_{50}) was 31 mm, and all males exhibiting a SL ≥42 mm were sexually mature (Figure 2.5).

2.4.4 Body condition

The exponential model provided the best fit to each of the pooled condition factor-SL relationships (Table 2.3 and Figure 2.6). Strong correlation coefficients indicate length-bias in these condition factor indices (Table 2.4) precluding their utility with regard to comparing average condition among the populations studied (Gerow et al. 2004; Rennie and Verdon 2008). Analysis revealed between-site differences in CF_{WWSOFF}-SL relationships and CF_{DWSOFF}-SL relationships in FB, but there were no between-site differences in condition factor-SL relationships in the HS (Table 2.5). Plots of the lines of best fit with 95% confidence intervals (CIs) revealed that although the intercepts differed significantly between sites in FB for the CF_{WWSOFF}-SL relationships (Table 2.5), the 95% CIs overlapped such that there was no evidence of a significant difference in condition factor at length over the SL range of truncated soft-shell clams examined (Figure 2.7). However, a significant difference in slopes of CF_{DWSOFF}-SL relationships between sites in FB was accompanied by a clear separation among the 95% CIs. These results indicated CF_{DWSOFF} was able to detect differences in condition of truncated soft-shell clams within the 49 to 61 mm SL range from Site I2 in FB exhibiting a significantly higher condition factor than clams from Site I1 at that length range (Figure 2.8).

The exponential model was the best model to use for between population comparisons of the WWSON-SL, WWSOFF-SL, and DWSOFF-SL relationships (Table 2.6) and all relationships were highly correlated (Table 2.7). ANCOVA revealed the only significant difference in weight-SL relationships occurred for the DWSOFF-SL relationship among sites in FB (Table 2.8). Plots of the best fit line with 95% CIs indicate clams within the 49 to 63 mm SL range from site I1 exhibited a significantly higher dry weight at SL than clams from site I2 (Figure 2.9).

Between the two sites of FB and site K2, ANCOVA showed condition factor to shell length relationships did not differ between I1 and K2 (Table 2.9), and further pair-wise comparisons revealed that the CF_{DWSOFF} -SL relationships between sites I2 and K2 differed significantly ($p<0.001$) (Table 2.10). A plot of this comparison shows clams $\geq$47 mm SL from I2 had higher CF_{DWSOFF} than similar sized clams from K2 (Figure 2.10). ANCOVA analysis showed no significant differences between weight to shell length relationships between site I2 and K2 (Table 2.11). Subsequent pair-wise comparisons between the two sites in FB and site K2 revealed that the DWSOFF -SL relationships of sites I2 and K2 also differed significantly (Table 2.12). Figure 2.11 shows that clams ≥49 mm SL from site I2 had higher DWSOFF than similar sized clams from site K2.

Clam moisture content was found to differ significantly among populations of *M. truncata* examined (Chi-square=140.29, df=3, $p<0.001$) (Figure 2.12). Post-hoc analysis revealed a significant difference in moisture content between sites within each community and between communities (i.e., Site I2 and K1; Figure 2.12). Overall, clams from Site I2 exhibited the lowest mean moisture content. Moisture content varied significantly by stage of gonadal development (Chi-square= 70.536, df = 4, $p<0.001$), where undifferentiated and indifferent clams contained significantly higher moisture content than clams at all other stages of gonadal development (Figure 2.13).

2.5 Discussion

According to the maturity ogive constructed, the size at which 50% of the *M. truncata* population of southern Baffin Island is sexually mature is 31mm in males and 32mm in females. This size is small in comparison to the size at which *M. arenari*a, a sister species to *M. truncata,* are sexually mature in other parts of Canada, such as in the Gulf of St. Lawrence at 41mm (DFO 1996). This could be due to differences between species, or that in colder water temperatures, clams have slower growth rates, and so mature at a smaller size compared to southern populations (Weymouth et al. 1931) It should be noted that *M. truncata* have truncated shells, which may influence comparisons between the size at maturation of *M. truncata* and *M. arenaria*. Nevertheless, these results also support past research that has found that life history characteristics of bivalves, including *Mya* species, can vary along a latitudinal gradient (Appeldoorn 1995; Santos et al. 2011).

Most mature clams collected in FB and HS in late August or mid-September were observed to be in the ripe stage of gonadal development, but the period of spawning was not observed. *M. arenaria* in the northwest Atlantic commence gametogenesis in late winter or early spring and spawn from June to September, sometimes with a second fall spawning event taking place (Christian et al. 2010). Spawning in bivalves is thought to be triggered by increasing water temperatures, such as in the spring (Chicharo and Chicharo 2000), and fluctuations in chlorophyll *a* concentration, where phytoplankton blooms provide food for larvae (Brandner et al. 2017; Chicharo and Chicharo 2000). The spawning period of *M. truncata* has been observed to occur in April in the North Sea (Amaro et al. 2005), with larvae observed in the water column of the White Sea from June to August, peaking in July (Günther and Fedyakov 2000). Brandner et al. 2017 used D-shaped larvae abundance to infer the spawning time of various bivalve species in Western Svalbard, as D-shaped larvae is the first larval stage to occur post-spawning (Sullivan 1948). They observed D-shaped *M. truncata* larvae in May with maximum chlorophyll *a* concentration, and a second cohort in September when chlorophyll *a* concentration was low (Brandner et al. 2017). So, past research has shown that *M. truncata* spawn in early spring, occasionally with a second fall spawning event.

These observations may help to infer the spawning period of *M. truncata* of southern Baffin Island.

Another factor that may help to infer the spawning season of *M. truncata* is phytoplankton abundance because larval *Mya* sp. filter feed on surrounding microplankton, such as autotrophic phytoplankton and cyanobacteria (Raby et al. 1997). During ice-covered months in FB, algae occupy the underside of the ice and are of higher concentration than phytoplankton in the water beneath, but algae mixes with phytoplankton to produce maximum chlorophyll *a* concentration in the summer once ice has melted (Hsiao 1992). In HS, chlorophyll *a* concentration due to phytoplankton is highest in the summer for similar reasons (Harvey et al. 1997). Ice cover occurred from the end of November 2017 to mid-July 2018 around southern Baffin Island, and ice cover returned towards the end of November 2018 (Canadian Ice Service 2018). Therefore, *M. truncata* collected from southern Baffin Island may have spawned from late September to early November to align with chlorophyll *a* concentration levels for feeding larvae before ice cover returns. It is also possible that *M. truncata* had spawned early in the spring with maximum chlorophyll *a* concentration and had already commenced gametogenesis before time of collection. It will be important in future work to track how stages of gonadal development change as seasons progress, and with variation in ice cover and differences in phytoplankton levels and species composition that may arise with climate change. This chapter provides a base to monitor potential changes in aspects of the life history of truncated soft-shell clams of southern Baffin Island with climate change-induced environmental fluctuations, as any changes may impact recreational fisheries and commercial fishery development.

Many fisheries and aquaculture operations use body condition to infer the health of a population, including bivalves (Lucas and Beninger 1985). In the past, mollusc studies using condition factor indices have either not checked for length-bias in data (e.g. Pillay et al. 2007), constrained size ranges so as to avoid length bias altogether (e.g. Ellis et al. 2002), or used weight to length relationships instead of condition factor indices (e.g. Eckblad et al. 1971). Assessing body condition using length-weight relationships for descriptive purposes is an effective way to avoid length-based bias in condition analyses (Bolger and Connolly 1989; Gerow et al. 2004). Strong relationships were identified between CF_{WWSON}, CF_{WWSOFF}, and CF_{DW} and SL, which provides evidence of length-related bias in these calculated condition factors. Therefore, the present study also assessed body condition between sites using WWSON, WWSOFF, and DWSOFF to SL relationships.

Plotted CF_{DWSOFF}-SL and DWSOFF-SL relationships with CIs both showed significant differences between sites I1 and I2, and I2 versus K2. Therefore, weight-SL relationships give similar results as CF-SL relationships, yet weight-SL relationships do not require additional calculations that could introduce error, nor the need to check for length bias. Further, it was noted that differences in moisture content reflected differences in condition between sites I1 and I2, where clams from site I2 had significantly lower moisture content than those of site I1, but subsequently higher DWSOFF-SL body condition. The same is true for the significant differences observed between DWSOFF-SL condition of sites I2 and K2, where again I2 had significantly lower moisture yet higher condition than K2. No WWSON-, nor WWSOFF-SL relationships showed significant differences in body condition within or between communities. Therefore, differences in condition emerged once moisture content was removed with DWSOFF.

Further, differences in shell weight, not attributable to condition, could have influenced WWSON values, making WWSON-SL relationships unreliable. By considering these findings, the most reliable method to compare the body condition of *M. truncata* populations is to compare the DWSOFF-SL relationships of clams within similar size ranges using plotted confidence intervals.

For the DWSOFF-SL relationship observed between FB sites, a significant difference emerged at 52mm in SL. At this size, 100% of male and female clams were mature. Further, clams pooled across all sites showed significantly higher moisture content in early stages of gonadal development, and subsequently would show a higher DWSOFF-SL condition. Therefore, condition may be influenced by stage of gonadal development, where later stages of development may contribute to a higher condition. In the future, it would be beneficial to account for how body condition may vary with time as clams cycle through gonadal development. Nevertheless, the body condition of bivalves can be the result of a variety of factors, such as phytoplankton abundance and sediment suspension, or sewage effluent and heavy metal contamination that could lower body condition (Page et al. 1984; Jorgensen 1996; Filgueira et al. 2014; Nobles and Zhang 2015). These factors may have contributed to differences in condition observed on small and large spatial scales. Spatial differences in body condition may also infer differences in reproductive potential, as body condition in bivalves at the ripe stage of gonadal development, right before spawning, tends to be higher than at other periods of gonadal development (e.g. Etim 1996; Adjei-Boateng and Wilson 2013), and higher body condition infers higher reproductive output in bivalves (Jokela 1996). These hypotheses should be tested in future studies to thoroughly understand the reproductive potential of populations of *M. truncata* of southern Baffin Island as it relates to biological condition.

In conclusion, this study provides baseline information to monitor how Arctic *M. truncata* will be affected by potentially life history-altering climate change effects for conservation and management purposes and is expected to help with regard to future community-based resource harvest plans for recreational fishery development that has the potential to provide significant benefits in terms of revenues and job creation.

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2.7 Tables

Table 2.1. The number of immature, male, and female clams examined at each site, and the resulting F:M sex ratio.

Community	Site	Immature	Female	Male	Sex Ratio (F:M)
Iqaluit	I1	4	24	13	1.85:1
	I2	9	23	24	0.95:1
Kimmirut	K1	42	15	9	1.67:1
	K2	36	69	69	1 : 1
All Sites Combined		91	131	115	1.14:1

Table 2.2. Akaike's information criteria (AICc) values obtained from four different models applied to maturity curves for male and female truncated soft-shell clams. Models in bold font exhibited the lowest AICc value and highest weight.

	Logistic model	AICc	dAICc	df	Weight
Males					
	Logit	**-1.2**	**0.0**	**2**	**0.38**
	Probit	-1.3	0.1	2	0.36
	Gompertz	-1.7	0.8	2	0.25
	Weibull	-3.8	8.5	3	<0.01
Females					
	Logit	**-1.2**	**0.0**	**2**	**0.39**
	Probit	-1.2	0.2	2	0.36
	Gompertz	-1.5	0.9	2	0.25
	Weibull	-3.8	8.8	3	<0.01

Table 2.3. Akaike's information criteria (AICc) values obtained from 4 different models applied to condition factor versus shell length plots for clams collected across southern Baffin Island. CF_{WWSON} is the wet weight shell-on (g) based condition factor, CF_{WWSOFF} is the wet weight shell-off (g) based condition factor, and CF_{DWSOFF} is the dry weight shell-off (g) based condition factor. Models in bold exhibited the lowest AICc value.

Relationship	Model	AICc	dAICc	df	Weight
CF_{WWSON}-SL	Linear	2427.5	2395.9	3	<0.001
	Quadratic	2376.2	2344.6	4	<0.001
	Exponential	**31.6**	**0.0**	**3**	**1**
	Cubic	2373.7	2342.1	5	<0.001
CF_{WWSOFF}-SL	Linear	2068.8	1941.1	3	<0.001
	Quadratic	2024.6	1896.8	4	<0.001
	Exponential	**127.7**	**0.0**	**3**	**1**
	Cubic	2019.9	1892.2	5	<0.001
CF_{DWSOFF}-SL	Linear	2704.5	2387.7	3	<0.001
	Quadratic	2705.6	2388.8	4	<0.001
	Exponential	**316.8**	**0.0**	**3**	**1**
	Cubic	2697.4	2380.6	5	<0.001

Table 2.4. Summary of regression constants and correlation coefficient (r^2) for three truncated soft-shell clam condition factors versus shell length relationships obtained for clams collected across southern Baffin Island. The number of clams (n) examined is shown. CF_{WWSON} is the wet weight shell-on based condition factor, CF_{WWSOFF} is the wet weight shell-off condition factor, and CF_{DWSOFF} is the dry weight shell-off condition factor.

		Regression Constants			
Relationship	N	a	b	R^2	p
CF_{WWSON} - SL	337	1.16	0.05	0.912	$<2.2^{-16}$*
CF_{WWSOFF}- SL	337	0.53	0.06	0.895	$<2.2^{-16}$*
CF_{DWSOFF}- SL	337	1.09	0.06	0.837	$<2.2^{-16}$*

*significantly different at p<0.05

Table 2.5. ANCOVA results of condition factor versus shell length regressions between sites of Frobisher Bay and Hudson Strait.

		ANCOVA results			
		Slope		Intercept	
Location	Relationship	t-value	p	t-value	p
FB	CF_{WWSON}	1.651	0.102	-1.790	0.077
	CF_{WWSOFF}	1.525	0.131	-2.153	0.034*
	CF_{DWSOFF}	2.690	0.008*	-1.757	0.082
HS	CF_{WWSON}	0.089	0.929	0.496	0.621
	CF_{WWSOFF}	1.596	0.113	-0.462	0.644
	CF_{DWSOFF}	1.330	0.186	-0.938	0.350

*significantly different at p<0.05

Table 2.6. Akaike's information criteria (AICc) values obtained from four models applied to weighing methods versus shell length (SL) relationships for each site within Frobisher Bay and Hudson Strait. WWSON is the wet weight shell-on (g), WWSOFF is the wet weight shell-off (g), and DWSOFF is the dry weight shell-off (g). Models in bold exhibited the lowest AICc value.

	Logistic Model	AICc	dAICc	df	Weight
WWSON-SL					
Site I1	Linear	277.3	324.0	3	<0.001
	Quadratic	263.3	309.9	4	<0.001
	Exponential	**-46.6**	**0.0**	**3**	**1**
	Cubic	256.2	302.9	5	<0.001
Site I2	Linear	338.9	448.5	3	<0.001
	Quadratic	325.9	435.5	4	<0.001
	Exponential	**-109.6**	**0.0**	**3**	**1**
	Cubic	328.3	437.9	5	<0.001
Site K1	Linear	1272.3	1327.4	3	<0.001
	Quadratic	1041.5	1096.6	4	<0.001
	Exponential	**-55.0**	**0.0**	**3**	**1.0**
	Cubic	1043.8	1098.8	5	<0.001
Site K2	Linear	343.5	404.3	3	<0.001
	Quadratic	295.7	356.5	4	<0.001
	Exponential	**-60.8**	**0.0**	**3**	**1.0**
	Cubic	295.7	356.6	5	<0.001

Table 2.6 (continued). Akaike's information criteria (AICc) values obtained from four models applied to weighing methods versus shell length (SL) relationships for each site within Iqaluit and Kimmirut. WWSON is the wet weight shell-on (g), WWSOFF is the wet weight shell-off (g), and DWSOFF is the dry weight shell-off (g). Models in bold exhibited the lowest AICc value.

	Logistic Model	AICc	dAICc	df	Weight
WWSOFF-SL					
Site I1	Linear	221.9	279.9	3	<0.001
	Quadratic	206.7	264.7	4	<0.001
	Exponential	**-58.0**	**0.0**	**3**	**1**
	Cubic	206.1	264.2	5	<0.001
Site I2	Linear	301.1	401.6	3	<0.001
	Quadratic	292.5	393.0	4	<0.001
	Exponential	**-100.4**	**0.0**	**3**	**1**
	Cubic	295.0	395.5	5	<0.001
Site K1	Linear	1075.6	1136.7	3	<0.001
	Quadratic	819.6	880.6	4	<0.001
	Exponential	**-61.1**	**0.0**	**3**	**1.0**
	Cubic	821.8	882.9	5	<0.001
Site K2	Linear	283.0	341.8	3	<0.001
	Quadratic	232.7	291.5	4	<0.001
	Exponential	**-58.8**	**0.0**	**3**	**1.0**
	Cubic	233.4	292.2	5	<0.001

Table 2.6 (continued). Akaike's information criteria (AICc) values obtained from four models applied to weighing methods versus shell length (SL) relationships for each site within Iqaluit and Kimmirut. WWSON is the wet weight shell-on (g), WWSOFF is the wet weight shell-off (g), and DWSOFF is the dry weight shell-off (g). Models in bold exhibited the lowest AICc value.

	Logistic Model	AICc	dAICc	df	Weight
DWSOFF-SL					
Site I1	Linear	88.3	144.8	3	<0.001
	Quadratic	77.1	133.6	4	<0.001
	Exponential	**-56.5**	**0.0**	**3**	**1.0**
	Cubic	77.6	134.1	5	<0.001
Site I2	Linear	154.7	243.9	3	<0.001
	Quadratic	152.7	241.9	4	<0.001
	Exponential	**-89.2**	**0.0**	**3**	**1.0**
	Cubic	155.3	244.4	5	<0.001
Site K1	Linear	424.6	492.4	3	<0.001
	Quadratic	232.8	300.6	4	<0.001
	Exponential	**-67.8**	**0.0**	**3**	**1.0**
	Cubic	327.1	395.0	5	<0.001
Site K2	Linear	59.2	113.3	3	<0.001
	Quadratic	23.6	77.7	4	<0.001
	Exponential	**-54.1**	**0.0**	**3**	**1.0**
	Cubic	25.9	80.0	5	<0.001

Table 2.7. Summary of regression constants and correlation coefficient (r^2) for three truncated soft-shell clam weighing methods versus shell length relationships obtained for two sites near Iqaluit and two sites near Kimmirut. The number of clams (n) at each site is also shown. WWSON is the wet weight shell-on, WWSOFF is the wet weight shell-off, and DWSOFF is the dry weight shell-off.

				Regression Constants		
Community	Relationship	Site	n	Slope	Intercept	r^2
Iqaluit	WWSON-SL	I1	41	0.01	3.47	0.711
		I2	56	0.01	3.49	0.864
	WWSOFF-SL	I1	41	0.02	3.44	0.779
		I2	56	0.02	3.50	0.843
	DWSOFF-SL	I1	41	0.13	3.44	0.772
		I2	56	0.09	3.52	0.801
Kimmirut	WWSON-SL	K1	64	0.04	3.08	0.754
		K2	72	0.04	3.07	0.756
	WWSOFF-SL	K1	64	0.07	3.08	0.744
		K2	72	0.06	3.08	0.747
	DWSOFF-SL	K1	64	0.35	3.09	0.720
		K2	72	0.32	3.10	0.744

Table 2.8. ANCOVA results of three different weighing methods versus shell length regressions between sites of Frobisher Bay and Hudson Strait.

		ANCOVA results			
		Slope		Intercept	
Location	Relationship	t-value	p	t-value	p
FB	WWSON-SL	1.408	0.162	-1.384	0.169
	WWSOFF-SL	1.241	0.218	-1.663	0.997
	DWSOFF-SL	2.965	0.004*	-1.864	0.070
HS	WWSON-SL	0.345	0.731	0.154	0.878
	WWSOFF-SL	1.655	0.100	-0.619	0.537
	DWSOFF-SL	1.399	0.164	-0.850	0.397

*significantly different at $p<0.05$

Table 2.9. ANCOVA results of shell-on wet weight condition factor (CF_{WWSON}), shell-off wet weight condition factor (CF_{WWSOFF}), and dry weight shell-off condition factor (CF_{DWSOFF}) versus shell length regressions between one site of Frobisher Bay (I1) and Hudson Strait (K2).

		ANCOVA results			
		Slope		Intercept	
Condition Factor	Relationship	t-value	p	t-value	p
CF_{WWSON}	I1 vs. K2	1.922	0.056	-1.831	0.067
CF_{WWSOFF}	I1 vs. K2	1.472	0.142	-1.870	0.063
CF_{DWSOFF}	I1 vs. K2	-0.646	0.519	0.024	0.981

Table 2.10. Pair-wise comparison results of an ANCOVA of the wet weight shell-on condition factor (CF_{WWSON}), the wet weight shell-off condition factor (CF_{WWSOFF}), and the dry weight shell-off condition factor (CF_{DWSOFF}) versus shell length regressions between two sites of Frobisher Bay (I1, I2) and Hudson Strait (K2).

Condition Factor	Site-Site Contrast	Estimate	S.E.	df	t-ratio	p-value
CF_{WWSON}	I1-K2	-0.498	1.69	224	-0.295	0.953
	I2-K2	-0.848	1.45	224	-0.587	0.827
CF_{WWSOFF}	I1-K2	0.880	1.03	224	1.427	0.329
	I1-K2	-0.792	0.88	224	-0.900	0.641
CF_{DWSOFF}	I1-K2	3.830	2.67	224	1.437	0.324
	I2-K2	11.590	2.20	224	5.068	<0.001*

*significantly different at p<0.05

Table 2.11. ANCOVA results of the wet weight shell-on (WWSON), the wet weight shell-off (WWSOFF), and the dry weight shell-off (DWSOFF) versus shell length regressions between one site of Frobisher Bay (I1) and Hudson Strait (K2).

		ANCOVA results			
		Slope		Intercept	
Weight	Relationship	t-value	p	t-value	p
WWSON	I1 vs. K2	1.772	0.078	-1.348	0.179
WWSOFF	I1 vs. K2	1.312	0.191	-1.311	0.191
DWSOFF	I1 vs. K2	-0.243	0.808	-0.142	0.887

Table 2.12. Pair-wise comparison results of an ANCOVA of the wet weight shell-on (WWSON), the wet weight shell-off (WWSOFF), and the dry weight shell-on (DWSOFF) versus shell length regressions between two sites of Frobisher Bay (I1, I2) and one site of Hudson Strait (K2).

Weight	Site-Site Contrast	Estimate	S.E.	df	t-ratio	p-value
WWSON	I1-K2	-1.013	0.958	224	-1.057	0.542
	I2-K2	-0.816	0.821	224	-0.994	0.581
WWSOFF	I1-K2	-0.034	0.562	224	-0.060	0.998
	I2-K2	-0.604	0.481	224	-1.256	0.422
DW	I1-K2	0.130	0.140	224	0.900	0.640
	I2-K2	0.600	0.120	224	4.99	<0.001*

*significantly different at p<0.05

2.8 Figures

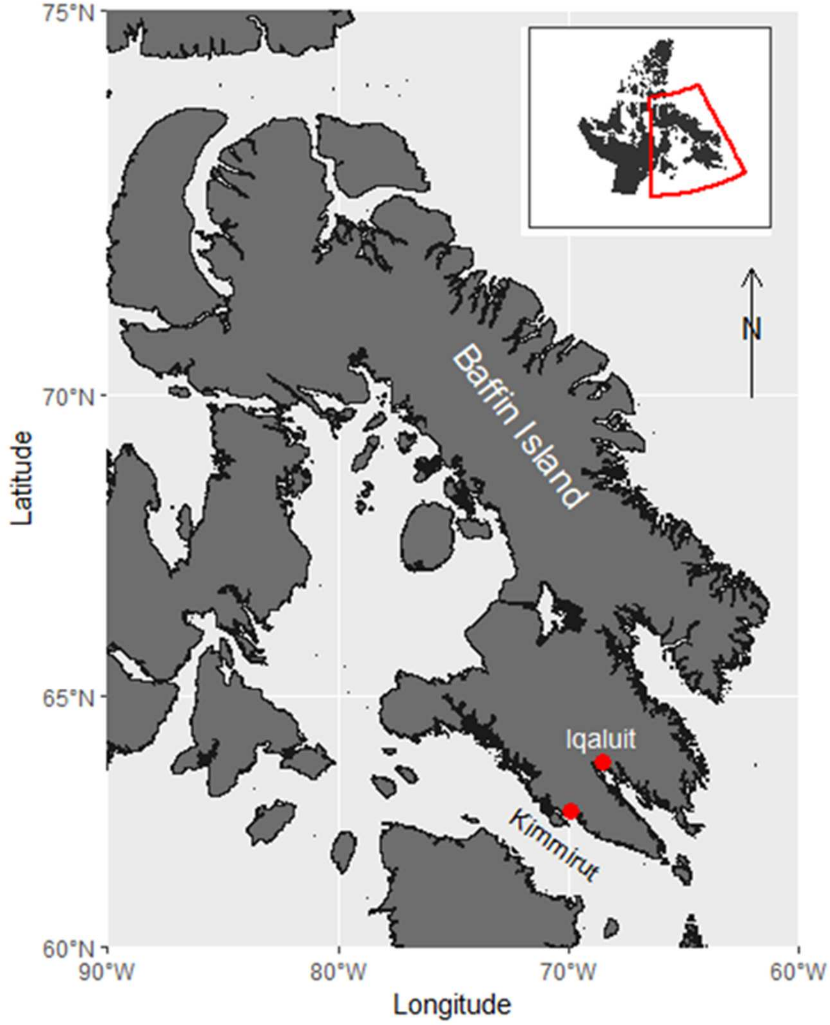

Figure 2.1. Location of the two communities (Iqaluit and Kimmirut) where clams were collected near southern Baffin Island, Nunavut, and insert showing the territory of Nunavut.

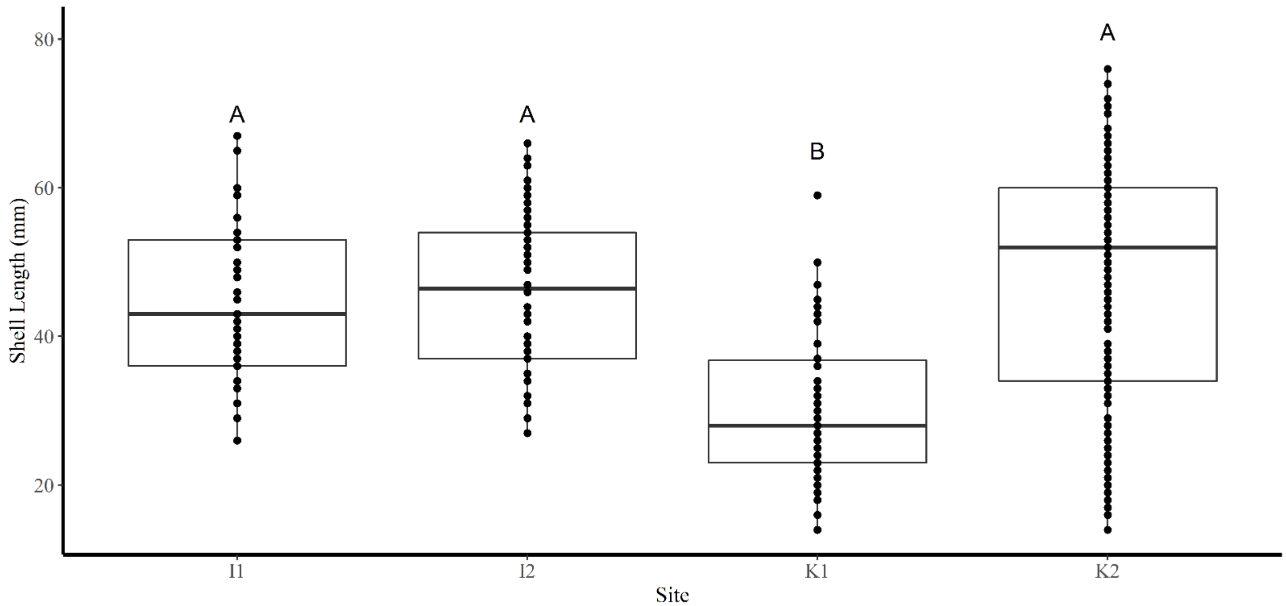

Figure 2.2. Boxplots of the shell length (mm) of clams collected from two sites near Iqaluit (I1 and I2), and two sites near Kimmirut (K1 and K2). Homogenous subsets are shown (i.e., A and B). Horizontal lines within the boxes represent the median value. Lower and upper edge of the boxes show the first and third quartiles, respectively. Lower and upper whiskers represent values outside of the interquartile range.

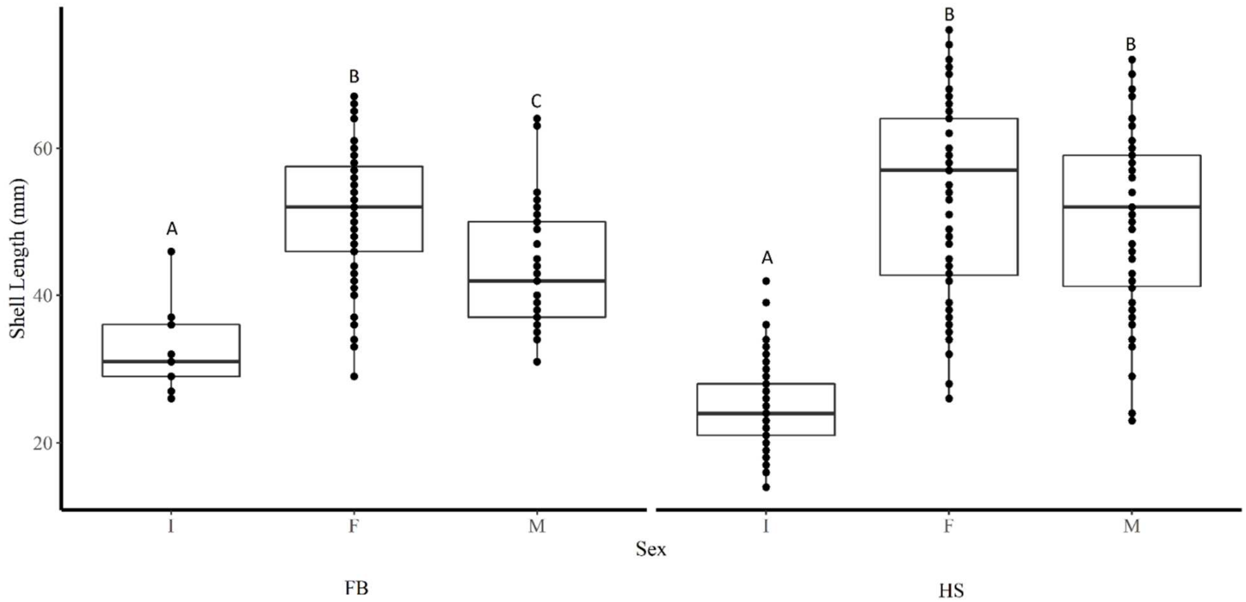

Figure 2.3. Boxplots of the shell length of Immature (I), Female (F), and Male (M) clams collected from Frobisher Bay (FB) and the Hudson Strait (HS). Homogenous subsets are shown (i.e., A, B, and C). Horizontal lines within the boxes represent the median value. Lower and upper edge of the boxes show the first and third quartiles, respectively. Lower and upper whiskers represent values outside of the interquartile range.

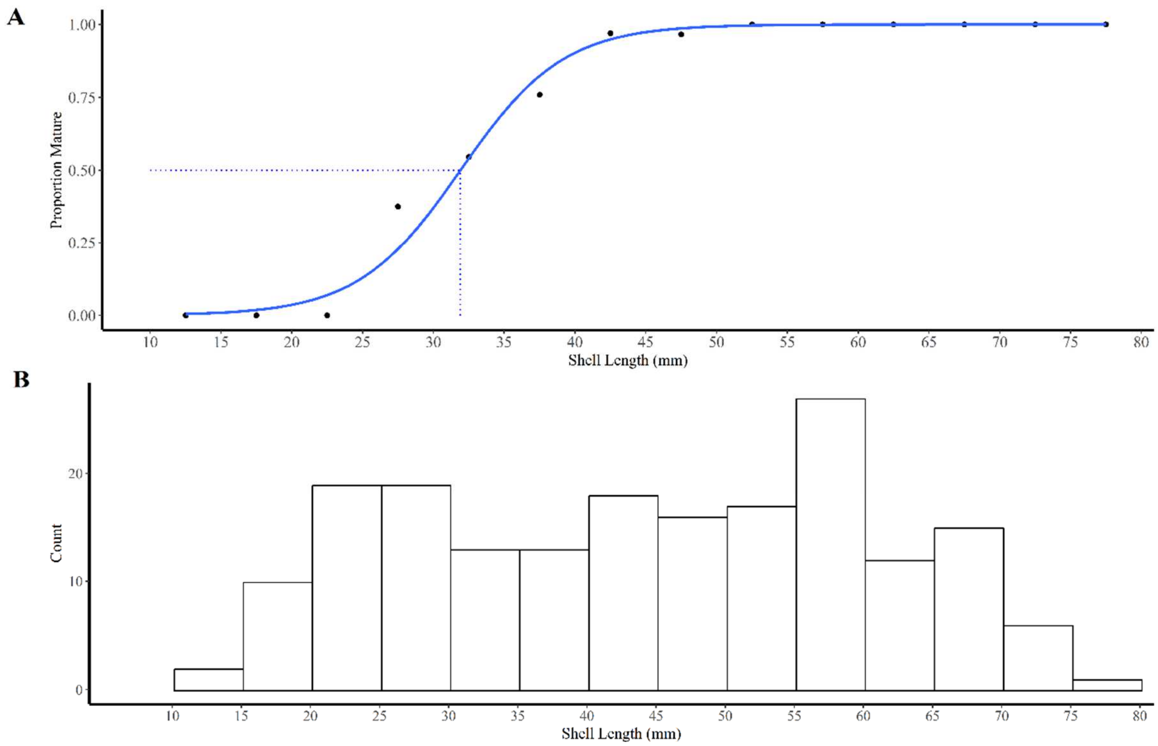

Figure 2.4. Shell length maturity ogive for female truncated soft-shell clams from southern Baffin Island, Nunavut (Panel A). Shell length at 50% maturity is also shown. A histogram of the number of female clams examined at each 5 mm shell length-class is also shown (Panel B).

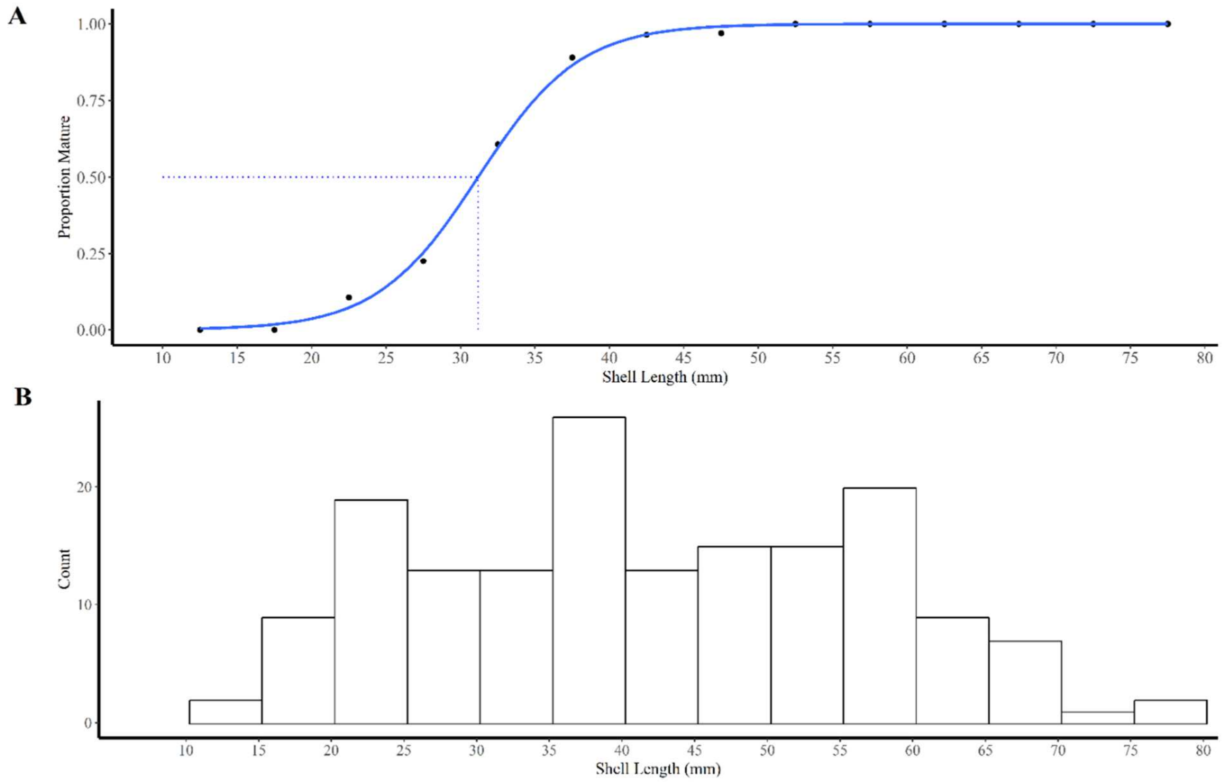

Figure 2.5. Shell length at maturity ogive of male truncated soft-shell clams from southern Baffin Island, Nunavut (Panel A). Shell length at 50% maturity is also shown. A histogram of the number of male clams examined at each 5 mm shell length-class is also shown (Panel B).

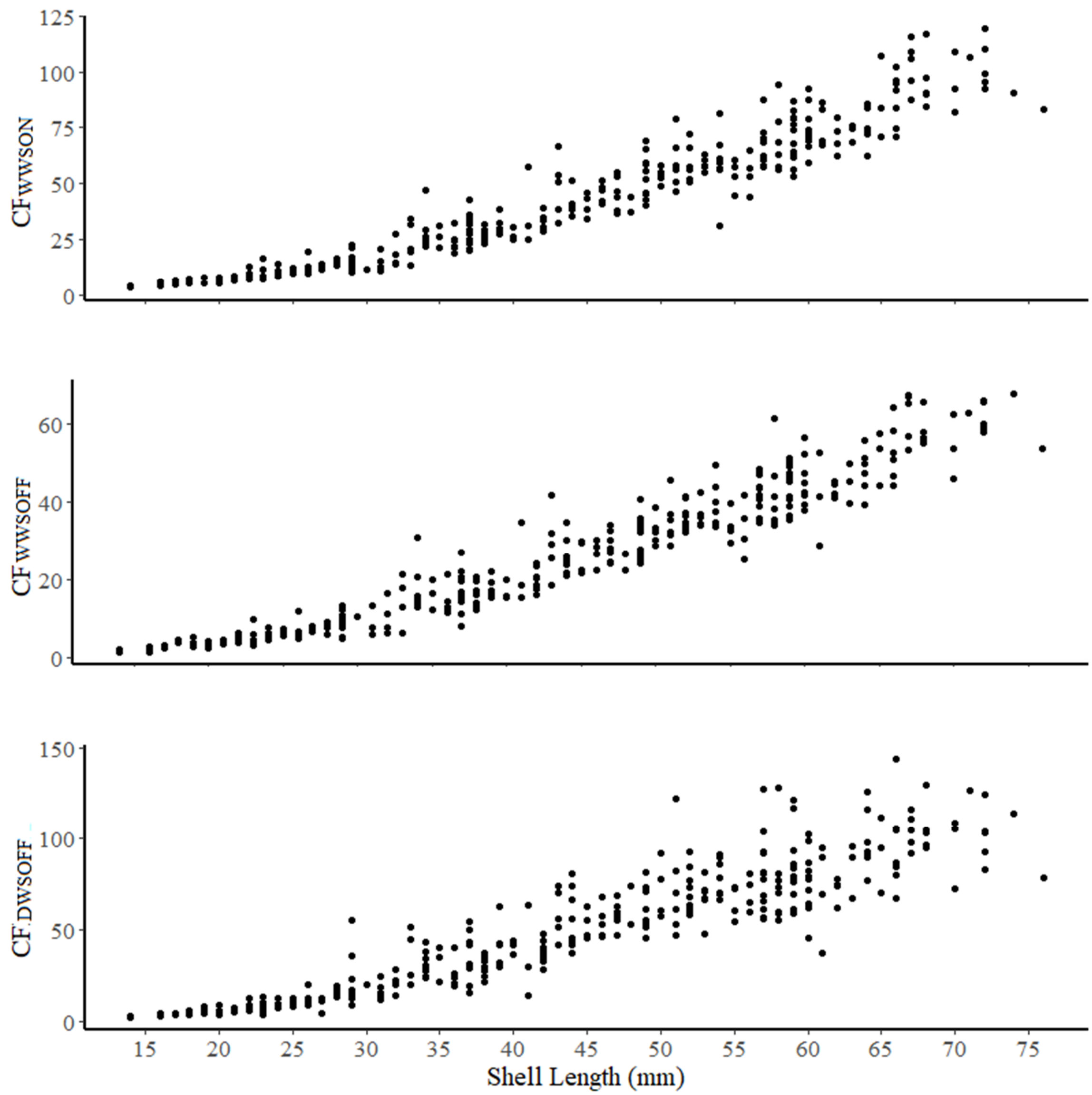

Figure 2.6. Wet weight shell-on condition factor (CF_{WWSON}), the wet weight shell-off condition factor (CF_{WWSOFF}), and the dry weight shell-off condition factor (CF_{DWSOFF}) versus shell length relationships for combined samples of truncated soft-shell clams collected from Frobisher Bay and the north shore of the Hudson Strait.

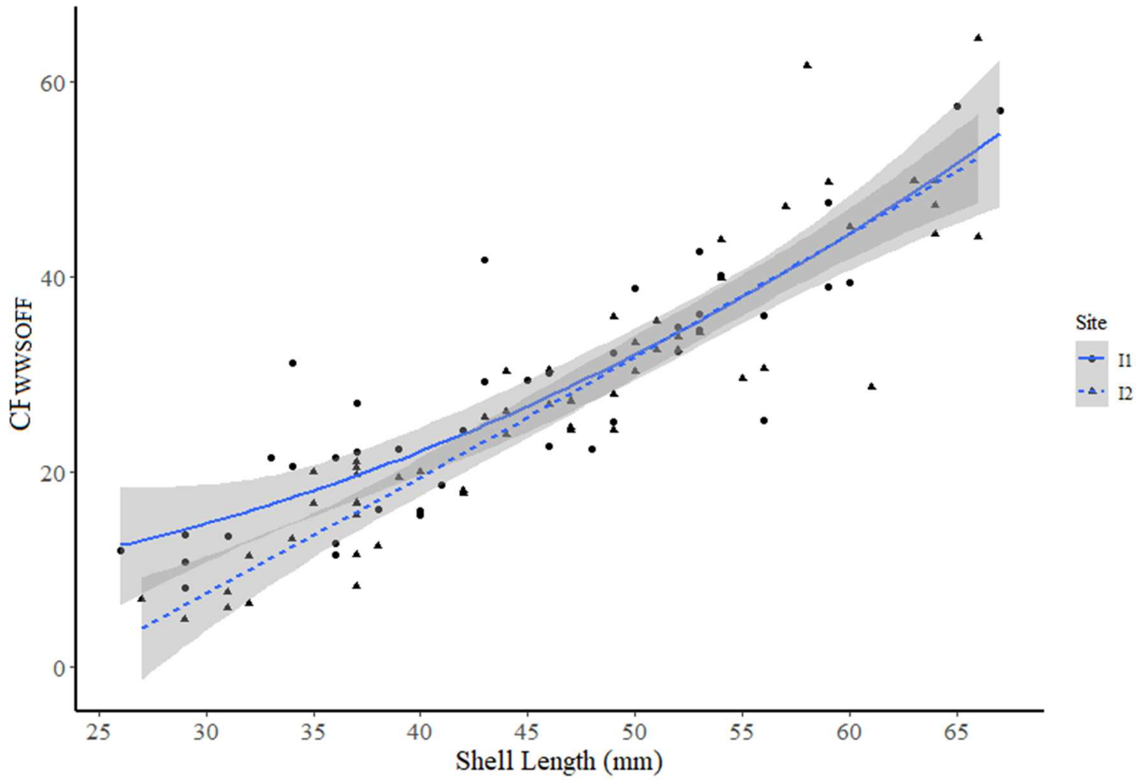

Figure 2.7. Wet weight shell-off condition factor (CF_{WWSOFF}) versus shell length relationship for truncated soft-shell clams from two sites within Frobisher Bay; I1 and I2. The 95% confidence intervals are shown in grey.

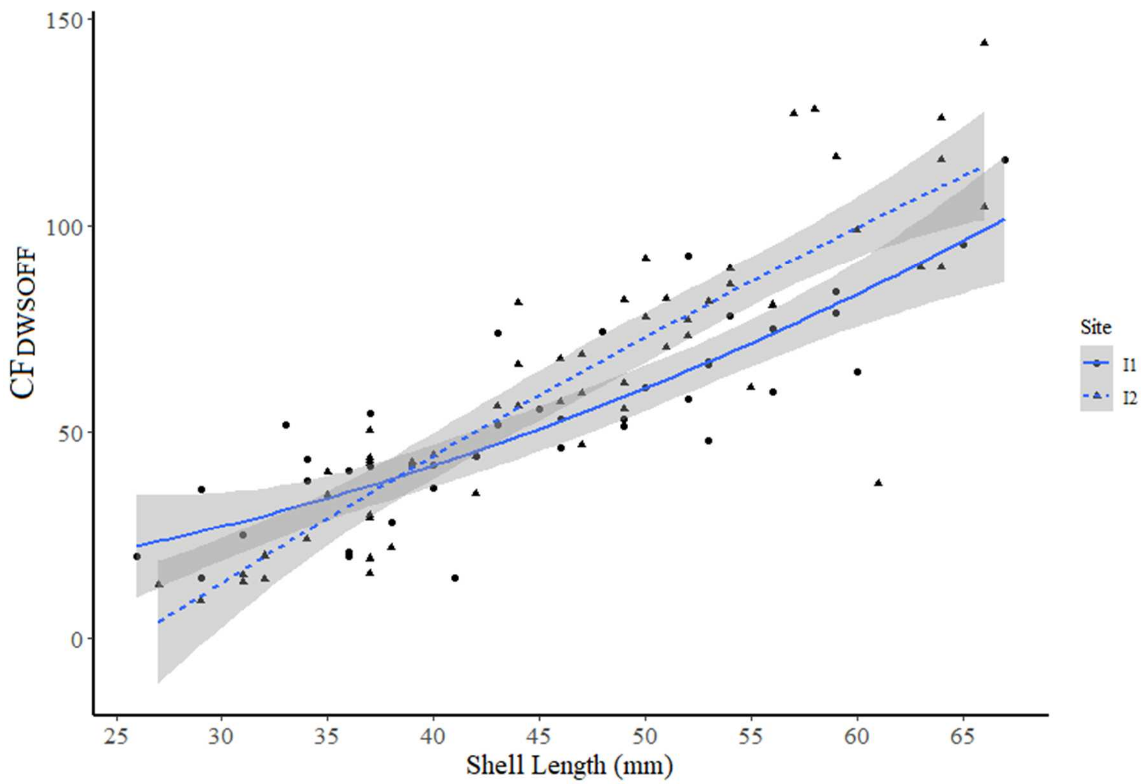

Figure 2.8. Dry weight shell-off condition factor (CF_{DWSOFF}) versus shell length relationship for truncated soft-shell clams from two sites within Frobisher Bay; I1 and I2. The 95% confidence intervals are shown in grey.

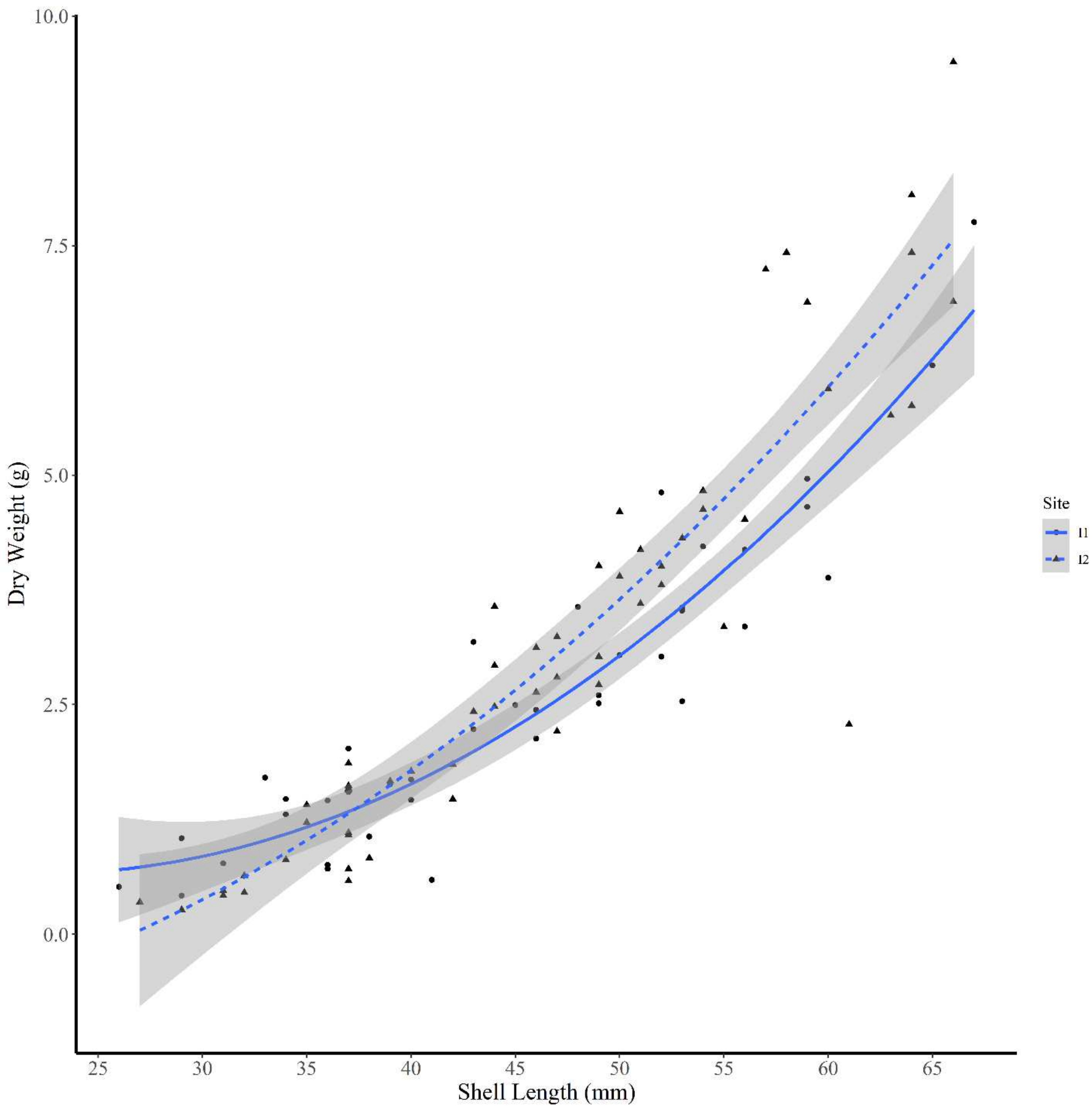

Figure 2.9. Dry weight versus shell length relationship for truncated soft-shell clams from two sites within Frobisher Bay; sites I1 and I2. The 95% confidence intervals are shown in grey.

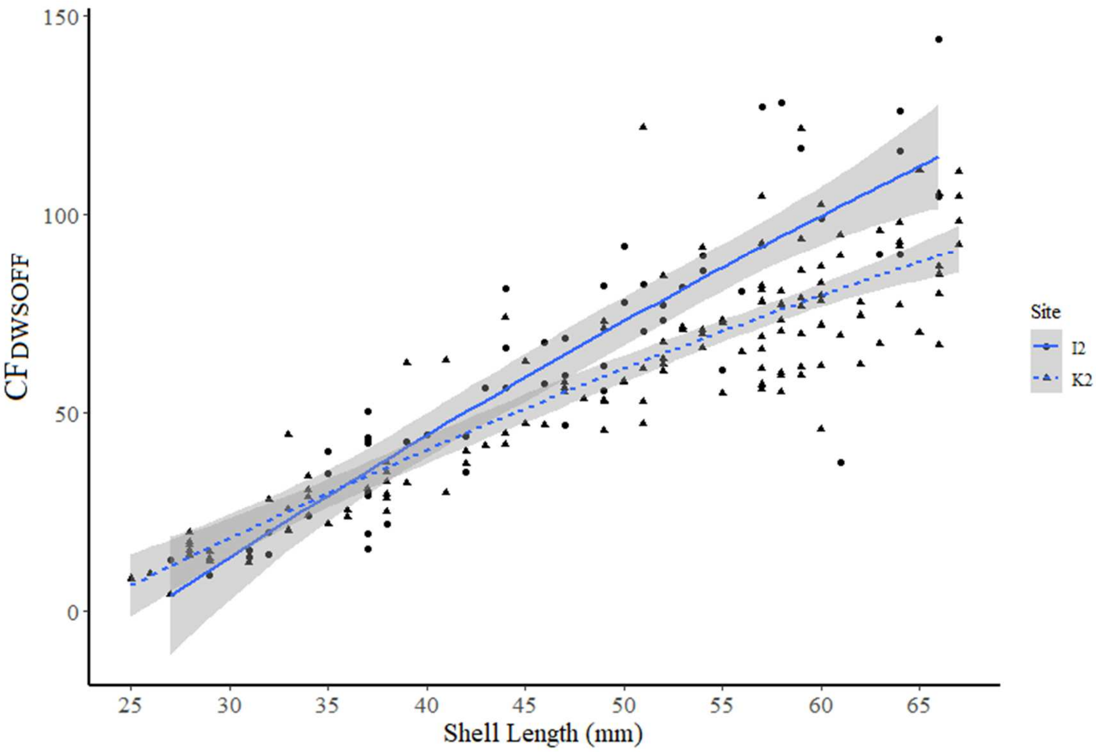

Figure 2.10. Dry weight shell-off condition factor (CF_{DWSOFF}) versus shell length relationships for truncated soft-shell clams from two sites: one within Frobisher Bay (I2), and one within the Hudson Strait (K2). The 95% confidence intervals are shown in grey.

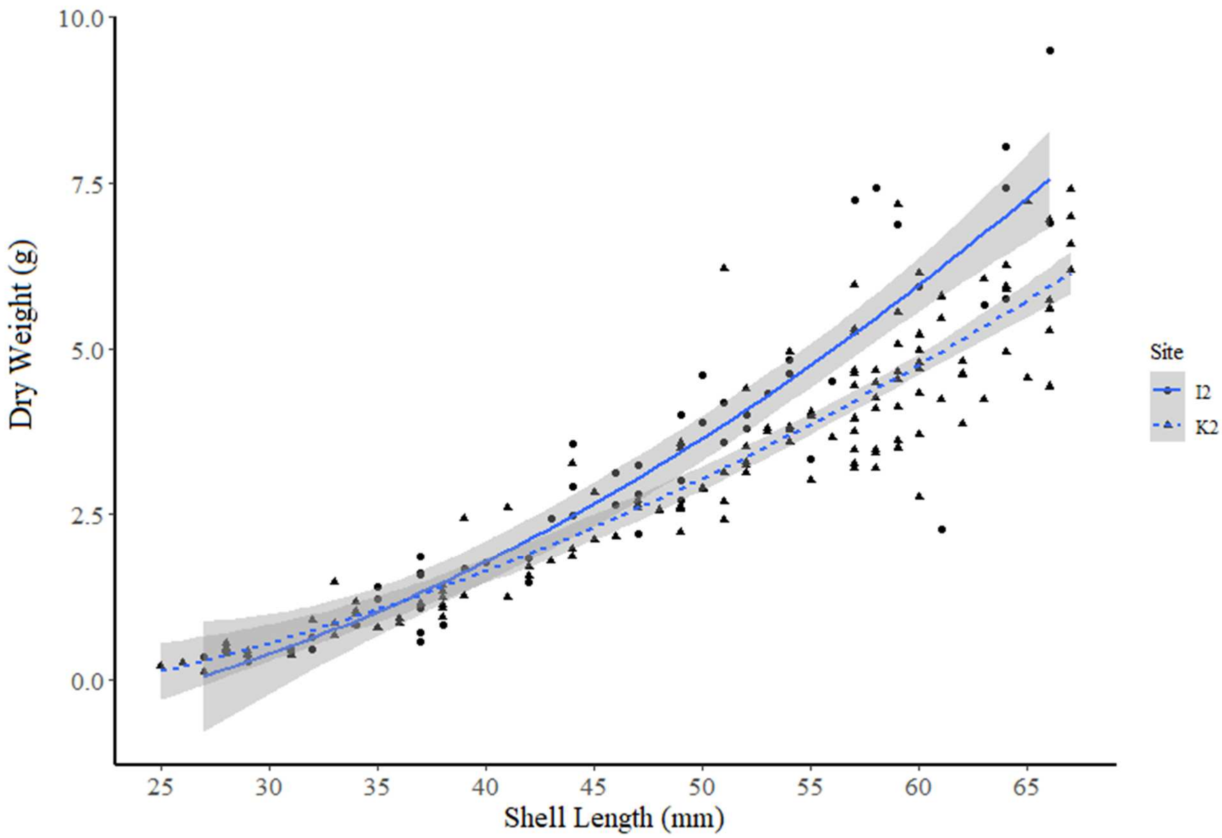

Figure 2.11. Dry weight versus shell length relationships for truncated soft-shell clams from two sites: one within Frobisher Bay (I2), and one within the Hudson Strait (K2). 95% confidence intervals are shown in grey.

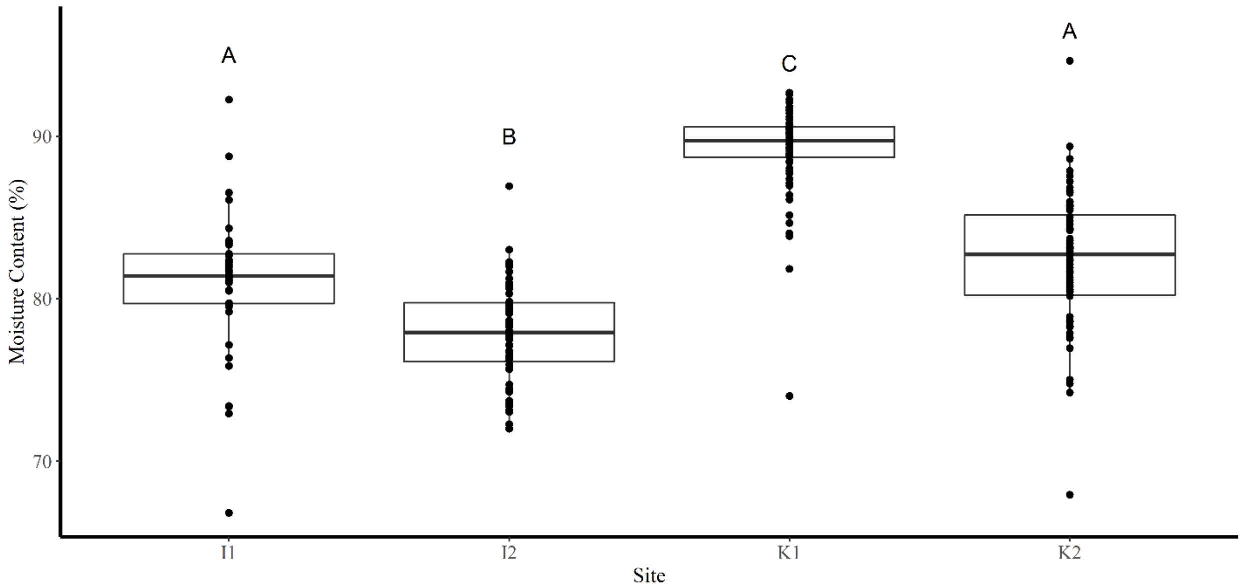

Figure 2.12. Boxplots of the percent moisture content of the body of truncated soft-shell clams collected from two sites near Iqaluit (I1 and I2) and two sites near Kimmirut (K1and K2). There were 102 samples above the size of 47mm removed from site K2 to restrain analyses to populations that exhibited similar size ranges to avoid length-biased results. Homogenous subsets are shown (A, B, and C). Horizontal lines within the boxes represent the median percent moisture content. Lower and upper edge of the boxes show the first and third quartiles, respectively. Lower and upper whiskers represent moisture content values outside of the interquartile range.

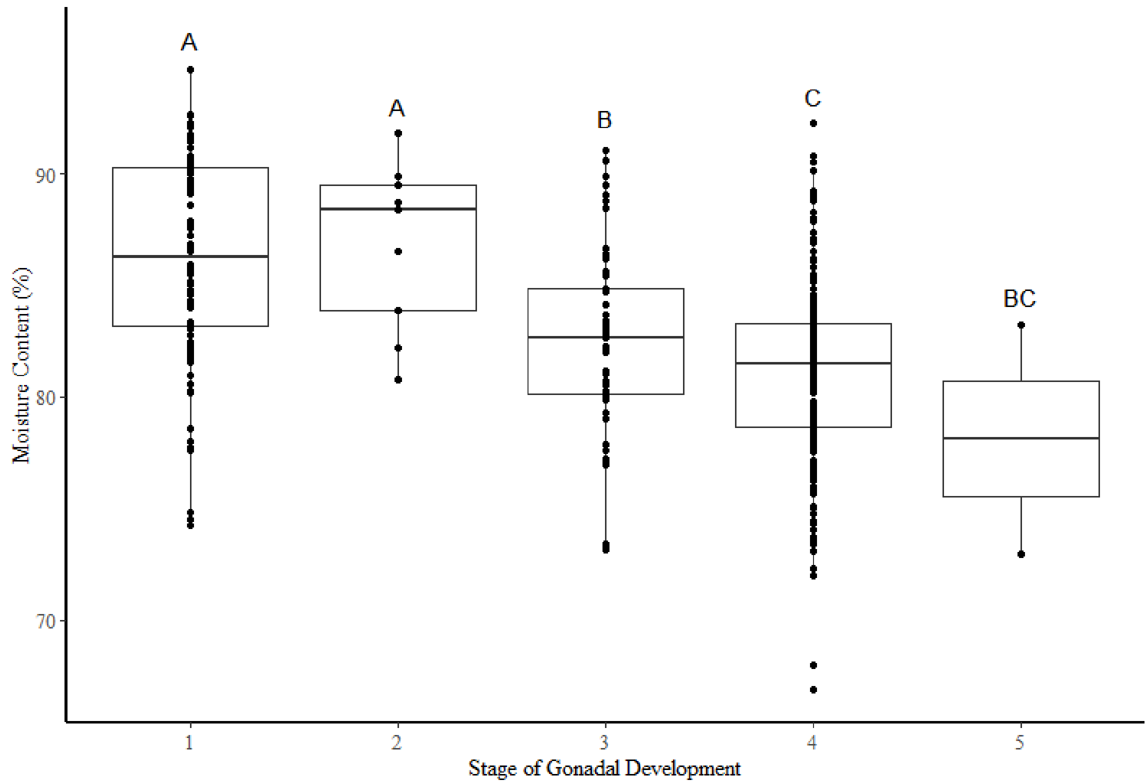

Figure 2.13. Boxplots of the percent moisture content of the body of truncated soft-shell clams at different stages of gonadal development: 1) undifferentiated, 2) indifferent, 3) developing, 4) ripe, and 5) spawning. Homogenous subsets are shown (A, B, and C). Horizontal lines within the boxes represent the median percent moisture content. Lower and upper edge of the boxes show the first and third quartiles, respectively. Lower and upper whiskers represent moisture content values outside of the interquartile range.

Chapter 3. Smile! You're on "clam-did" camera: assessing the effectiveness of drop-camera to measure truncated soft-shell clam (*Mya truncata*) density within the intertidal zone.

3.1 Abstract

Underwater video cameras are often used to assess the density of marine bivalves, including the truncated soft-shell clam (*Mya truncata*). There is demand for the design of easy to use and effective underwater video set-ups that can expedite field work and accurately assess species density. Increasing recreational fishing pressure and potential commercial fishery development creates a need to develop an accurate method to estimate *M. truncata* density near southern Baffin Island to monitor how increasing harvesting pressure may affect clam density. This study implemented a drop-camera set-up using the frame of a snow crab trap, a GoPro camera, lasers and a weight strung on a monofilament line for scale to assess *M. truncata* density within the intertidal zone at sites close to the communities of Iqaluit (Frobisher Bay) and Kimmirut (Hudson Strait), Nunavut. The drop-camera density estimates were then compared with those obtained by manual excavations which showed that drop-camera deployments estimated significantly fewer clams than excavation estimates across all sites. This difference was attributed to the siphons of smaller clams not appearing in the video, high tidal amplitude at the study sites and subsequently retraction of siphons during the tidal cycle, and sediment displacement covering siphons.

3.2 Introduction

The use of video cameras and photography to assess the density, abundance, and composition of underwater fauna has dramatically increased in recent years, with many studies incorporating the use of underwater video, still-images, time-lapse photography, camera tows, and aerial drone surveys into their methods (reviewed by Mallet and Pelletier 2014). Specific to fisheries science, cameras are often used for benthic studies. For example: evaluating the effectiveness of benthic fish traps (e.g. Meintzer et al. 2017), predator-prey interactions of harvested species (e.g. Mills et al. 2005), and abundance estimates of fish (e.g. Stoner et al. 2008). Cameras also have their place when studying static animals such as bivalves. McDonald et al. (2015) have implemented cameras to study clam abundance, Stokesbury et al. (2004) developed the SMAST camera system, which is used to assess scallop (*Placopecten magellanicus*) abundance on George's Bank, and Taylor et al. (2008) developed the HabCam to also assess scallop abundance.

With a rapidly growing population (StatsCan 2019), the communities of Iqaluit and Kimmirut, located in the southern region of Baffin Island, Nunavut (Figure 3.1), are expected to increase recreational harvesting pressure on intertidal truncated soft-shell clams (*Mya truncata*). This increase in fishing pressure, as well as recreational fisheries facing potential commercial development (Government of Nunavut 2005), creates a need to estimate the density of *M. truncata* of southern Baffin Island to monitor how increasing harvest pressure may affect clam density. In the past, bivalve density has been estimated using excavation sampling (e.g. Defeo 1996; Seitz et al. 2001; Azouzi et al. 2002) or the use of SCUBA divers (e.g. Othman et al. 2010; Seitz et al. 2001; Neo and Todd 2012).

These methods can be labour intensive, so the use of underwater video to assess *M. truncata* density can greatly expedite field work and increase the ability to estimate density in harsh Arctic environments.

Siferd (2001) used still photographs of an underwater camera mounted on a frame to estimate the abundance of *M. truncata* near Sachs Harbour, Northwest Territories. Siferd (2005) then used the same set-up to provide density estimates of *M. truncata* within the subtidal zone near the community of Qikitarjuaq, eastern Baffin Island, along transects of clam beds. Despite this first assessment of the density of Baffin Island clams, a density estimate needs to be performed specifically in the coastal waters of Iqaluit and Kimmirut, and there is always room for development of different methods that are cost efficient, and easy to implement.

This study utilized a drop-camera set-up developed at the Marine Institute in St. John's, NL, to assess clam densities within the intertidal zone at popular clam-digging beaches near the communities of Iqaluit and Kimmirut, Nunavut. Density estimates were performed in the intertidal zone because the accuracy of the drop-camera could be compared to manual excavations with hand-held trowels at low tide, as the accuracy of video to assess *M. truncata* density must be known before using video density estimates to inform fisheries management decisions. The objective of this study is to provide a base estimate of truncated soft-shell clam densities near the communities of Iqaluit and Kimmirut that can be carried out locally and compared from year to year to determine the effect of harvesting on clam density and factors related to density, such as recruitment (reviewed by Rose et al. 2001). This study discusses the pros and cons of using underwater cameras to estimate clam density within the intertidal zone by evaluating their effectiveness in comparison to manual excavations. In addition, the sediment type at each site of camera deployment was classified.

3.3 Materials and Methods

3.3.1 Study sites

This study was carried out at two sites within Frobisher Bay, near the community of Iqaluit from July 31 to August 7, 2019, and two sites in the Hudson Strait, near Kimmirut from August 31 to September 2, 2019. These sample dates coincided with the new moon phase when maximum tidal amplitudes of 10.7 m and 11.7 m occurred within Iqaluit and Kimmirut coastal waters, respectively. Within Frobisher Bay, one site (Tundra Ridge) was accessible by road near Iqaluit and the other site (American Islands) was accessible only by boat (Figure 3.2). Near Kimmirut, the two sites (North Bay and Itivirk Bay) were only accessible by boat (Figure 3.3). We chose these sites through consultation with local Hunters and Trappers Associations. It is noteworthy, that few people within the community of Iqaluit harvest clams from the region of the Tundra Ridge site chosen for this study because of its proximity to the community and subsequently risk of contamination from sewage outfall. This led to the hypothesis that clam densities in Frobisher Bay would be highest at this site compared to American Islands, which is harvested regularly by the community.

Although each site was subject to high tidal amplitude, local Inuit explained that clams only occupy the lower intertidal zone because ice scour from land-fast ice in the winter can uproot and kill clams. Therefore, communities harvest clams at new moon tides where tidal amplitude is at a maximum to be able to reach clams at the border of the intertidal and subtidal zone. As such, the drop-camera deployments and manual excavations were performed in the lower intertidal zone.

3.3.2 Camera frame and mounted accessories

The frame from a conical Japanese-style snow crab trap with a bottom diameter of 1.2m used in Newfoundland and two parallel aluminum bars mounted on the top of the frame were used to provide a mount for a GoPro Hero 6 camera in a water-proof housing and two SCUBA diving flashlights to illuminate the seafloor (Figure 3.4). Two lasers (Laser Tools Co., Inc. Little Rock, AR) spaced 75 mm apart were also mounted on one of the aluminum bars, or a 3.5 cm diameter lead weight strung on monofilament line along the bottom of the trap was used for scaling purposes when the lasers were not available (Figure 3.4). When on the seafloor, the area of seafloor observable by the drop-camera system was 0.929 m^2 and the camera was suspended 0.44m above the seafloor (Figure 3.5).

The conical frame protects the camera and lighting, while ensuring the camera remains stable on the seabed. The frame and camera attachments were lightweight, and easy to deploy and haul from small community vessels. The video was self-contained with the option to provide live feedback to the surface if connected to a smartphone, but a lack of cellphone reception at study sites deemed this feature unusable. Through experimenting with the drop-camera set up, it was found that the set up could also be used to drift over the seabed along transects by holding the frame 30-60cm above the seabed, although this method was not used in this study.

3.3.3 Methods of Drop-Camera Deployment

Deployment of the frame to observe siphons of clams works best when the seafloor is visible, or bottom type is known. If the camera is deployed on a substrate other than gravel, sand, or mud, the risk of the frame being slanted or camera covered by seaweed exists, hindering the ability to scale the video taken or see clam siphons. In the current study, deployments that met these conditions were not used for density estimates. The drop-camera system was deployed at a variety of depths in the lower region of the intertidal zone at each site (i.e., extreme low tide region), and the GPS coordinates of each drop were recorded. Deployments were carried out from a 7.9m aluminum boat and 4.3m inflatable boat. During a drop, the camera frame was on the seafloor at a specific drop-site for 45-60 seconds. Because water depth at a deployment site could only be assessed from the aluminum boat, the variable depth was not recorded for this study.

3.3.4 Counting Clams Using Drop-Camera and Manual Excavation

As the drop-camera frame descended through the water column, siphons of clams on the seafloor became visible. Siphons of clams would often retract when the camera frame struck the seafloor making the best method to count the number of siphons to be observing for retracting movement within the first few seconds before the frame landed on the seafloor. Throughout the remainder of a deployment, it was not uncommon for retracted siphons to appear again or for new siphons to emerge from existing holes. Therefore, it was important to observe the video throughout the entire deployment to reduce the risk of underestimating the number of clams within the field of view. Video footage was taken in 4K quality, and reviewed in Windows Media Player, with ImageJ available to provide measurements if needed.

To access as much of the beach area as possible and maximize overlap with the GPS-recorded drop-camera deployment sites, manual excavations were carried out on dates with the highest tidal amplitude (i.e., new moon tide). Specific excavation sites were randomly selected by tossing a $0.062m^2$ bucket lid on the beach and excavating where the lid landed to a depth of 0.3m. As with the drop-camera frame, if the bucket lid landed on a rocky area, no excavation was performed.

The number of clams counted by both the drop-camera and excavation methods were standardized to a density estimate of the number of clams per 1 $metre^2$. The shell length (mm) of clams that were collected from approximately 50% of the excavations at the North Bay and Itivirk Bay sites were recorded.

3.3.5 Sediment Classification

Three 125 ml samples of sediment were collected from widely spaced locations where clams were excavated at each of the four study sites (i.e., clams were recovered from the sediment sample site). In the laboratory, each sample was sieved using a 4000 um, 2000 um, and 500 um sieve, and the portion of sediment retained in each sieve, as well as the finer sediment collected in the pan after the 500 um sieve, were dried to a constant weight at 50ºC and weighed (±0.01 g). Sediment was classified by size using the Unified Soil Classification System (ASTM 2010), where all sediment retained in the 4000 um sieve was deemed fine gravel, sediment retained in the 2000 um sieve was deemed coarse sand, sediment retained in the 500 um sieve was deemed medium sand, and all sediment that remained in the pan was deemed fine sand/silt/clay. The percent composition of each sediment class to the overall weight of the sediment sample was calculated, and the average of these values taken to represent each site.

3.3.6 Statistical Analyses

The relationship between the number of clams counted and method of count by site was modelled by fitting a generalized linear model (GLM) with a negative binomial distribution and log link function using the MASS package in R (Ripley et al. 2019) using the following equation:

$$\text{Equation 1:} \qquad \eta_i = \beta_0 + \beta_1\text{Method} + \beta_2\text{Site} + \varepsilon.$$

Here, η_i represents the number of clams counted, β_0 is the intercept, β_1Method is the method of counting clams, either drop-cam or excavation, β_2Site is the study site, and ε is the error term. Model assumptions were validated by testing for patterns in residuals of model covariates.

Differences between each method and site were determined by a type II Wald X^2-test (ANOVA function in the R car package), and if significant ($p<0.05$), a post-hoc general linear hypothesis test was performed using the glht function in the multcomp package for

R. This test makes pair-wise comparisons between factors and among interactions of factors with adjustment of p-values for multiple comparisons, in this case a Tukey adjustment (Hothorn et al. 2020). All statistical analyses were performed in R Studio version 3.5.1 for windows (2018), and the significance level was set to $\alpha=0.05$.

3.4 Results

A total of 58 camera drops and 72 excavations were performed at the study sites in Frobisher Bay and on the north shore of Hudson Strait (Table 3.1). The average number of truncated soft-shell clams counted by manual excavation ranged from 17.1±17.7SE clams/m^2 at Itivirk Bay and up to 64.5±77.9SE clams/m^2 at North Bay (Table 3.2). During the excavations, it was not uncommon to recover truncated soft-shell clams from a dig site where there were no siphon holes or depressions present. Similarly, it was not uncommon to recover more truncated soft-shell clams from a dig site than the number of siphon holes or depressions present. The average number of clams counted by drop-camera ranged from 0.2±0.4 clams/m^2 at American Islands to 5.7±7.8 clams/m^2 at North Bay (Table 3.2).

Overall, the drop-camera method estimated significantly fewer clams than the manual excavation which led to counting 97% fewer clams across all sites ($p<0.001$) (Table 3.3). A Wald X^2-test revealed that method ($X^2=82.30$ df=1, $p<0.001$) and site ($X^2=27.78$, df=3, $p<0.001$) produced significantly different densities of clams. The site with the highest average density estimated by both drop-camera and excavations was North Bay (5.7±7.8SE clams/m^2 and 64.5±77.9SE clams/m^2, respectively). Post-hoc analysis showed that drop-camera deployments and excavations estimated a significantly lower density of truncated soft-shell clams at Itivirk Bay than all other sites (0.4±0.5SE clams/m^2 and 17.1±17.7SE clams/m^2, respectively) (Table 3.3) (Figures 3.6 and 3.7). A map of standardized clam densities of number/m^2 estimated by drop-camera and manual excavation was rendered for each site (Figures 3.8 to 3.11).

A shell-length frequency histogram of clams collected from manual excavations at Itivirk Bay and North Bay was constructed to demonstrate the size range of clams counted by manual excavation (Figure 3.12). The majority of the clams excavated were above the shell-length at 50% attainment of sexual maturity reported in chapter 2 of this thesis (i.e., 31-32 mm).

The average percent composition by dry weight of each sediment class is illustrated in Table 3.4 and Figure 3.13. Overall, the most prominent sediment class at each site was fine sand/silt/clay followed by medium sand. At all sites except Itivirk Bay, the third most prominent sediment class was fine gravel, followed by coarse sand. At Itivirk Bay, this order was reversed (i.e. coarse sand followed by fine gravel).

3.5 Discussion

Drop-camera deployments estimated significantly lower mean clam densities than the manual excavations across all study sites. Qualitative analyses of maps of clam density estimated by drop-camera compared to excavations showed that although there is overlap in high densities observed in certain locations at each site, clam density was higher in excavation samples compared to neighbouring drop-camera observations. Accurately estimating the density of an animal population is key to effective conservation, and in the case of bivalves potentially being commercially harvested, accurate density estimates are essential for determining quotas and harvesting intensity. The quantitative and qualitative results of this study show that within the intertidal zone there are many more clams below the sediment surface that we cannot account for when counting clam siphons using video. In addition, size distributions of clams collected from excavations in North Bay and Itivirk Bay show smaller clams that may not be detected by video.

There were significant differences in the mean density of clams assessed using manual excavations compared to drop-camera estimates across sites within and between communities, where Itivirk Bay showed the significantly lowest mean density estimate by both manual excavations and drop-camera compared to all other sites. Differences in the mean density estimated between sites using either technique could be due to the history of clam harvesting at each site. For example, Tundra Ridge is not usually harvested by Iqaluit community members in recent years due to uncertainty in contamination from local sewage outfall and North Bay is a lesser known clam digging site to Kimmirut community members. These site characteristics may explain why these two sites showed the highest clam densities estimated via excavations and drop-camera. The American Islands and Itivirk Bay are very well-known clam digging areas, which may explain their lower observed densities.

Discrepancies in the density of clams estimated by drop-camera compared to excavations within the intertidal zone may be attributed to retraction of truncated soft-shell clam siphons resulting from tidal induced sediment displacement and subsequently interfering with filter feeding. Tidal induced sediment displacement within the intertidal zone may also fill the depressions made by clam siphons which can account for not all clams being visible and removed during recreational harvests. In the current study, fine sand/silt/clay dominated the sediment types at the study sites and these fine sediments may be expected to be transported due to tidal forces within the intertidal zone. Depressions made by siphons of smaller clams may be more readily filled with sediment and go undetected by both the drop-camera and by harvesters.

Ragnarsson and Thórarinsdóttir (2002) commented that stock assessments of the ocean quahog (*Artica islandica*) by dredge are not accurate unless the efficiency of the dredge is known and subsequently tested whether underwater photography would be a viable candidate to assess quahog density. They noted that the siphons of small bivalves are unlikely to show up in photographs, and retraction of siphons in absence of food and deeper burrowing depths where siphons cannot be seen at the sediment surface also complicate density estimates. This could pertain to the Arctic intertidal zone, as ice scour during the winter months may cause *M. truncata* to burrow deeper in these areas. McDonald et al. (2015) were able to account for retracted or hidden siphons by implementing a "show-factor" which compared known geoduck (*Panopea generosa*) densities in nearby areas with siphon-only counts to accurately estimate density by siphon count. In the future, a similar mechanism could be applied for clam density estimates in Nunavut. This study was restricted to the intertidal zone where low cost manual excavations could be made at extreme low tide. The accuracy of previous drop-camera density estimates of truncated soft-shell clams within the shallow and deep subtidal zone are unknown at this time (i.e., Sifred 2005). Future studies should consider the use of density estimates made by SCUBA divers or dredges to determine accuracy within the subtidal zone and whether a show-factor correction similar to that employed by MacDonald et al. (2015) is warranted.

The average density of *M. truncata* observed at each site by drop-camera ranged from 0.2±0.4 clams/m^2 at American Islands to 5.7±7.8 clams/m^2. These estimates are low in comparison to the density estimates of *M. truncata* near Qikitarjuaq, eastern Baffin Island, made by Siferd (2005). Siferd (2005) used still photographs and estimated a mean density of *M. truncata* up to 108.3 clams/m^2 at one study site. In addition, Siferd (2005) noted that at four of their nine study sites, the maximum density of *M. truncata* was observed at 30m in depth, while others continued to increase to a maximum at 40m. Siferd (2005) took photographs at depths of 9.9-41.2m, while the drop-camera deployments of this study were carried out in the intertidal zone at estimated depths of 1-10m. Therefore, some of Siferd (2005)'s estimates would not have been influenced by tidal flooding of siphon holes, nor experience ice scour that could influence *M. truncata* density. In addition, the intertidal sites of this study have a history of being harvested by communities, while the deeper sites examined by Siferd (2005) had not been harvested by SCUBA divers. These discrepancies in deployment methods may account for differences in density estimates between this study and that of Siferd (2005).

Results from this study show drop-camera is not a reliable method of performing density estimates in the intertidal zone, yet its effectiveness in the subtidal zone is unknown. Future studies could ground-truth the estimates of drop-camera in the subtidal zone using a small clam dredge that can be towed behind community vessels, as is being currently developed by researchers at the Marine Institute of Memorial University of Newfoundland.

These dredges are expected to provide Inuit communities access to clams in the subtidal zone, where Siferd (2005) estimated higher densities of *M. truncata* to exist, as a means of supporting increased demands of recreational fisheries and, where clam densities are sufficient, the potential for commercial fishery development.

Past research has shown that sediment type can greatly affect the fitness and survival of the soft-shell clam *Mya arenaria*, a sister species to *M. truncata*. Overall, the census on which sediment type best supports the survival of soft-shell clams is that finer sediments increase juvenile settlement (St-Onge and Miron 2007), allow increased growth rates (Newell and Hidu 1982), and decrease predation risk by easing the ability to burrow (Thomson and Gannon 2013). The sediment type at each site examined in this study was predominantly fine sand/silt/clay. The sediment type within Frobisher Bay has been further classified as sandy mud, with increasing gravelly sandy-mud with increased proximity to the community of Iqaluit (Deering et al. 2018). In addition, Misiuk et al. (2018) identified the sediment composition of subtidal Qikitarjuaq to be predominantly sand, which may explain the high density of *M. truncata* observed by Siferd (2005). Although this study does not take into consideration the effect of predominant sediment class on truncated soft-shell clam density or the effects of harvesting, these results do show that the presence of fine sand/silt/clay is an important factor influencing truncated soft-shell clam density. Especially in the intertidal zone, fine sediment may be key to allowing bivalves to burrow deep enough to avoid ice scour in the winter. In the future, sediment samples could be collected at transects along the intertidal zone to determine sediment composition and could be combined with aerial drone surveys to determine the percent coverage of finer sediments to help explain clam positioning in the intertidal zone, i.e. clams always being found in the lower intertidal.

Developing and testing the drop-camera set up in the intertidal zone where recreational harvests are taking place and with the assistance of Inuit is the first stage in the development of a monitoring program to determine the effects of recreational harvesting on *M. truncata* density. In addition, drop-camera results in the intertidal zone provide insights to consider for subtidal deployment, and opens the door for further density estimates using tools such as small toothed dredges. Finally, this drop-camera set up provides a unique, inexpensive, and easy-to-use method for benthic observation in coastal Baffin Island.

3.6 References

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3.7 Tables

Table 3.1. Number of drop-camera deployments and excavations carried out at each study site.

Site	Drop-camera	Excavation
Tundra Ridge	20	13
American Islands	19	9
North Bay	11	16
Itivirk Bay	8	34
Total	58	72

Table 3.2. Mean density (number/m^2 ± 1 S.E.) of soft-shell clams by assessment method.

	Assessment Method	
Site	Manual excavation	Drop-camera
Tundra Ridge	50.8 ± 18.8	1.5 ±2.2
American Islands	21.4 ±19.6	0.2 ± 0.4
North Bay	64.5 ± 77.9	5.7 ± 7.8
Itivirk Bay	17.1 ± 17.7	0.4 ± 0.5

Table 3.3. Estimated regression parameters, standard errors, Z-values, and p-values for the negative binomial GLM in eqn (1). Post-hoc analysis of pair-wise comparisons are also shown.

Coefficient	Estimate	Std. error	Z-value	p-value
GLM				
Intercept	2.987	0.072	41.405	<0.001*
Drop-camera	-3.128	0.104	-30.142	<0.001*
Tundra Ridge	0.918	0.081	11.310	<0.001*
Itivirk Bay	-0.151	0.083	-1.935	0.053
North Bay	1.211	0.078	15.537	<0.001*
Comparisons				
Excavation: Tundra Ridge – American Islands	-1.085	0.958	-1.133	0.830
Excavation: Itivirk Bay- Am. Is.	-3.492	1.155	-3.022	0.022*
Excavation: North Bay- Am. Is.	1.116	1.227	0.909	0.928
Excavation: Itivirk Bay- Tundra Ridge	-2.407	0.656	-3.726	0.002*
Excavation: North Bay- Tundra Ridge	2.201	1.172	1.878	0.349
Excavation: North Bay- Itivirk Bay	4.608	1.456	3.166	0.014*
Drop-camera: Tundra Ridge- Am. Is.	0.229	0.611	0.374	0.999
Drop-camera: Itivirk Bay- Am. Is.	-4.677	0.741	-6.311	<0.001*
Drop-camera: North Bay- Am. Is.	1.336	0.493	2.712	0.055
Drop-camera: Itivirk Bay- Tundra Ridge	-4.906	0.875	-5.606	<0.001*
Drop-camera: North Bay- Tundra Ridge	1.107	0.678	1.634	0.505
Drop-camera: North Bay- Itivirk Bay	6.014	0.797	7.547	<0.001*

*significantly different at p<0.05.

Table 3.4. Mean (± 1 S.E.) percent composition by dry weight of sediment class at four *M. truncata* study sites on the southern Baffin Island, Nunavut.

	Percent composition by dry weight			
Site	Fine gravel	Coarse sand	Medium sand	Fine sand/silt/clay
Tundra Ridge	8.9±0.9	2.3±0.2	14.9±3.9	73.9±4.6
American Islands	14.4±8.1	3.5±1.3	25.7±10.9	56.4±15.3
North Bay	6.2±3.0	5.5±1.5	42.4±6.8	45.8±9.9
Itivirk Bay	2.4±1.1	2.5±0.4	30.5±5.7	64.7±4.9

3.8 Figures

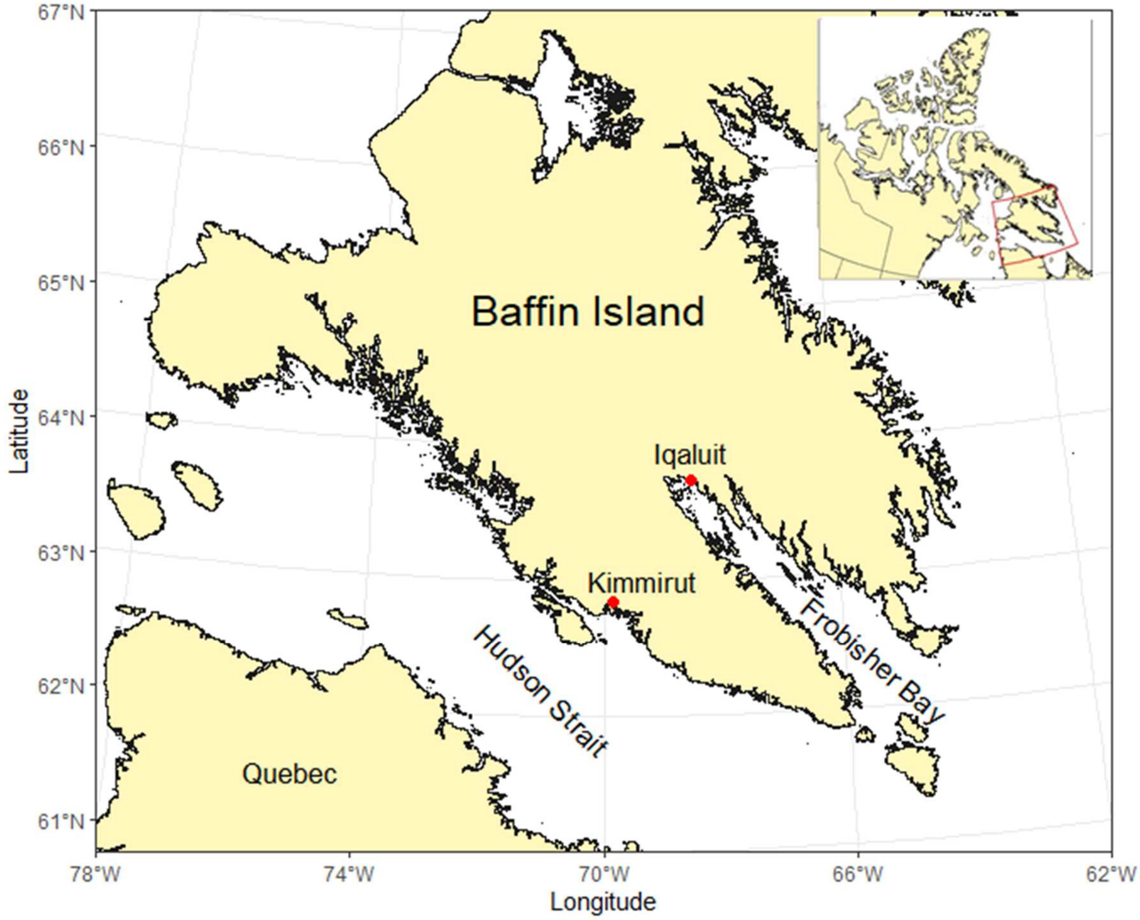

Figure 3.1. Map of southern Baffin Island showing the location of two study communities (i.e., Iqaluit and Kimmirut) where drop-camera deployments and manual excavations for truncated soft-shell clams were carried out. The red rectangle shown on the inset illustrates the location of map relative to the rest of the territory of Nunavut. Map data from GADM database of Global Administrative Areas (http://gadm.org/).

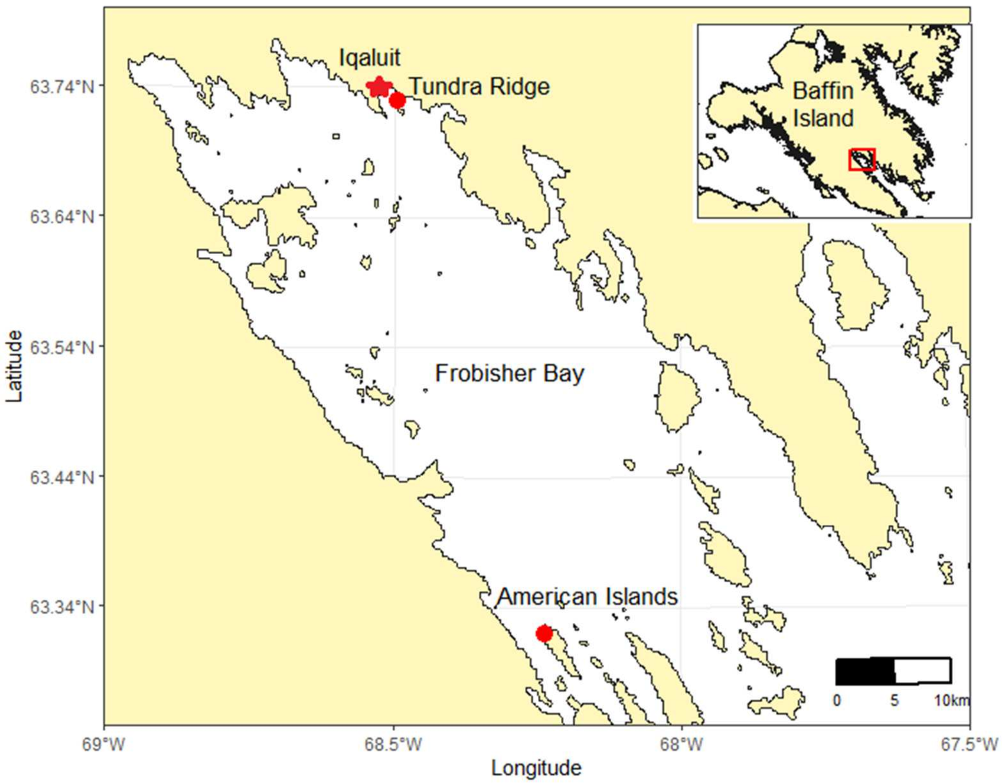

Figure 3.2. Map of Frobisher Bay showing the location of two study sites where drop-camera deployments and manual excavations of truncated soft-shell clams were carried out. The red square on inset shows location of map relative to the rest of southern Baffin Island.

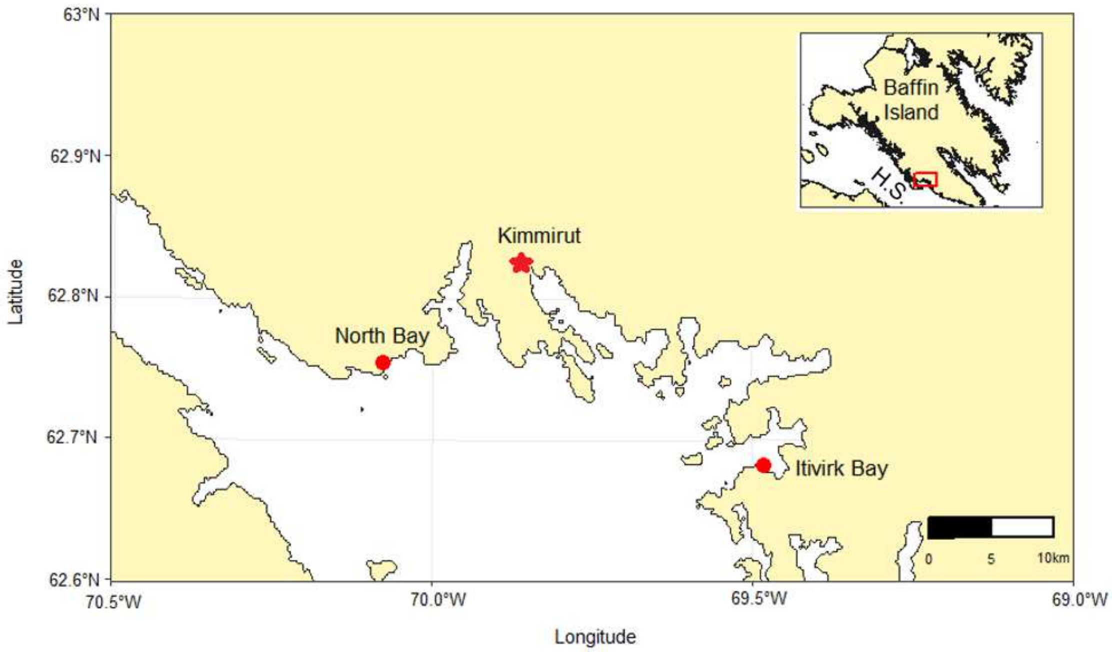

Figure 3.3. Map of north shore of Hudson Strait (H.S. in insert map) showing the where drop-camera deployments and manual excavations of truncated soft-shell clams were carried out. The red square on inset shows location of map relative to the rest of southern Baffin Island.

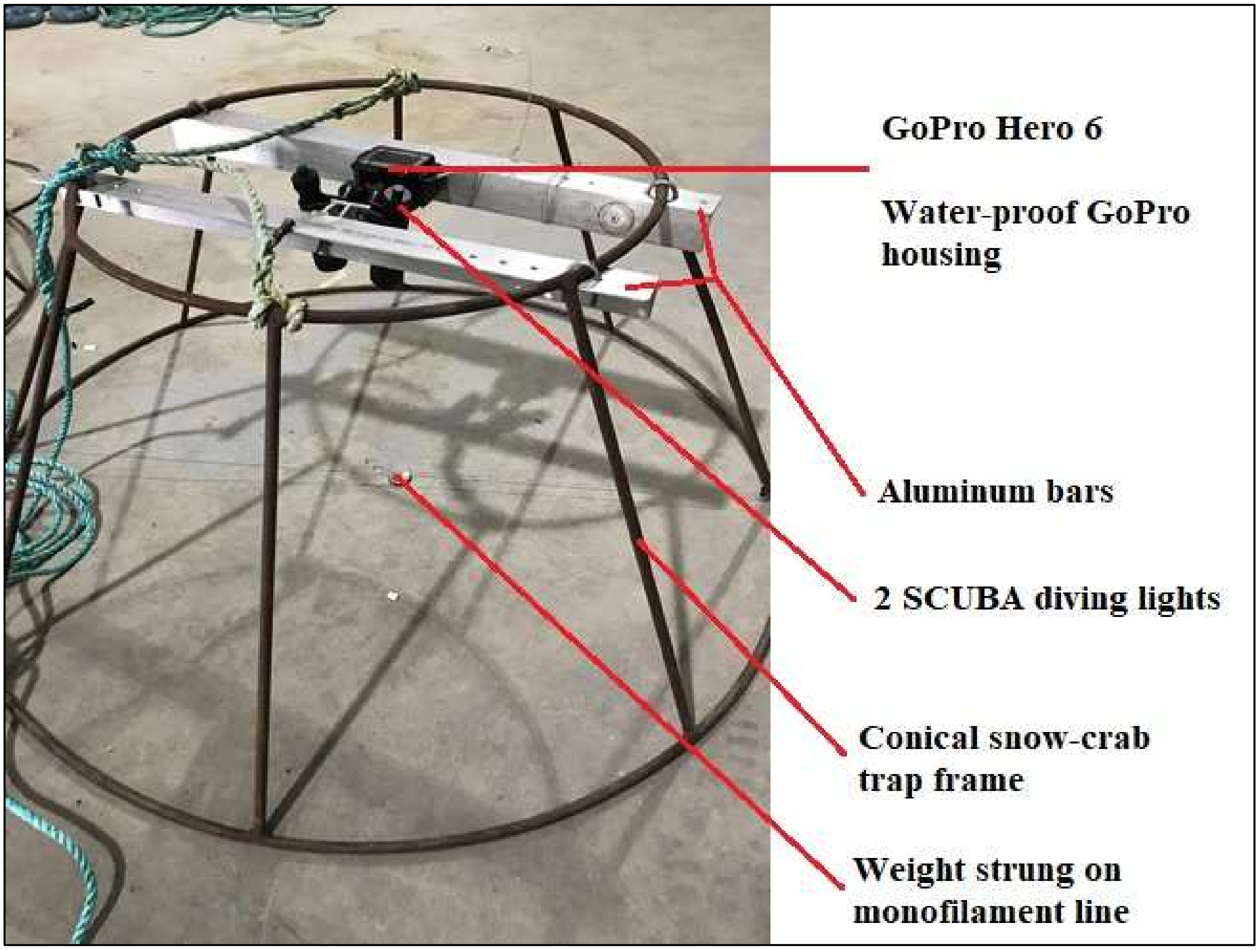

Figure 3.4. Photograph of the drop-camera system used during the current study. The weight strung on a monofilament line was used when lasers were not available (visible in Figure 3.5).

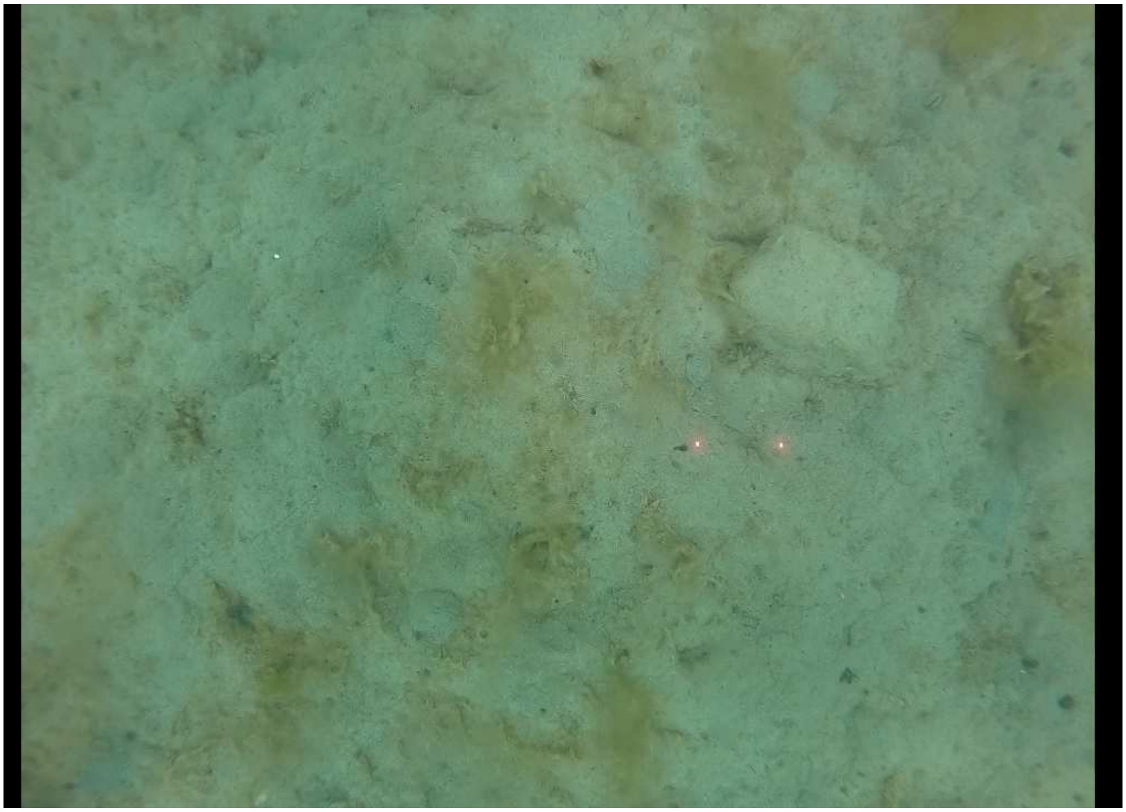

Figure 3.5. Photograph of seafloor taken by the drop-camera system. Red dots are lasers spaced at 75 mm and used for scaling images in video. In some deployments when lasers were not available, the lasers were replaced by a 35 mm diameter lead weight strung on a monofilament line (see Figure 3.4).

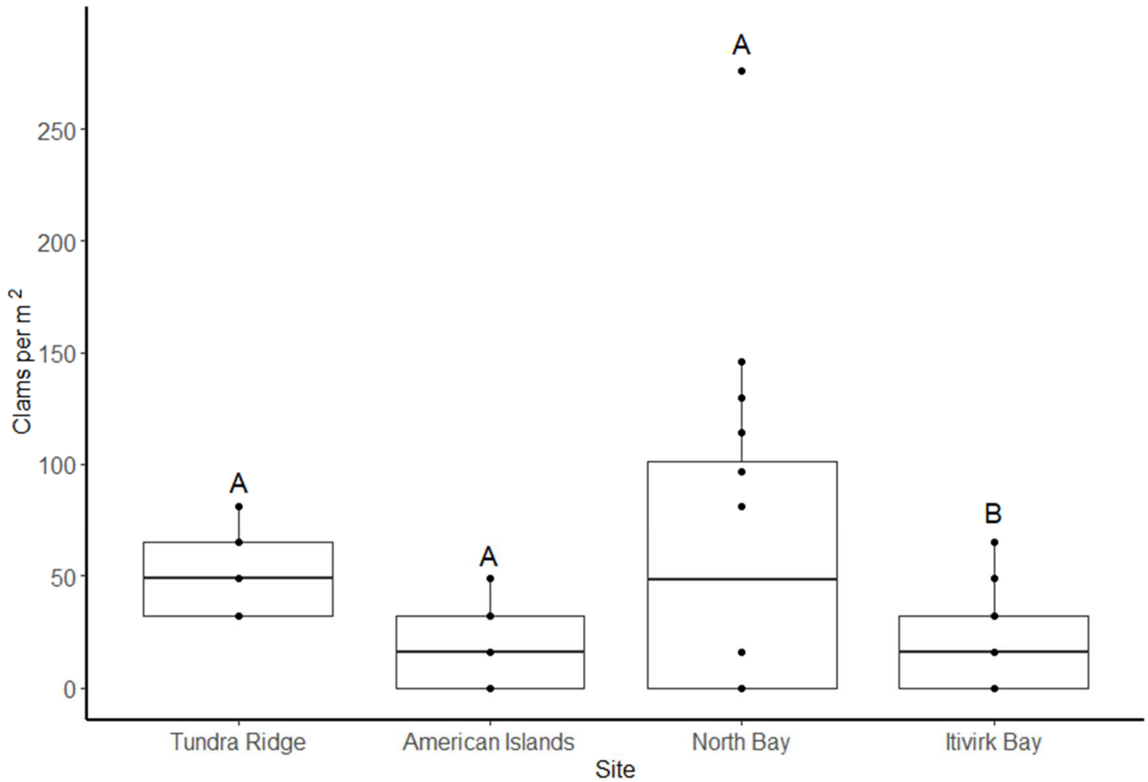

Figure 3.6. Box plots summarizing truncated soft-shell clam counts (per m^2) using manual excavations at sites across southern Baffin Island. Homogenous subsets are shown (A-B). Horizontal lines within the boxes represent the median density. Lower and upper edge of the boxes show the first and third quartiles, respectively. Lower and upper whiskers represent density estimates outside of the interquartile range.

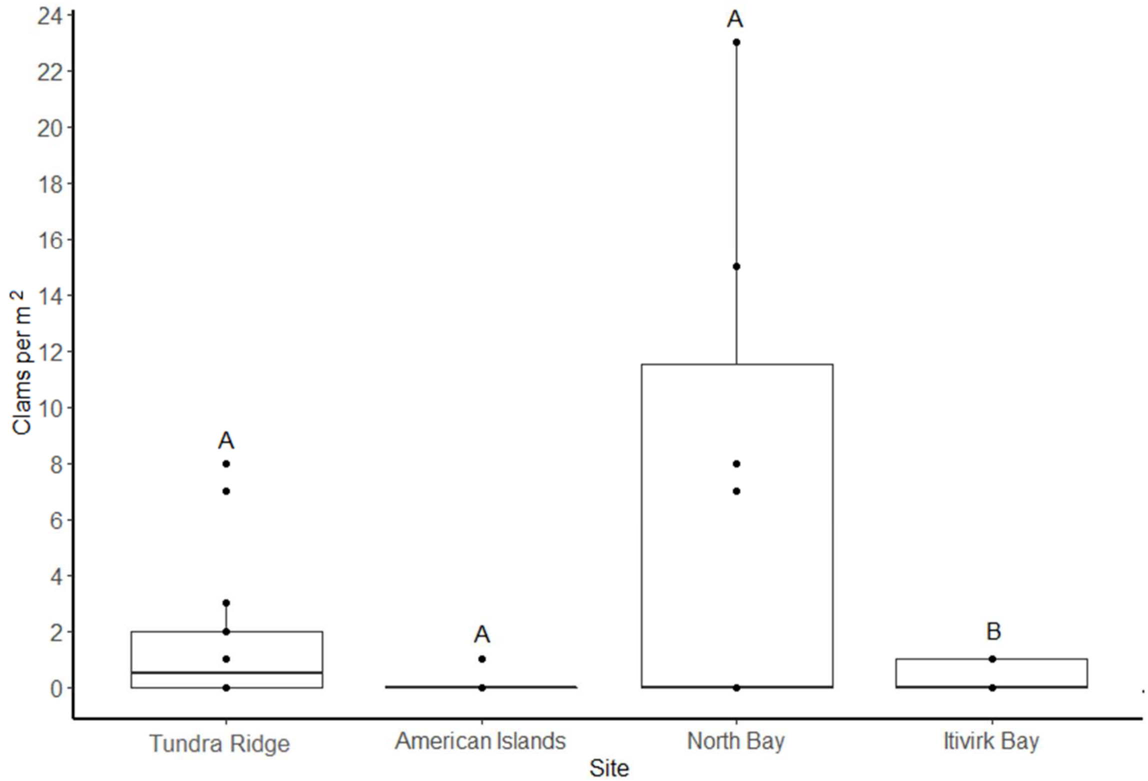

Figure 3.7. Box plots summarizing truncated soft-shell clam siphon counts (per m^2) using drop-camera system at sites on southern Baffin Island. Homogenous subsets are also shown (i.e., A and B). Horizontal lines within the boxes represent the median density. Lower and upper edge of the boxes show the first and third quartiles, respectively. Lower and upper whiskers represent density estimates outside of the interquartile range.

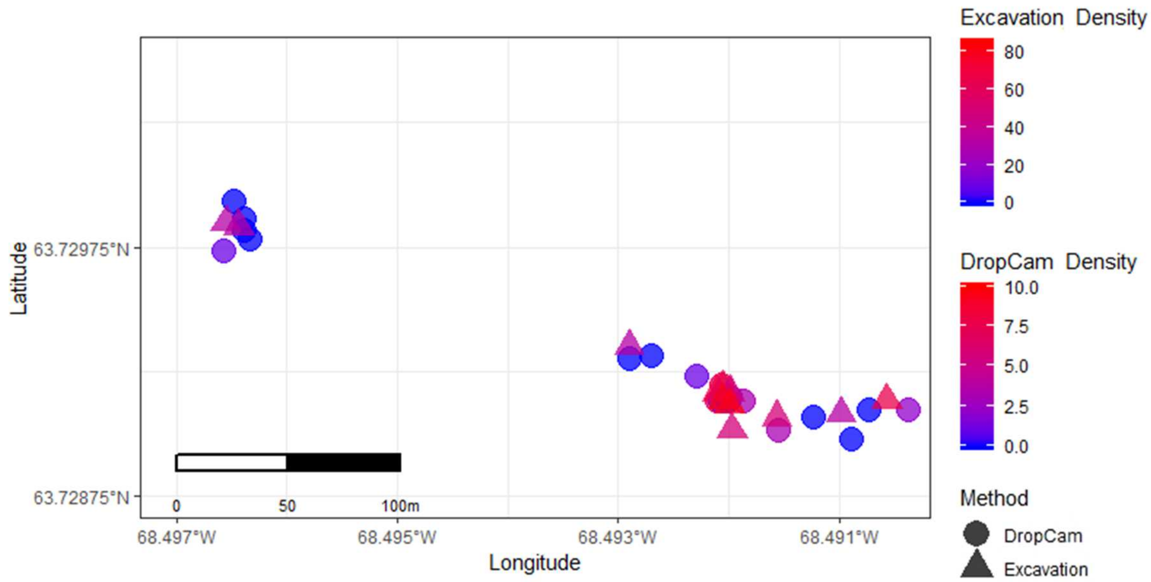

Figure 3.8. Map of Tundra Ridge site, Frobisher Bay, depicting intertidal sample locations and truncated soft-shell clam densities (number/m^2) by assessment method (i.e. drop camera and excavation).

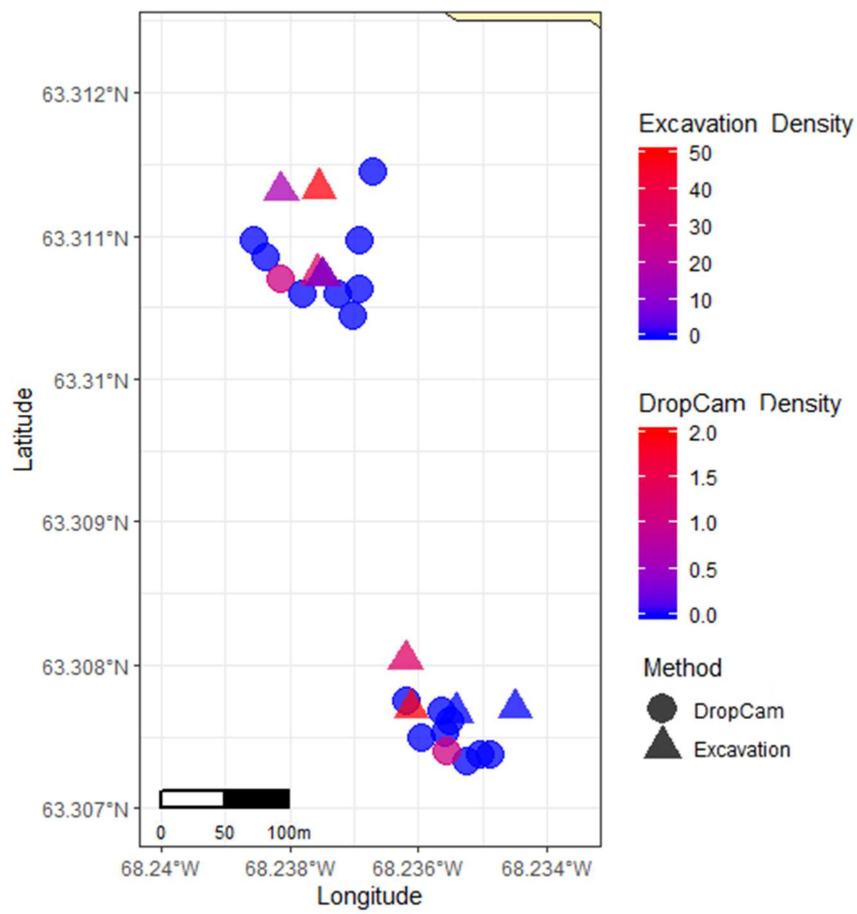

Figure 3.9. Map of American Islands site, Frobisher Bay, depicting intertidal sample location of truncated soft-shell clams and density (number/m^2) by assessment method (i.e. drop camera and excavation). Yellow area in upper right corner represents land at high tide based on the GADM database.

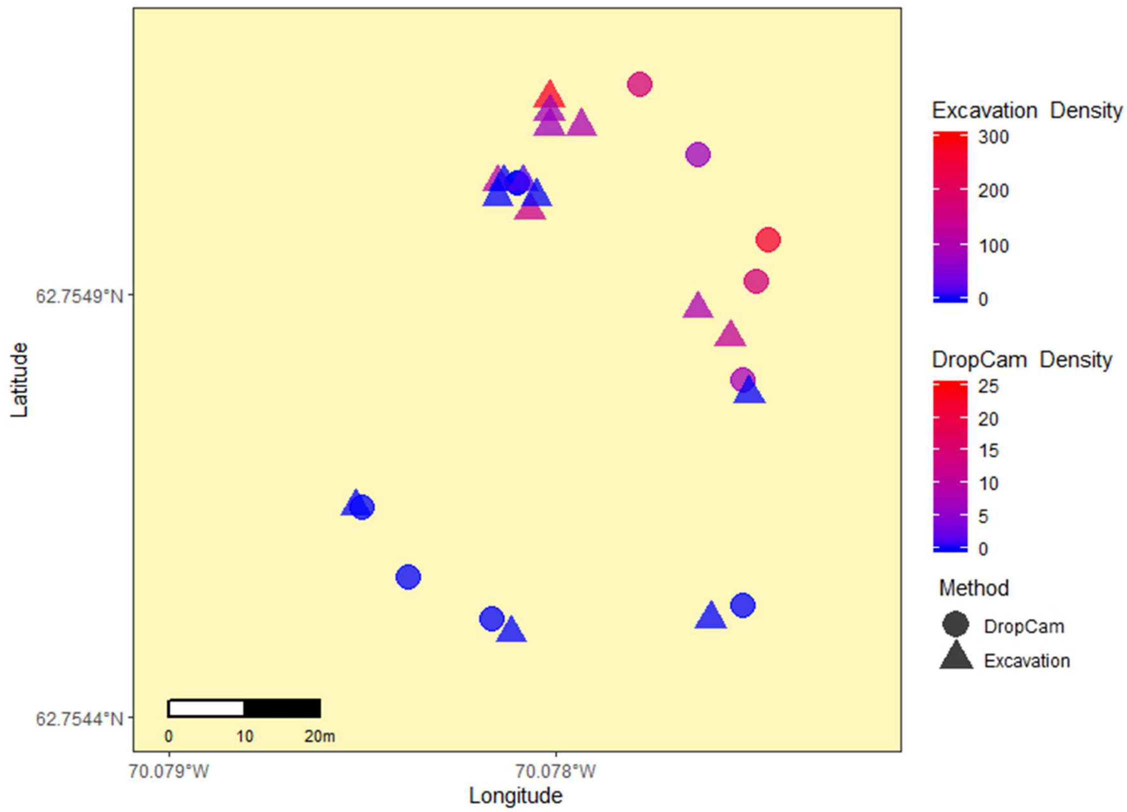

Figure 3.10. Map of North Bay site, Hudson Strait, depicting intertidal sample locations and truncated soft-shell clam densities (number/m^2) by assessment method (i.e. drop camera and excavation). Yellow area represents land at high tide based on the GADM database.

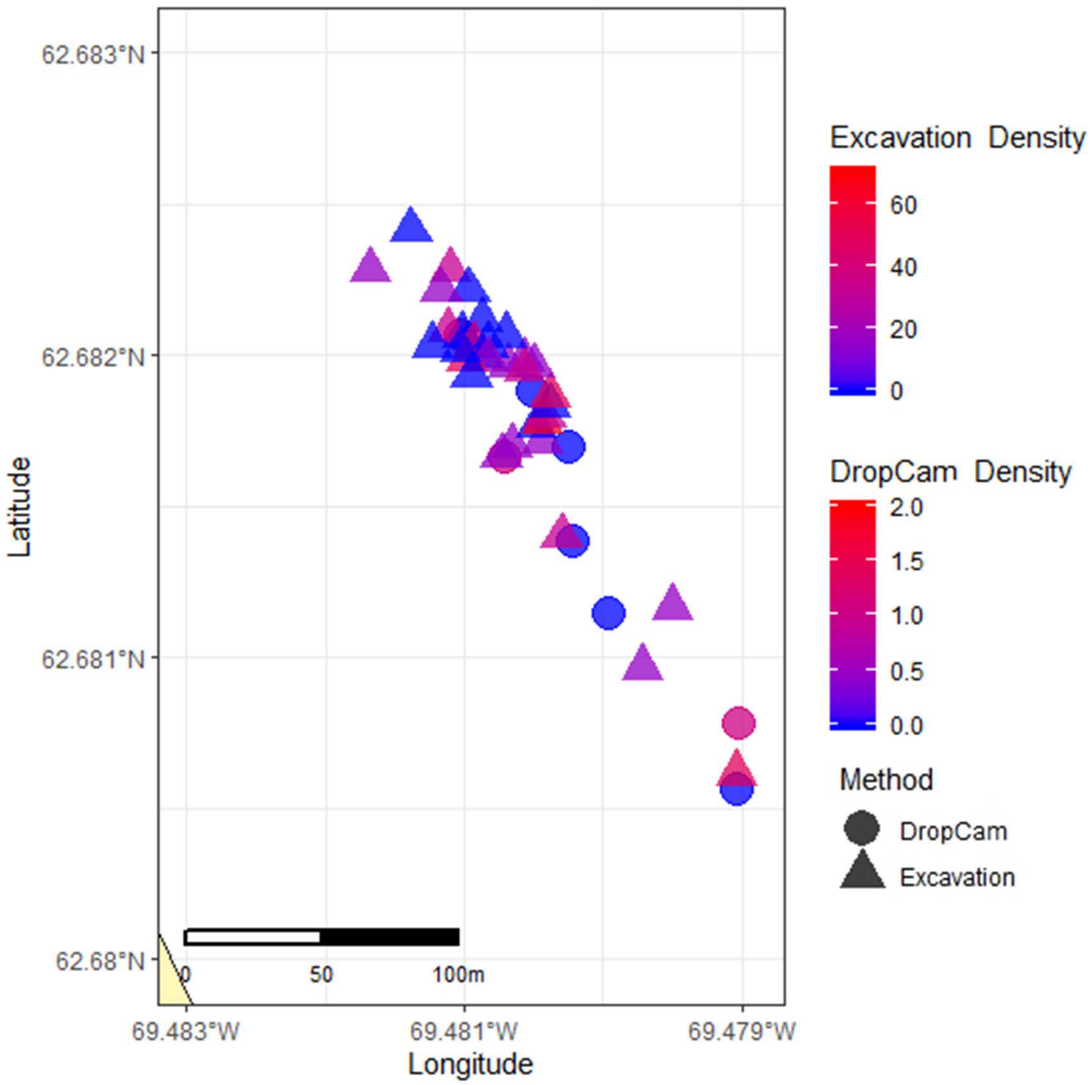

Figure 3.11. Map of Itivirk Bay site, Hudson Strait, depicting intertidal sample locations and soft-shell calm densities (number/m^2) by assessment method (i.e., drop-camera and excavation). Yellow area in lower left corner represents land at high tide based on the GADM database.

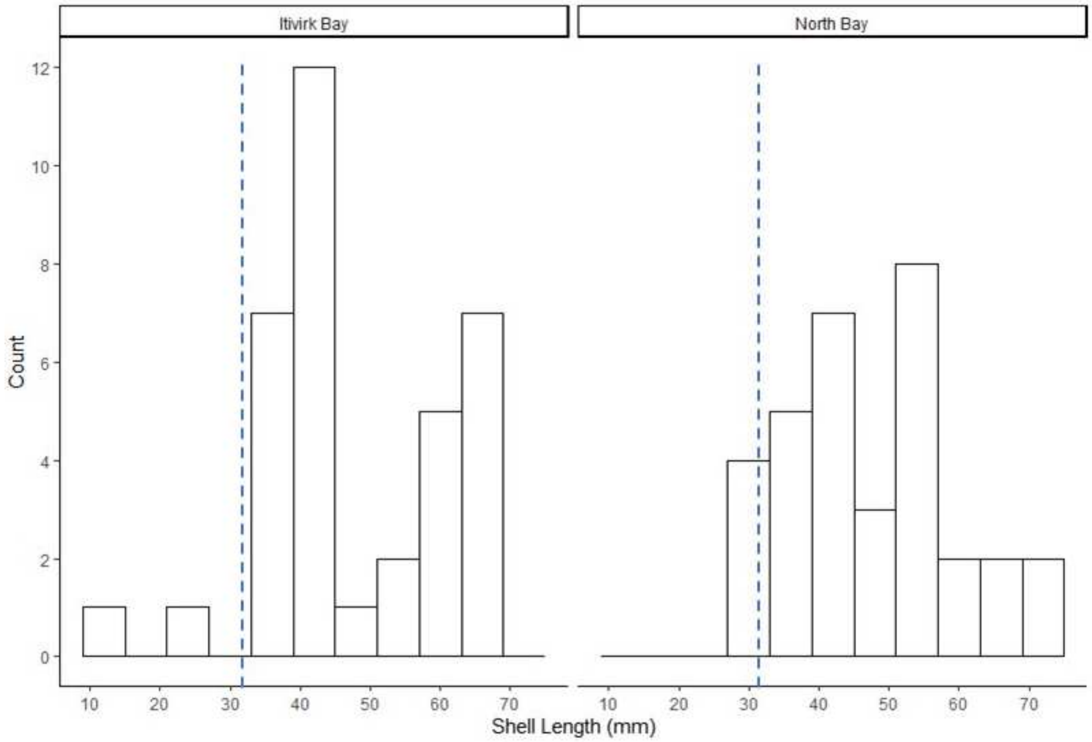

Figure 3.12. Size distribution of truncated soft-shell clams excavated at the Itivirk Bay and North Bay sites. Blue dashed lines represent the average of size at sexual maturity of male and female *M. truncata* (31.5mm) based on results of Chapter 2.

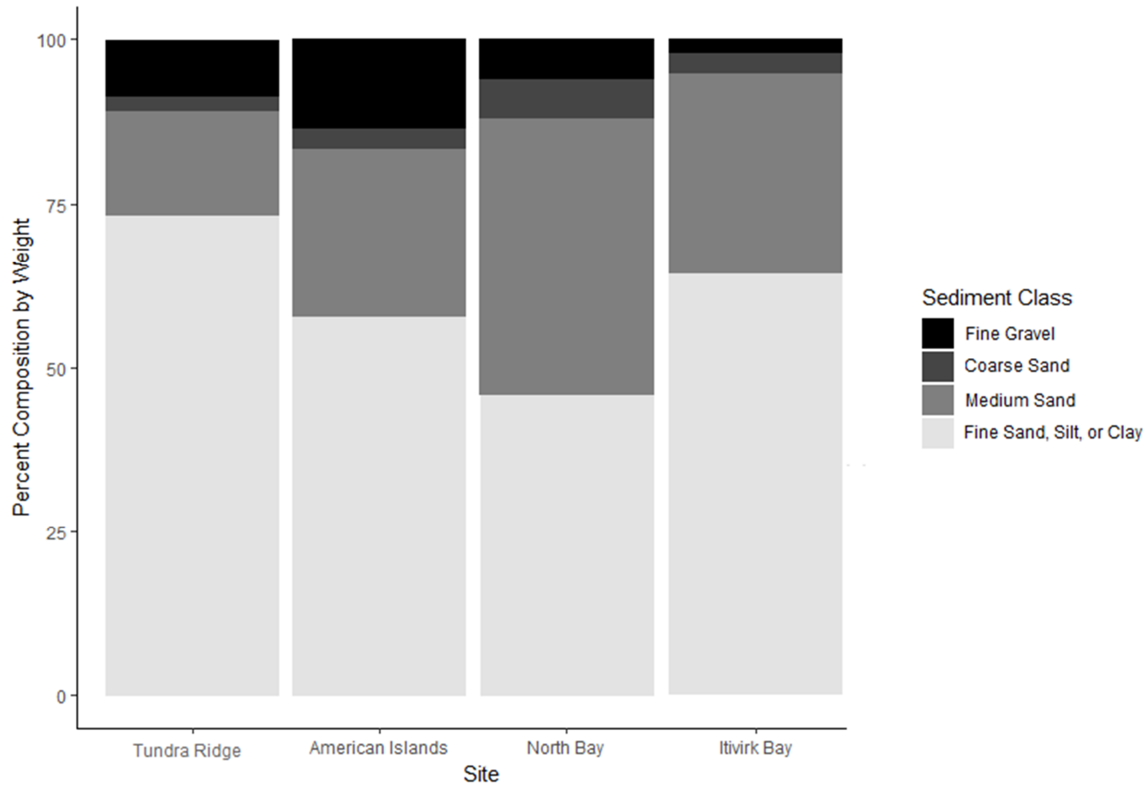

Figure 3.13. Mean percent composition by dry weight of sediment class at four *M. truncata* sample sites on southern Baffin Island, Nunavut.

Chapter 4: General discussion and conclusions

4.1 Summary

I began my work by studying aspects of the life-history of *M. truncata* of southern Baffin Island by assessing the stage of gonadal maturity of clams collected within Frobisher Bay and the north shore of the Hudson Strait and found that the SL at 50% maturity of male and female *M. truncata* were similar, 31 mm and 32 mm, respectively. I was also able to provide evidence that *M. truncata* collected near each community were mostly in the ripe stage of gonadal development by mid-September 2018 but were not yet spawning. Finally, I suggest that dry weight to shell length relationships provide a reliable way to estimate body condition of clams. The results of this first field study of my thesis will provide life history and condition-based information to inform fisheries management decisions and conservation measures with impending climate change.

I then focused on evaluating the effectiveness of a unique drop-camera design to assess *M. truncata* density within the intertidal zone of Frobisher Bay and the north shore of the Hudson Strait. Across all sites, I found that drop-camera deployments estimated significantly lower densities than manual excavations and deemed this to be due to many more clams in the sediment that could not be accounted for on video. This could be because of tidal flow in the intertidal zone upsetting fine sediment, leading to siphons and siphon depressions being covered. In addition, I hypothesize *M. truncata* density to be higher in the subtidal zone than the intertidal zone, based on the findings of Siferd (2005) and hypothesizing that clams in the subtidal zone would not be as disrupted by land-fast ice in the winter months. In conclusion, the third chapter of this thesis provides the first step in being able to monitor the response of *M. truncata* density to recreational harvesting pressures.

4.2 Limitations to my approach

While the results of this thesis provide contributions to the fields of Arctic biology and ecology, there is always room for improvement. Regarding my first study, it would have been ideal to collect clams at monthly intervals year-round, or at least throughout the ice-free season to monitor how stage of gonadal development varies over time. Cross et al. (2012) were able to collect *M. arenaria* for 16 consecutive months to monitor the number of clams in each stage of gonadal development over time, providing a more comprehensive analysis of spawning in coastal Ireland. Collecting samples at monthly intervals would have also allowed for tracking population condition with changes in gonadal development, which could mean inferring stage of gonadal development from condition in the future.

In my second study, it would have been ideal to carry out manual excavations in the exact same locations as drop-camera deployments. This was not an option for the present study, as it would have required leaving the drop-camera frame on the seafloor at high tide and returning to excavate at low tide, which would have greatly increased the time needed to complete field work. In the future, a marker could be deployed on the seafloor in the location that drop-camera deployments were performed to be excavated at low tide. Paired with sieving of excavations to detect very small clams, this technique would reap the most accurate assessment as to exactly how accurate drop-camera estimates are, or even help create a “show-factor” as discussed by McDonald et al. (2015). Finally, a live-feed of the video being taken during drop-camera deployments would help avoid dropping the camera into seaweed beds, rock fields, or other areas that create unusable footage. In fact, Fox (2018) praised their live-feed video for their towed video sleds, and Faggetter (2011) regretted not having a live-feed, as their benthic camera deployments lasted 3 hours, and so time was well-wasted if the deployment was not successful. Nevertheless, my study provides insight for future studies wishing to use underwater video to study *M. truncata* density.

It must be said that as with any fishery under increasing harvesting pressure, we must not only consider how to sustainably manage the fishery, but also what effects greater harvests might have on the population. For example, fishing-induced extinctions are quite common, as are changes in life history characteristics due to fishing selecting certain phenotypes (reviewed by Stergiou 2002). Especially in a fishery where larger adult individuals are targeted, the population may start to mature earlier in life (reviewed by Uusi-Heikkilä et al. 2015). This opens another avenue for research in terms of *M. truncata* fishery development in the north. It is my hope that the results of this thesis act merely as a baseline to support fishery management decisions, and future management work can preserve the population and avoid detrimental effects of fishing pressure.

4.3 Conclusion

Over the course of this thesis, I have estimated *M. truncata* size at maturity and developed a method to assess body condition in the coastal waters of Iqaluit and Kimmirut, Nunavut. Finally, I have made preliminary density estimates through exploring new technology. The results presented in this thesis will be passed on to government officials and Indigenous stakeholders to inform sustainable management decisions and ensure that science remains at the forefront of fishery development and conservation.

4.4 References

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