

University of Windsor

## Scholarship at UWindor

---

Electronic Theses and Dissertations

Theses, Dissertations, and Major Papers

---

2016

# EFFECTS OF ACOUSTIC DISTURBANCE CAUSED BY SHIP TRAFFIC ON COMMON FISH SPECIES IN THE HIGH ARCTIC

Silviya Vasileva Ivanova  
*University of Windsor*

Follow this and additional works at: <https://scholar.uwindsor.ca/etd>

---

### Recommended Citation

Ivanova, Silviya Vasileva, "EFFECTS OF ACOUSTIC DISTURBANCE CAUSED BY SHIP TRAFFIC ON COMMON FISH SPECIES IN THE HIGH ARCTIC" (2016). *Electronic Theses and Dissertations*. 5829. <https://scholar.uwindsor.ca/etd/5829>

This online database contains the full-text of PhD dissertations and Masters' theses of University of Windsor students from 1954 forward. These documents are made available for personal study and research purposes only, in accordance with the Canadian Copyright Act and the Creative Commons license—CC BY-NC-ND (Attribution, Non-Commercial, No Derivative Works). Under this license, works must always be attributed to the copyright holder (original author), cannot be used for any commercial purposes, and may not be altered. Any other use would require the permission of the copyright holder. Students may inquire about withdrawing their dissertation and/or thesis from this database. For additional inquiries, please contact the repository administrator via email ([scholarship@uwindsor.ca](mailto:scholarship@uwindsor.ca)) or by telephone at 519-253-3000ext. 3208.

EFFECTS OF ACOUSTIC DISTURBANCE CAUSED BY SHIP TRAFFIC ON  
COMMON FISH SPECIES IN THE HIGH ARCTIC

By

Silviya Vasileva Ivanova

A Thesis  
Submitted to the Faculty of Graduate Studies  
through the Great Lakes Institute for Environmental Research  
in Partial Fulfillment of the Requirements for  
the Degree of Master of Science  
at the University of Windsor

Windsor, Ontario, Canada

2016

© 2016 Silviya Vasileva Ivanova

EFFECTS OF ACOUSTIC DISTURBANCE CAUSED BY SHIP TRAFFIC ON  
COMMON FISH SPECIES IN THE HIGH ARCTIC

by

Silviya Vasileva Ivanova

APPROVED BY:

---

T. Lau  
Communications, Media and Film

---

O. Love  
Biological Sciences

---

S. Kessel, Special Member  
Great Lakes Institute for Environmental Research

---

K. Nelson, Co-Advisor  
School of Creative Arts

---

A. Fisk, Co-Advisor  
Great Lakes Institute for Environmental Research

August 18, 2016

## DECLARATION OF CO-AUTHORSHIP

I hereby declare that this thesis incorporates material that is the result of joint research, as follows:

Chapter 2 contains material from a manuscript entitled “Shipping activity disturbs key fish species in the high Arctic” that will be submitted to *Nature Journal*. This manuscript is co-authored by S.T. Kessel, S.Vagle, M. Espinoza, M. McLean, C. O’Neill, J. Landry, N.E. Hussey and A.T. Fisk. In all cases, the first author performed key ideas, primary contributions, data analysis and interpretation, and the contribution by the co-authors was through assistance with data analysis and advice.

I certify that, with the above qualification, this thesis, and the research to which it refers, is the product of my own work.

Additionally, I am aware of the University of Windsor Senate Policy on Authorship and I certify that I have properly acknowledged the contribution of other researchers to my thesis, and have obtained written permission from each of the co-author to include the above-mentioned materials in my thesis.

I declare that, to the best of my knowledge, my thesis does not infringe upon anyone’s copyrights nor violate any proprietary rights and that any ideas, techniques, quotations, or any other material that is the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices. Furthermore, to the extent that I have included copyrighted material that surpasses the bounds of fair dealing



within the meaning of the Canada Copyright Act, I certify that I have obtained a written permission from the copyright owner(s) to include such material(s) in my thesis (included in Appendix B).

I declare that this is a true copy of my thesis, including any final revisions, as approved by my thesis committee and the Graduate Studies office, and that this thesis has not been submitted for a higher degree to any other university or institution.

## ABSTRACT

Due to climate change the high Arctic is experiencing growth in acoustic anthropogenic disturbance that may affect aquatic species, such as Arctic cod (*Boreogadus saida*), and Inuit residents. To our knowledge, no studies have been conducted on this topic and species. Furthermore, there is urgent need for conservation action through much needed collaboration between Inuit and researchers, and an engagement of different audiences, and thus, a documentary film was added to the project as means of communication. Resolute Bay is a small Inuit community located just north of the Northwest Passage, where ships are often visitors in the summer and the bay is a home to Arctic cod, making this the perfect location to address this gap of knowledge and communication. In Chapter 2, we show that Arctic cod was horizontally displaced from its home range and individuals reduced the extent of their habitat use and changed their swimming patterns during vessel presence and movement. In Chapter 3, we describe and put into context the different techniques the film uses to accomplish the set objectives: highlighting the issues facing the Inuit and the arctic ecosystem, the value of Inuit traditional ecological knowledge and need for its incorporation into future studies in the region. Arctic cod spatial distribution and behavioral changes carry consequences for the whole Arctic ecosystem and need to be well understood by scientists as well as by a wide range of audiences to allow for sustainable management and timely conservation action.

## DEDICATION

I dedicate this thesis to my husband, Daniel Ure, who supports all my endeavors and encouraged me to pursue my passion. Also, this work is dedicated to my mother, Margarita Ivanova, and my daughter, Isabelle Petrova, for their understanding, friendship and love, and my father Vasil and grandmother Elisaveta who nurtured my curiosity.

## ACKNOWLEDGEMENTS

I thank my co-advisors Dr. Aaron T. Fisk, Dr. Steven T. Kessel and Prof. Kim Nelson for their patience, support, guidance and encouragement; and my committee members Dr. Oliver Love and Tony Lau for their support, helpful comments and advice. Thank you to Justin Landry, Caitlin O’Neill, Dr. David Yurkowski, Meagan McCloskey, Cherry Theresanathan and Daniel Ure for their friendship and hard work during fieldwork in 2014 and 2015 in Resolute Bay; Dr. Mario Espinoza, Montana McLean and Dr. Svein Vagle for their help with data analysis and advice; Kevin Xu for his indispensable support in both filming and maintaining time-lapse equipment, and Min Bae for his help filming in Resolute in 2014. Additional thank you to Anna Hussey for her friendship and support; Dr. Nigel Hussey for many insights, sample collections and friendship; all Fisk lab members and GLIER faculty, administration and students for their continuing encouragement and support; John North from Canadian Coast Guard for his hard work, help and patience. Also, many thanks to all who participated in the making of the documentary film, both crew and participants.

TABLE OF CONTENTS

DECLARATION OF CO-AUTHORSHIP..... iii

ABSTRACT..... v

ACKNOWLEDGEMENTS..... vii

LIST OF TABLES..... x

LIST OF FIGURES ..... xi

LIST OF APPENDICES..... xiii

CHAPTER 1 ..... 1

INTRODUCTION ..... 1

Background..... 2

Ecology..... 3

Communications ..... 13

Objectives and Rationale ..... 18

BIBLIOGRAPHY..... 24

CHAPTER 2 ..... 36

SHIPPING ACTIVITY DISTURBS KEY FISH SPECIES IN THE HIGH ARCTIC..... 36

Introduction..... 37

Methods..... 40

Results and Discussion ..... 44

Broader implications of Arctic cod displacement for the high Arctic region..... 52

BIBLIOGRAPHY..... 54

CHAPTER 3 ..... 77

“AN ICE-FREE SUMMER” ..... 77

Synopsis .....	78
Methods.....	78
Film main topics, goals and impact .....	80
Description of film process.....	81
Description of film element choices .....	87
Rationale for editorial structure choices .....	91
Reflections/Conclusion.....	92
BIBLIOGRAPHY.....	94
CHAPTER 4 .....	103
CONCLUSIONS: CONTEXT AND RECOMMENDATIONS .....	103
Arctic Ecosystem Changes .....	106
Contributions .....	106
Suggestions for future research, social science and collectively .....	107
BIBLIOGRAPHY.....	110
APPENDICES .....	112
Appendix A Supplementary material for Chapter 2.....	112
Appendix B (Co-author letters of permission).....	115
VITA AUCTORIS .....	118

## LIST OF TABLES

<b>Chapter 2</b>		
Table 2.1	Number of detections used in the estimation of KUD home ranges and MCP	73
Table 2.2	Overlap metrics for Arctic cod home ranges as a population	74
Table 2.3	Frequency and proportion values of movement patterns (MP) 1, 2 and 3	75
Table 2.4	Influences of environmental variables on movement patterns	76

## LIST OF FIGURES

<b>Chapter 1</b>		
Figure 1.1	Northwest Passage routes and location of Resolute Bay, Nunavut	21
Figure 1.2	Number of one-way voyages undertaken in the Parry Channel from 1920 to 2009	22
Figure 1.3	Shipping lanes for vessels entering and exiting the bay of Resolute	23
<b>Chapter 2</b>		
Figure 2.1	Northwest Passage routes and location of Resolute Bay, Nunavut	64
Figure 2.2	Bathymetry of Resolute bay, noise-field directionality around a vessel, and sound transmission losses model of vessels entering Resolute bay along the Eastern and Western shipping lanes	66
Figure 2.3	Vemco 180kHz acoustic receiver array mapped on a bathymetry map of Resolute bay	68
Figure 2.4	Core home ranges and overlap	69
Figure 2.5	Individual extent of spatial use	70
Figure 2.6	Movement patterns 1, 2 and 3 of Arctic cod	71
<b>Chapter 3</b>		
Figure 3.1	Still image examples from footage of key events in the work of researchers	95



Figure 3.2	Still image examples from footage of the everyday life of Inuit hunters	97
Figure 3.3	Still image example from dynamic footage	99
Figure 3.4	Still image example from footage in which artificial sound effects were not employed	100
Figure 3.5	Still image examples from footage in which music is used as a metaphor	101
Figure 3.6	Still image example from footage with narration	102

## LIST OF APPENDICES

Appendix A	Supplementary material for Chapter 2	112
Appendix B	Permissions of Co-authors	115

# CHAPTER 1

## INTRODUCTION

## *Background*

One of the major consequences of climate change in the Arctic is the withdrawal of sea ice (Corell, 2005; Johannessen et al., 2004). The extent of melting of the multi-year ice has been increasing since the 1970s, and more rapidly since 2000 (Comiso et al., 2008). This has opened up the Northwest Passage and other areas of the Arctic marine environment that were previously only accessible to icebreakers. More extensive and longer periods of open water has led to increased ship traffic through the Arctic and an interest in development and exploitation of natural resources (Cressey, 2011; Bradstreet and Cross, 1982; US Energy Information Administration, 2012).

The same reasons that have kept industry away from the Arctic (extent of ice cover) have also made it very difficult for researchers to study the ecosystem, and, thus, relatively little research has been focused on the ecology of arctic organisms. Even less research has been focused on the movement and behavior ecology of arctic fish. Without an understanding of how noise from the increased vessel presence and traffic in the Arctic Ocean will affect species movement and behavior, it will be difficult to manage the Arctic Ocean ecosystem in a sustainable manner.

A key to effective science and successful management is communication. At present, relationships between the local Inuit population and scientists and policy-makers are strained and inefficient, due, in part, to residual contempt over Inuit relocation issues in the 1950s (Christian Aboriginal Infrastructure Developments, 2014). For the successful management and conservation of current and emerging resources in the North, it is imperative to improve these relationships and the communication between the parties with involvement of the local communities. Thus, the aims of my research were: 1)

ecological: to examine any influence of ship presence and traffic on the movement of Arctic Cod (*Boreogadus saida*) in the high Arctic, and 2) communications: to document the undertaken research, the collaboration with locals and the issues facing the local populations and the Arctic as a whole, and communicate those to policy and decision-makers at both municipal and provincial governments, and the general population in the form of a documentary film.

The two aims would be mutually beneficial to gather and disperse much needed information for management and conservations decisions, and set the stage for further anthropogenic disturbance studies in the Arctic that are supported by strong community involvement, cooperation and leadership.

### *Ecology*

Marine fishery landings in Canada were worth \$2.2 billion dollars in 2013, creating over 80,000 jobs (DFO, 2014). These numbers did not include the Canadian Arctic, such as the growing Greenland halibut (*Reinhardtius hippoglossoides*) fishery around Baffin Island. Landings for 2006 for seal harvest reported for the southeastern part of Baffin Island included Newfoundland and were worth \$34.3 million (DFO, 2007). Considering that the Arctic encompasses 40% of Canada's total landmass, has approximately 162,000 kilometers of coastline, (approximately 2/3 of the total Canadian coastline) (Morrison, 2006) and is believed to hold vast natural resources, it is easy to understand why the Canadian government and multiple industries, including the fishery industry, are planning its exploration and development. Thus, the importance of the Arctic for the Canadian economy will continue to grow.

### *Anthropogenic disturbance*

With the growing economic importance of the Arctic, anthropogenic disturbance will also grow. Anthropogenic disturbance is a type of ecological disturbance (White and Pickett, 1985). Sousa (1984) defined ecological disturbance as a discrete cause of mortality, displacement or damage to individuals or colonies. White and Pickett (1985) provided another definition: disturbances “disrupt an ecosystem, community or population structure and change resources, substrate availability or the physical environment.” Anthropogenic disturbance, unlike natural disturbance, is caused by humans, or at least humans have an important influence on the event that causes the disturbance (White and Pickett, 1985). The concept of anthropogenic disturbance in its basic idea can be traced back to Plato and his unfinished “Critias” (Clark, 1986; Plato, 360 B.C.E.). Plato describes the human-made changes to an island, such as agriculture, landscape and construction of paved cities, and the consequence of these actions: “Moreover, the land reaped the benefit of the annual rainfall, not as now losing the water which flows off the bare earth into the sea...” (Plato, 360 B.C.E.). More recently, in 1874, George Perkins Marsh, talks about “man’s ignorant disregard of the laws of nature” and produces extensive accounts of these in his book “The Earth as Modified by Human Action.” By the mid 1900s, the idea of anthropogenic disturbance started to gain more and more ground, with the appearance of works by F. Osborne, Harrison Brown, Rachel Carson (in Clark, 1986), Mercer (1978) and others.

In “Critias” Plato (360 BCE) focuses on the long lasting effects of the disturbances. However, anthropogenic disturbances on a temporal scale could be caused by short-term or long-term activity or events, and could have short-term or long-term

effects (Bejder et al., 2006). An example of a short-term event in the aquatic environment is a passing vessel, which introduces higher levels of noise and turbulence in the waters (Picciulin et al., 2010). An example of a long-term event in the aquatic environment is the construction of a channel to accommodate vessels with large draft, which alters the depth, the substrate, and the presence and types of vegetation. The effects are dependent on a number of factors. For example, these depend on whether the event or activity causing the disturbance was of short-term or long-term nature; and depend on the size and properties of the area, and/or the organism. There are also different types of anthropogenic disturbances, for example, exploitation of resources, urban development or pollution, which can range from chemical to light to noise pollution (Slabbekoorn et al., 2010; van der Oost et al., 2003). Noise pollution, or acoustic disturbance, is not a new concept, but has only recently been considered as a stressor in aquatic ecosystems (Popper and Hastings, 2009; Scholik and Yan, 2001), which were previously considered quiet. The infamous Captain Nemo (Verne, 1869) asks the question “Where could one find greater... silence,” and also tells us of the silence of the coral reefs. Yet, in the same book, Professor M. Aronnax notes “the slightest noise [is] transmitted with a quickness to which the ear is unaccustomed on the earth; indeed, water is a better conductor of sound than air, in the ratio of four to one” (Verne, 1869). Later on, Jacques Cousteau’s 1956 film “The Silent World”, as the title suggests, represented the aquatic world as silent (Popper and Hastings, 2009). The first scientific publication on underwater sound appears in 1948, by Knudsen et al. entitled “Underwater ambient noise”. In 1960 D. E. Weston, publishes in Proceedings of the Physical Society “Underwater Explosions as Acoustic Sources.” In the following years measurements of ambient sound (Milne and Ganton,

1964) and sound propagation (Marsh and Mellen, 1963; Buck and Greene, 1964) were made in the Arctic Ocean (in Au and Hastings, 2009). Even though more studies have come out since then, in 1994, a report by the Natural Research Council stressed the “extremely limited” amount of data collected on noise in the oceans (Jasny and Natural Resources Defense Council, 1999). Dr. Sylvia Earle explains that underwater noise “is creating a totally different environment than existed even 50 years ago” (Jasny and Natural Resources Defense Council, 1999). In Canada a similar report concerned with the effects of vessel traffic noise on mammals came out in 1983, published by the Arctic Biological Station, Department of Fisheries and Oceans (Mansfield, 1983). According to scientists (Slabbekoorn et al., 2010) sound travels five times faster and farther in water than it does in air. This shows that underwater acoustic disturbance is a growing concern.

#### *Acoustic Anthropogenic Disturbance*

Underwater noise can cause acoustic disturbance only if the organisms living in that environment are able to hear and produce sound. The first studies on marine mammal hearing were performed in tanks by Johnson in 1966, and Schusterman et al. in 1972 (in Mansfield, 1983), Ridgway and Joyce 1975 (in Nedwell et al., 2004), and included audiogram data for the respective mammals of the study. An audiogram is defined as “the threshold of hearing of the subject as a function of frequency” (Nedwell et al., 2004). The first fish audiograms (experiments also performed in tanks) were published by Dijkgraaf in 1952, Tavalga and Wodinsky in 1963; Tavalga and Wodinsky in 1965; and Enger in 1966 (in Nedwell et al., 2004), among others, and established clearly the fact



that fish can hear. Since these original studies, audiograms have been published for many species of mammals and a number of fish species (Nedwell et al., 2004). Many studies have been conducted on the different types of sound mammals produce, their sound frequencies, how they use sound, and how they may be affected by acoustic disturbance. Although audiograms have been published for a number of fish species, the influence of noise pollution on these has largely been ignored (Mansfield, 1983; Scholik and Yan, 2001). With an estimated 33,200 fish species in the world (Froese and Pauly, 2015), it is important to understand the role of sound in the ecology of fish, and the effects acoustic disturbance may have on that ecology and behavior.

### *Importance of Sound*

Sound is an important tool for marine animals and is used by fish for communication, exploration, navigation and exploitation, thus an accurate interpretation of the environment is of vital importance (Scholik and Yan, 2001). Fish use sound to detect predators and prey, and in locating mates (Nedwell et al., 2004; Popper and Hastings, 2009; Hastings et al., 1996). All fish species studied to date can hear sound (Fay and Popper, 2000; Popper and Fay, 2011; Kasumyan, 2005) and their hearing ranges fall within the same frequency as anthropogenic noise (Slabbekoorn et al., 2010). A number of papers have shown that sound could cause a change in the behaviour in different fish species, and may result in internal injuries, hearing loss, damage to auditory tissues and /or death (Vaudo and Lowe, 2006; Russell et al., 1998; Slabbekoorn et al., 2010; Picciulin et al., 2010; Wysocki et al., 2006; Sandstrom et al., 2005).

## *Acoustic Telemetry*

Acoustic disturbance and the effects on different species are widely studied in the terrestrial environment, however few studies have focused on aquatic species and even fewer on fish (Popper and Hastings, 2009; Slabbekoorn et al., 2010) in part due to accessibility challenges. Studies are easier to perform in captivity, however these often fail to account for the complexity of the natural environment (Cooke et al., 2013). Recent developments in technology have provided new opportunities to study and quantify the behavior of aquatic animals (Hussey et al., 2015). From real-time GPS to low-frequency electro-magnetic telemetry to acoustic telemetry, there is a wide range of ways to track marine species. However, different tracking technologies have different limitations and strengths, which need to be considered during research planning. For example, real-time GPS tags provide, provide real-time positioning of an animal's movements but are large and only transmit when at the surface, thus the animal needs to be large and surface regularly (Cooke et al., 2013). This makes real-time GPS tags only feasible for large fish that surface, a very small percentage of the fish species. Radio-telemetry is another method available for tracking fish, and is done via manual tracking or fixed stations. This type of telemetry is only feasible for freshwater, because radio waves are unable to propagate in salt water (Hussey et al., 2015). Another technology, archival tags, provide temperature and depth, and if the animal comes near the surface, location information based on light levels, however these tags have to be recovered to download the logged data (Cooke et al., 2013). Recovery of tags can be very difficult for animals that make large-scale movements or have low fishing pressure, such as arctic fish (Kessel unpublished data). Satellite tags often translate binned data (summary of data over

various time periods, e.g., 6, 12 or 24 hours), have problems off loading data, and are problem in areas where ice can block these from coming to the surface (Cooke et al., 2013).

Acoustic telemetry is yet another technology that can be used with manual tracking and fixed stations, and is designed for underwater transmission and use in both freshwater and salt water. Manual tracking is unfeasible for long term tracking in the Arctic due to the requirement for personnel operation, also the use of a boat is required for tracking and its approach and engine noise may cause a disruption of the normal behavior of the species studied. The fixed stations method, however, allows for remote monitoring with fine-scale two- or three-dimensional positioning of the organism (Hazen et al., 2012; Hussey et al., 2015; Cooke et al., 2013) obtained through triangulation via sophisticated software. The stations are battery operated and recent advances allow for longer deployments in the order of a few months to more than 10 years (Hussey et al., 2015), thus suitable for long-term use (Kessel et al., 2015). All information is time-stamped and logged by the fixed receivers, and recovery rate of the receivers is 100% (Kessel et al., 2015). Battery duration of tags is often dictated by the size of the tag, the attachment method, and the resolution of the data, i.e. how often a signal is transmitted (Hussey et al., 2015). The attachment method is either external or internal; in the internal, the tag is implanted surgically in the gut cavity of the organism (Donaldson et al., 2012). The stations and tags are able to operate under severe weather conditions, such as ice cover (Kessel et al., 2015), and a variety of tag sizes are available for different sizes fish species or life stages with a range of logging abilities, from basic time and location information to depth, acceleration and temperature (Hussey et al., 2015). Acoustic

telemetry has been widely used in the establishment of horizontal 2D movement (home-ranges, species distributions, migrations) of a number of species worldwide (Dean et al., 2014; Taylor and Ko, 2011), and due to its capacity to track the movements of large number of individuals, it is now possible to understand population processes that are based on individual behavior (Hussey et al., 2015). The 3D movement capabilities of this technology are most notable for revealing the extent and variation of depth utilization behaviors in different species (Harrison et al., 2013; Sims et al., 2008).

Animal tracking studies are very useful for conservationists and management, for example, using acoustic telemetry showed that coastal development influenced the movements of round stingrays (*Urobatis halleri*) (Vaudo and Lowe, 2006) and that salmonids change their movement pattern when estuarine barrages are present (Russell et al., 1998).

*Study Site:*

At the present time, the Northwest Passage in the Canadian Arctic (Fig. 1.1) experiences relatively little shipping traffic, but with receding ice during the summer months it is expected to become the preferred shipping route for goods between Eastern and Western North America, and Europe and Asia (Young, 1987). Vessel activity in the vicinity of the Parry Channel has been fairly low in the last 50 or so years (see Fig. 1.2), taking place during the summer months, and practically non-existent before that. The first vessel to cross the Northwest Passage was Amundsen's fishing boat *Gjøa* in 1903-1906 (Fram Museum, 2016), followed by Canadian RCMP supply vessel *St. Roch* in 1940 to 1942 (USCG, 2011). Between 1906 and 1940, travels in the region were made by the

CGS Arctic as patrol vessel and by steamer-icebreaker SS Naskopie of the Hudson Bay Company in 1926 and 1936 (University of Calgary, 2016).

The first icebreaker to cross the Northwest Passage was the Canadian HMCS Labrador in the summer of 1954. Since then, the vessel was in the Arctic on assignment to patrol the area and later as a Coast Guard vessel to conduct various studies and services. In 1950 another Canadian icebreaker began operation, the C.D. Howe, in the eastern Arctic, followed in 1960 by the John A. Macdonald (University of Calgary, 2016; MacFarlane, 2012). In these and the following years other ship activity has been fairly sporadic with single trips by US cutters USCGC Storis, USCGC Spar and USCGC Bramble in 1957 (USCG, 2011), US oil-tanker SS Manhattan in 1969 (Coen, 2012), and Soviet Union icebreaker Arktika in 1977 (USCG, 2011). Submarine activity in the area began with the *USS Nautilus* in 1958 (Submarine Force Museum, 2013). Voyages began increasing exponentially with opening of the mines in Nanisivik and on Little Cornwallis Island in 1976 (Brubacher & Associates, 2002) and 1980 (Dewing et al., 2006), respectively. It is important to note however, that activity of these vessels in the area occurred largely during the summer and early fall (end of July, and throughout August and September, although dependent on location in the Arctic). Thus, projected extended ice-free periods in the Northwest Passage should result in greater number of voyages per year and number of vessels travelling the area. However, at the present levels of traffic, Resolute Bay, Nunavut, located on the northern side of the Barrow Strait stretch of the Northwest Passage (see Fig. 1.1), is an excellent study location to examine the effects, if any, of vessel traffic on local species. Ships are often visitors of Resolute Bay in the summer months, with plenty of days left when no vessels are present in the area. As well,

Resolute has been a base for arctic research since the late 1960s, with many studies on the fish within the bay.

Resolute Bay is often ice-free from late June to end of September. Its total area is approximately 7 km<sup>2</sup> (Google Earth Pro measurement), with approximately 3.7 km width at the mouth and 3 km length north to south. The depth is variable, with the deepest area located on the northern side of the bay ~30 meters, and a shallow area in the center of the mouth of the bay ~2 meters in depth. The substrate consists of rock and soft sediment with patchy vegetation. Old tools and machinery are visible in the shallower areas. Three freshwater streams empty in the bay, along with raw sewage from the community of Resolute Bay with population of 243 as of 2013 (Government of Nunavut, 2013). There are also two shipping lanes for vessels entering and exiting the bay (see Fig. 1.3). A number of vertebrate species are common in the bay, such as Arctic cod (*Boreogadus saida*) (Graham and Hop, 1995; Welch et al., 1993), two sculpin species (*Myoxocephalus spp*), ringed seals (*Pusa hispida*), narwhals (*Monodon monoceros*), belugas (*Delphinapterus leucas*), Black guillemot (*Cephus grylle*) and Northern fulmar (*Fulmarus glacialis*).

#### *Study Species:*

Arctic cod, a member of the Gadidae family, is considered a key link between trophic levels in the Arctic (Welch et al., 1993). The species feed on zooplankton and due to their high energy content are a favorite food source for marine mammals, such as

whales and seals, and different types of birds, such as Black guillemot and Northern fulmar (Welch et al., 1993). They have a circumpolar distribution, tend to form large schools, are found in both shallow coastal areas as well as deep waters (Benoit et al., 2010; Matley et al., 2013), and are considered pelagic. Arctic cod show affiliation for ice, using it for cover to hide from predators and as spawning grounds (Welch et al., 1993; Graham and Hop, 1995). The spring and summer months in the Arctic are the most productive (Yool et al., 2015), and thus, these seasons may be an important feeding period for Arctic cod.

At present no audiogram has been published for this species, or studies on how they utilize noise, whether they make sound, or how they may be affected by vessel noise.

### *Communications*

To enable effective science and successful management and conservation efforts it is necessary for researchers and policy makers to communicate and collaborate with local communities. Living in the information era, policy and decision-makers may not live or even visit the places they make decisions about and are bombarded with information from different sources (Food and Agriculture Organization of the United Nations, 2015). However, scientists and even local residents are rarely able to communicate with the decision-makers directly and as a consequence a wealth of information is lost '*through the channels*' (McLuhan and Fiore, 1968; The Communication Initiative, 2007). In addition, collaboration between researchers and local

communities is not only helpful, but also required for any project in the Arctic and the building of such relationships requires that each side understands and respects the other. Such collaborations have shown to be very fruitful (The Communication Initiative, 2007), especially when traditional ecological knowledge is combined with the latest technology (Emery et al., 2014). However, at the present time these relationships are far from perfect in the high Arctic with local elder residents holding southern researchers and policy-makers in contempt over past political actions, such as bureaucratic and school control, and the relocation of Inuit in the 1950s (Christian Aboriginal Infrastructure Developments, 2014; Miller, 2000; Richardson, 1993; Kirmayer et al., 2000). Even though the government has made steps to mitigate the problem in different ways including through a public apology in 2010 (Aboriginal Affairs and Northern Development Canada, 2010), resentment in the elders of Inuit communities still persists (Kirmayer et al., 2000) and at times they disallow research initiatives (personal interviews). This is an issue because elder residents commonly govern these communities (Green, 1999; Kirmayer et al., 2000) and are the decision-makers in permitting any research and conservation initiatives. Thus, a documentary film with a strong Inuit presence made by and from the perspective of a scientist could help disseminate information directly to decision-makers in local and regional governments, and bridge the existing gaps in collaboration and understanding between local Inuit and researchers.

A documentary film by definition is “a series of visually and/or audibly expressed statements connected by narrative, and communicated from the author/authors to the viewer with the intention that it be received as fact” (Smith and Rock, 2014). The first film considered of partial documentary quality is “In the land of the War Canoes” (Curtis,



1914). It featured Native American culture, rituals and art. However, the first full feature documentary film, Robert Flaherty's "Nanook of the North," came out in 1922, featuring many conventions employed in today's documentary film-making such as, third-person narration, a subjective tone and a hero (UC Berkeley, 2016). "Nanook of the North" was a travelogue, or an exploratory ethnographic film, equivalent to today's travel documentaries, which aim to bring to the audience and teach them about far away places, cultures and others (UC Berkeley, 2016). The term "documentary" appears for a first time in 1926 in a review written by John Grierson of Flaherty's *Moana* (1926). A number of different non-fiction works appeared in the years between 1920 and 1930 that featured foundational elements of today's documentary films (UC Berkeley, 2016). Recognition of the documentary film as a way to influence, inform and impact the masses came from the draw of big crowds to the big screen (Marfo, 2007). The first film to present personal political belief to the masses came out in 1917 by Vertov in support of the Russian Revolution (Marfo, 2007). However, the 1930s marked the rise of using documentaries to further political propaganda, and social causes and viewpoints. A classical example of such documentary is "Triumph of the Will" by Leni Riefenstahl, a film that was commissioned by Adolph Hitler (UC Berkeley, 2016). In the 1950-60s, the development of light and hand-held cameras with synchronized sound brought about spontaneity in the filming style, allowing the filmmaker to employ techniques that bring audiences close to the action and the subject (UC Berkeley, 2016). One such technique gaining prominence was the interview (Nichols, 1991).

Interviews in documentary films are used to enrich the understanding of content. These are often seen as testimony of historical value (Nichols, 1991), due to their close

relation to journalism as a tool. Interviews allow the filmmaker to draw in the audience by making them sit in on the exchange with a person, or persons, affected or knowledgeable of the subject matter. This helps to highlight the issue, persuade and engage the audience on a personal level. Nichols (1991) defines four different types of interviews based on the degree of participation: conversation, masked interview, pseudo-dialogue and common interview. A conversation interview is largely that, a relaxed exchange with no specified agenda; a masked interview is discussion that is set up to a specified topic, yet the structure is not visible to the viewer; a pseudo-dialogue has a structure present during the dialog and both interviewee and filmmaker are visible; a common interview has more structure and the information extracted plays a role into a larger perspective. Each one of these holds benefits that a filmmaker could use, but the choice would be based on what they seek the film to accomplish. An example of common interview is seen in “Enron: The Smartest Guys in the Room” by Alex Gibney (2005). An example of pseudo-dialogue interview is Hotel Terminus by Marcel Ophuls (1988), where open-ended questions that acknowledge the presence of the interviewer produce a sense of honest conversation and allow for personalization. Interviews may lack a sense of spontaneity due to accepted norms of editing to select for only the needed short and focused bits of the conversation or answer. Often times such structuring of the interview fails to capture the feelings of the interviewee(s), and the reason why the filmmaker chose to interview this person, such as the initial stimulating encounter and exchange between the parties. Furthermore, the perspective the camera uses to film the interviewee may influence greatly the perception of the words said. A widely used practice to create intimacy is to bring the camera close and film the head in tight frame, however setting the

camera to a neutral distance allows for a comfortable conversation that doesn't manipulate the viewer. Another perspective of an interview is given to the viewer via imagery. Pictorial context, or the independent imagery used to complement or counterpoint the interviewee's words (Nichols, 1991), may be used in just such fashion: to affirm the testimony or to discredit it. This is done by establishing the interviewee and their position, cutting away to add important information regarding the discussed topic, and eventually going back to the interview. Thus, interviews in a documentary play an important role in establishing the documentary as one that looks at an issue from varying angles.

Different people, different cultures and circumstances, however can perceive facts differently. In the words of Max Stahl "the film is not a faithful record of what happened" not because it is inaccurate, but simply because the accounts presented in it do not always conform to the subjects' experiences and /or feelings (2014). Because of this, it is important to take into account the perspective that is used in a documentary film, and such choices as the presence of narration to convey information.

Narration is a technique used to convey information beyond the image. A simple definition of what narration is could be found in the translation of the Latin word "narrate" meaning, "telling a story" (Dyrenforth, 1951). According to Crews, narration "is really a continuation of the scene ... which may strengthen the overall structure" (in Dyrenforth, 1951). This is because narration can provide additional information or evidence that is often unknown to the audience. In addition, the narrator's familiarity and engagement with the subject matter often dictate how audiences perceive the story, due to

individuals' innate ability to distinguish between acting and genuine passion (Dyrenforth, 1951). Thus, a narration done by person that is also well informed in the subject matter helps to bring the audience closer to understanding and engaging with the problems presented.

### *Objectives and Rationale*

#### *Ecology:*

In the natural world animals' individual behavior is influenced by many factors, such as presence or absence of predators, presence or absence of disturbance, time of year, availability of food, availability of particular substrates and features in the environment. Acoustic disturbance is documented to elicit short-term changes in swimming behavior that include either a cessation of activity, a flight or a 'startle' response, in which the individual accelerates to produce brief but fast speed swimming and tight turns (Shafiei Sabet et al., 2016; Kastelein et al., 2008), both of which are considered anxiety related behaviors. Such response is seen when the noise levels are above a particular threshold and at particular frequency, with these varying between species (Kastelein et al., 2008). Any changes in behavior due to such disturbances are known to divert energy from mating, feeding, offspring care and territory defense activities (Picciulin et al., 2010). Atlantic cod (*Gadus morhua*) and herring (*Clupea harengus*) have been documented to actively avoid specific type of vessels based on noise emissions (Handegard et al., 2003; Mitson and Knudsen, 2003; Vabø et al., 2002). Higher noise levels due to vessel activity affect fish by causing spatial displacement

(Vabø et al., 2002). Thus, we examined Arctic cod's home ranges and movement patterns in relation to vessels. As mainly prey species, Arctic cod form shoals and schools, and thus, analyses were performed at both the population and individual levels.

The question I aimed to address was:

Does ship presence and movement influence the home ranges and movement behavior of Arctic cod in the high Arctic? *I hypothesized that vessel movement in the bay will alter the proportions of movement patterns of Arctic cod eliciting a flight response and schooling behavior as those seen during predator attacks, and ship presence will affect the spatial location of their home ranges in the bay displacing them from the area immediately around the docked vessel due to noise produced by generators on the ship and servicing tenders.* I aimed to understand and test these by comparing the home ranges and the movements pattern proportions of Arctic cod during periods of time when the bay is free of ships to periods when a ship is coming in or leaving and when it is docked in the bay. I looked at the short-term movement patterns of the species due to ships presence in the bay being in the order of a few days, and their entering and leaving the bay being in the order of a few hours. This research is presented in Chapter 2.

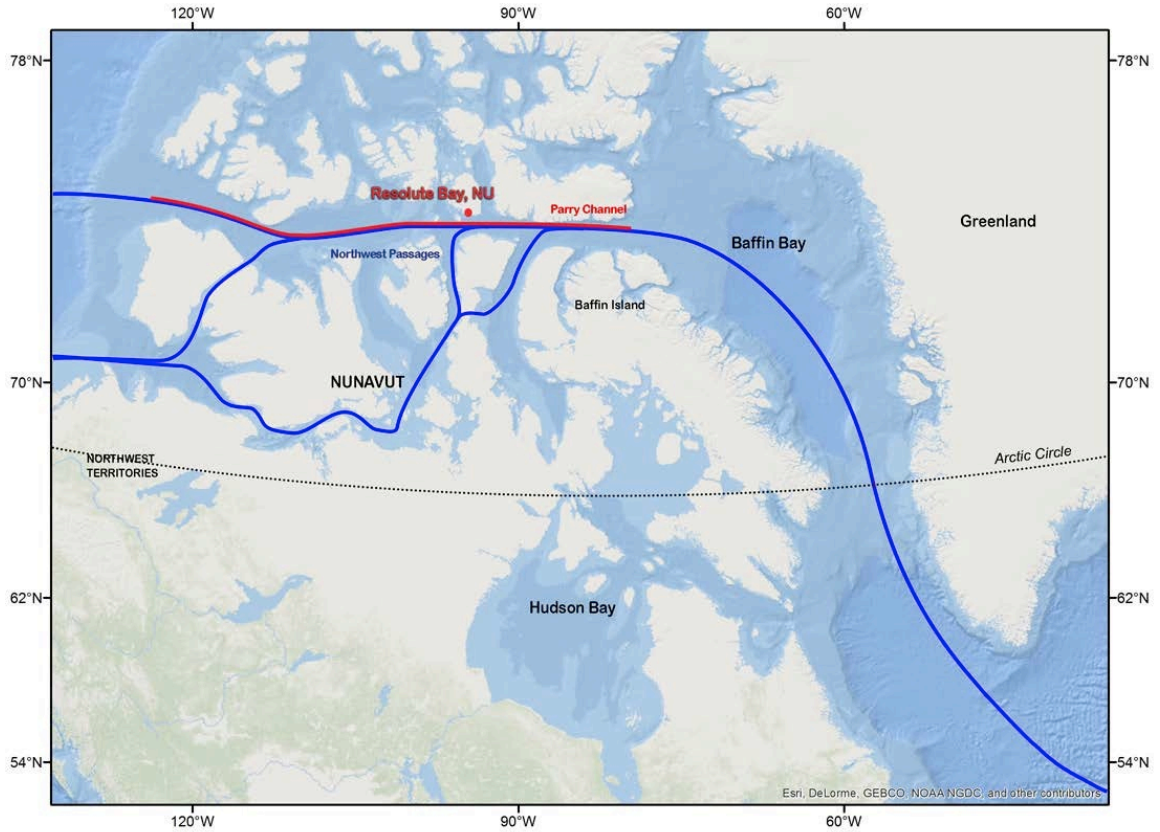
*Communications:*

Arctic cod are indirectly important to Inuit subsistence hunters (Kessel et al., 2015), who rely on marine mammals to provide food and income for their families. Marine mammals are known to follow cod schools as these move into bays and shallower

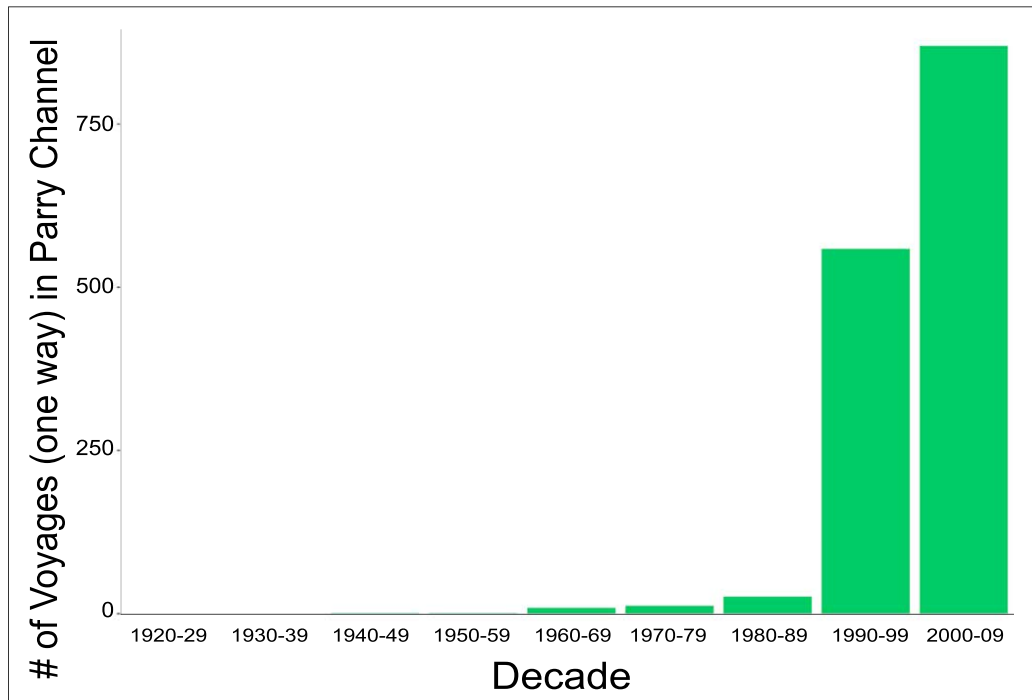
waters in an attempt to escape (Welch et al., 1993) and thus, move in close proximity to Inuit settlements, such as Resolute, providing subsistence hunters with opportunities to hunt. Collaboration and understanding between Inuit and researchers is imperative for furthering the gained knowledge and its local application for management and conservation.

The aim was:

To involve the local residents in documenting aspects of the undertaken research and issues facing the local population and the Arctic as a whole, and communicate those to policy and decision-makers at both municipal and provincial governments in the form of a documentary film. I sought to build understanding and promote collaboration between Inuit and researchers by exploring the complementation and benefits of combining traditional ecological knowledge with high-tech research, and by encouraging environmental stewardship and leadership in local residents through workshops. The work of this project along with a synopsis of the documentary film is presented in Chapter 3.

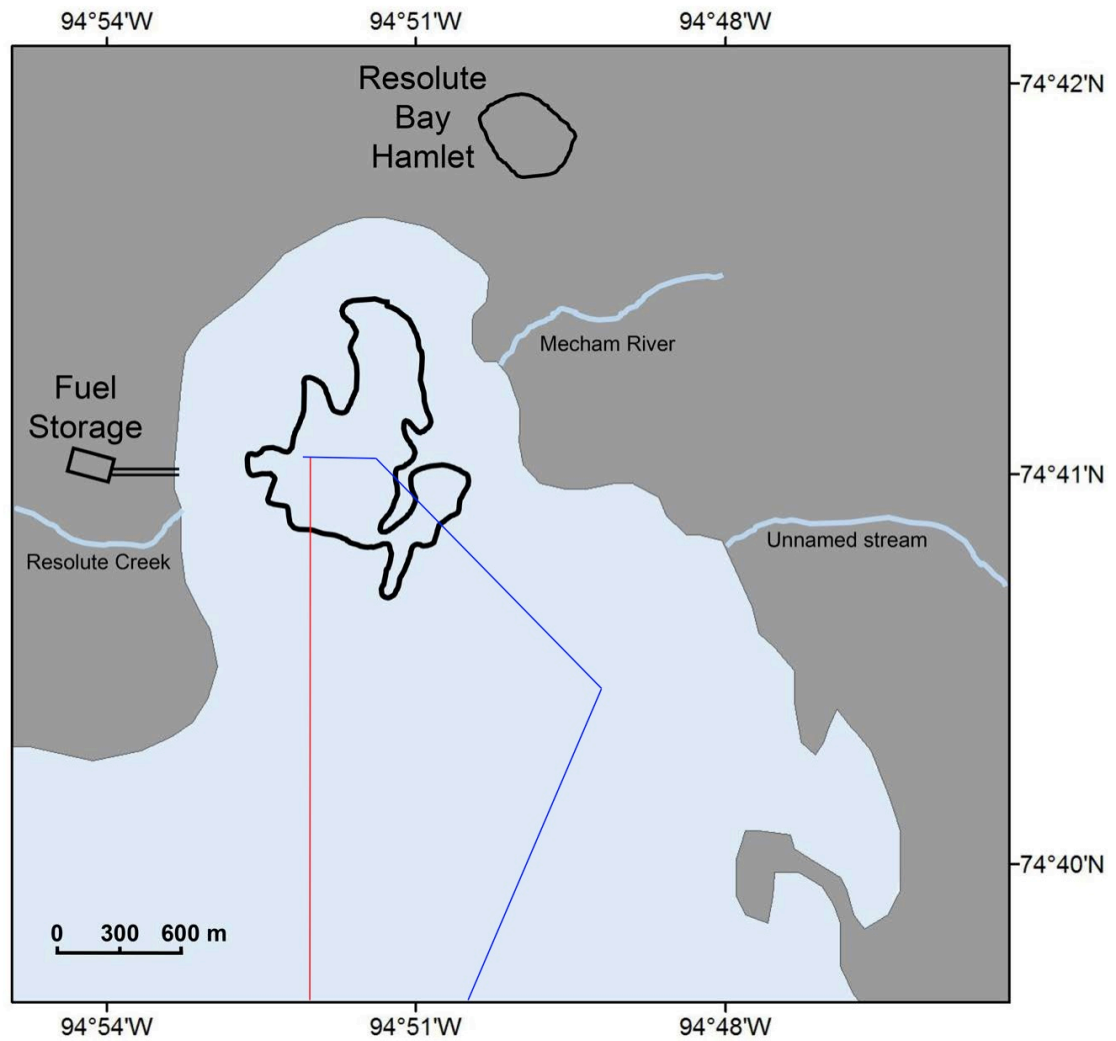


**Figure 1.1** | Northwest Passage routes and location of Resolute Bay, Nunavut (Base map used in this figure is from the public domain Natural Earth and is freely available for personal, educational and commercial uses. See <http://www.naturalearthdata.com/about/terms-of-use/> for more details.)



**Figure 1.2** | Number of one-way voyages undertaken in the Parry Channel from 1920 to 2009 (excludes yachts and other vessel <50m) shown here per decade. Information was obtained from Canadian Coast Guard Services (1995 to 2009), Headland (2015) and MacFarlane (2012).





**Figure 1.3** | Shipping lanes for vessels entering and exiting Resolute Bay. Blue denotes eastern shipping lane, used by cargo and tanker vessels, and red denotes the western navigation lane generally used by passenger ships.

## BIBLIOGRAPHY

- Aboriginal Affairs and Northern Development Canada. (2010). *Government Of Canada Apologizes For Relocation Of Inuit Families To The High Arctic*. Retrieved February 2, 2015, from Aboriginal Affairs and Northern Development Canada: <https://www.aadnc-aandc.gc.ca/eng/1100100015397/1100100015404>
- Au, W. W., and M. C. Hastings (2009). *Principles of Marine Bioacoustics*. New York: Springer Science & Business Media.
- Bejder, L., A. Samuels, H. Whitehead, and N. Gales (2006). Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. *Animal Behaviour*, doi:10.1016/j.anbehav.2006.04.003.
- Benoit, D., Y. Simard, J. Gagne, M. Geoffroy, and L. Fortier (2010). From polar night to midnight sun: photoperiod, seal predation, and the diel vertical migrations of polar cod (*Boreogadus saida*) under landfast ice in the Arctic Ocean. *Polar Biology*, 33, 1505-1520.
- Bradstreet, M. S., and W. E. Cross (1982). *Trophic relationships at high Arctic ice edges*. Retrieved March 2, 2015, from University of Calgary: <http://pubs.aina.ucalgary.ca/arctic/Arctic35-1-1.pdf>
- Brubacher & Associates. (2002). *The Nanisivik legacy in Arctic Bay: A socio-economic impact study*. Retrieved February 23, 2016, from Nunavut Economic Forum: <http://www.nunavuteconomicforum.ca/public/files/library/MININGAN/Arctic%20Bay%20-%20Nanisivik%20Report%20August%202002.pdf>
- Buck, B. M., and C. R. Greene (1964). Arctic deep-water propagation measurements. *Journal of the Acoustical Society of America*, 1526-1533.

- Caltrans. (2001). *Pile Installation Demonstration Project Fisheries Impact Assessment*. Retrieved January 12, 2016, from nrc.gov:  
<http://www.nrc.gov/docs/ML1434/ML14345A579.pdf>
- Christian Aboriginal Infrastructure Developments. (2014). Retrieved February 20, 2015, from Christian Aboriginal Infrastructure Developments:  
<http://caid.ca/RRCAP1.11.pdf>
- Clark, W. C. (1986). Sustainable development of the biosphere: Themes for a research program. In W. C. Munn (Ed.), *Sustainable development of the biosphere*: (pp. 5-48). Cambridge, England: Cambridge University Press.
- Coen, R. (2012). *Breaking Ice for Arctic Oil: The Epic Voyage of the SS Manhattan Through the Northwest Passage*. Fairbanks: University of Alaska Press.
- Comiso, J. C., C. L. Parkinson, R. Gersten, and L. Stock (2008). Accelerated decline in the Arctic sea ice cover. *Geophysical Research Letters*, 35 (L01703).
- Cooke, S. J., J. D. Midwood, J. D. Thiem, P. Kimley, M. C. Lucas, E. B. Thorstad, J. Eiler, C. Holbrook, and B. C. Ebner (2013). Tracking animals in freshwater with electronic tags: past, present and future. *Animal Biotelemetry*, 1:5.
- Corell, R. (2005). Arctic Climate Impact Assessment. *Bulletin of the American Meteorological Society*, 86 (6), 860-861.
- Cousteau, J. (Director). (1956). *The Silent World* [Motion Picture].
- Cressey, D. (2011). Open water: As Ice melts, fresh obstacles confront Arctic researchers. 174-177.
- Curtis, E. (Director). (1914). *In the land of the war canoes* [Motion Picture].

- Dean, M. J., W. S. Hoffman, D. R. Zemeckis, and M. P. Armstrong (2014). Fine-scale diel and gender-based patterns in behaviour of Atlantic cod (*Gadus morhua*) on a spawning ground in the Western Gulf of Maine. *ICES Journal of Marine Science*, 1474–1489.
- Dewing, K., R. J. Sharp, and T. Muraro (2006). Exploration History and Mineral Potential of the Central Arctic Zn-Pb District, Nunavut. *Arctic*, 415-427.
- DFO. (2007). *Commercial Fisheries: Landings: Seafisheries*. Retrieved February 2, 2015, from <http://www.dfo-mpo.gc.ca/stats/commercial/sea-maritimes-eng.htm>
- DFO. (2014). *Commercial Fisheries: Landings: Seafisheries*. Retrieved February 2, 2015, from <http://www.dfo-mpo.gc.ca/stats/commercial/sea-maritimes-eng.htm>
- Donaldson, M. R., S. G. Hinch, G. D. Raby, D. A. Patterson, A. P. Farrell and S. J. Cooke (2012). Population-Specific Consequences of Fisheries-Related Stressors on Adult Sockeye Salmon. *Physiological and Biochemical Zoology*, 729–739.
- Dyrenforth, H. O. (1951). Narration—The Cinderella of Radio and Film. *Western Speech*.
- Emery, M. R., A. Wrobel, M. H. Hansen, M. Dockry, W. K. Moser, K. J. Stark, and J. H. Gilbert (2014). Using traditional ecological knowledge as a basis for targeted forest inventory: paper birch (*Betula papyrifera*) in the US Great Lakes Region. *Journal of Forestry*, 112 (2), 207-214.
- Fay, R. R., and A. N. Popper (2000). Evolution of hearing in vertebrates: the inner ears and processing. *Hearing Research*, 149, 1-10.
- Flaherty, R. J. (Director). (1926). *Moana* [Motion Picture].
- Flaherty, R. J. (Director). (1922). *Nanook of the North* [Motion Picture].

- Food and Agriculture Organization of the United Nations. (2015). *Communicating with Policymakers*. Retrieved March 3, 2015, from Food and Agriculture Organization of the United Nations: <http://www.fao.org/docrep/014/i2195e/i2195e02.pdf>
- Fram Museum. (2016). *Polar Expeditions: THE GJØA EXPEDITION (1903-1906)*. Retrieved February 20, 2016, from The Fram Museum: [http://www.frammuseum.no/Polar-Expedition/The-Northwest-Passage-\(1903-1906\).aspx](http://www.frammuseum.no/Polar-Expedition/The-Northwest-Passage-(1903-1906).aspx)
- Froese, R. and D. Pauly. Editors. (2015). *FishBase*. Retrieved October 10, 2015, from World Wide Web electronic publication: <http://www.fishbase.org/>
- Gibney, A. (Director). (2005). *Enron: The Smartest Guys in the Room* [Motion Picture].
- Government of Nunavut. (2013). *Resolute Bay*. Retrieved February 23, 2016, from Government of Nunavut: <http://www.gov.nu.ca/sites/default/files/files/Resolute%20Bay%20Profile%20new%20layout.pdf>
- Graham, M., and H. Hop (1995). Aspects of Reproduction and Larval Biology of Arctic Cod (*Boreogadus saida*). *Arctic*, 48 (2), 130-135.
- Green, J. W. (1999). *Cultural Awareness in the Human Services*. Boston: Allyn and Bacon.
- Grierson, J. (1926, February 8). *New York Sun*.
- Handegard, N. O., K. Michalsen, and D. Tjorstheim (2003). Avoidance behaviour in cod (*Gadus morhua*) to a bottom-trawling vessel. *Aquatic Living Resources*, 16, 265-270.

- Harrison, P. M., L. F. G. Gutowsky, E. G. Martins, D. A. Patterson, A. Leake, S. J. Cooke, and M. Power (2013). Diel vertical migration of adult burbot: a dynamic trade-off among feeding opportunity, predation avoidance, and bioenergetic gain. *Canadian Journal of Fisheries and Aquatic Sciences*, 70, 1765–1774.
- Hastings, M. C., A. N. Popper, J. J. Finneran, and P. J. Lanford (1996). Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. *Journal of the Acoustical Society of America*, 1759-1766.
- Hazen, E. L., S. M. Maxwell, H. Bailey, S. J. Bograd, M. Hamann, P. Gaspar, B. J. Godley, and G. L. Shillinger (2012). Ontogeny in marine tagging and tracking science: technologies and data gaps. *Marine Ecology Progress Series*, 457, 221–240.
- Headland, R. K. (2015). *Transits of the Northwest Passage to end of the 2015 navigation season*. Cambridge: Scott Polar Research Institute.
- Hussey, N. E., S. T. Kessel, K. Aarestrup, S. J. Cooke, P. D. Cowley, A. T. Fisk, R. G. Harcourt, K. N. Holland, S. J. Iverson, J.F. Kocik, J. E. Mills Flemming, and F. G. Whoriskey (2015). Aquatic animal telemetry: A panoramic window into the underwater world. *Science*, 348 (6240), 1221-1231.
- Jasny, M., and Natural Resources Defense Council. (1999). *Sounding the depths: supertankers, sonar, and the rise of undersea noise*. Natural Resources Defense Council.
- Johannessen, O. M., L. Bengtsson, M. W. Miles, S. I. Kuzmina, V. A. Semenov, G. V. Alekseev, A. P. Nagurnyi, V. F. Zakharov, L. P. Bobylev, L. H. Pettersson, K.

- Hasselmann, and H. P. Cattle (2004). Arctic climate change: observed and modelled temperature and sea-ice variability. *Tellus. Series A, Dynamic meteorology and oceanography*, 56 (5), 328-341.
- Kastelein, R. A., S. van der Heul, W. C. Verboom, N. Jennings, J. van der Veen, and D. de Haan (2008). Startle response of captive North Sea fish species to underwater tones between 0.1 and 64 kHz. *Marine Environmental Research*, 65, 369-377.
- Kasumyan, A. O. (2005). Structure and function of the auditory system in fishes. *Journal of Ichthyology* , S223-S270.
- Kessel, S. T., N. E. Hussey, R. E. Crawford, D. J. Yurkowski, C. V. O'Neill, and A. T. Fisk (2015). Distinct patterns of Arctic cod (*Boreogadus saida*) presence and absence in a shallow high Arctic embayment, revealed across open-water and ice-covered periods through acoustic telemetry. *Polar Biology*, 39, 1057-1068.
- Kirmayer, L. J., M. E. Macdonald, and G. M. Brass (2000). The Mental Health of Aboriginal Peoples: Transformations of Identity and Community. *Canadian Journal of Psychiatry*, 45 (7), 607-616.
- Knudsen, V. O., R. S. Alford and J. W. Emling (1948). Underwater ambient noise. *Journal of Marine Research*, 7, 410.
- MacFarlane, J. M. (2012). *Full Transits of the Canadian Northwest Passage*. Retrieved February 22, 2016, from Nauticapedia.ca:  
[http://nauticapedia.ca/Articles/NWP\\_Fulltransits.php](http://nauticapedia.ca/Articles/NWP_Fulltransits.php)
- Mansfield, A. W. (1983). *The effects of vessel traffic in the Arctic on marine mammals and recommendations for future research*. Quebec: Arctic Biological Station, Department of Fisheries and Oceans.

- Marfo, A. (2007). *The evolution and impact of documentary films*. Rhode Island: Senior Honors Projects: University of Rhode Island.
- Marsh, G. P. (1874). *The Earth as Modified by Human Action*. New York: Scribner, Armstrong & Co.
- Marsh, H. W., and R. H. Mellen (1963). Underwater sound propagation in the Arctic Ocean. *Journal of the Acoustical Society of America*, 35, 552-556.
- Matley, J. K., A. T. Fisk, and T. A. Dick (2013). The foraging ecology of Arctic cod (*Boreogadus saida*) during open water (July–August) in Allen Bay, Arctic Canada. *Marine Biology*, 160, 2993-3004.
- McCauley, R. D., J. Fewtrell, and A. N. Popper (2003). High intensity anthropogenic sound damages fish ears. *Journal of the Acoustical Society of America* , 638-642.
- McLuhan, M., and Q. Fiore (1968). *The Medium Is the Massage*. Mono, CL: Columbia Stereo CS 9501.
- Mercer, J. H. (1978). West Antarctic ice sheet and CO2 greenhouse effect: a threat of disaster. *Nature*, 321-325.
- Miller, J. R. (2000). *Skyscrapers Hide The Heavens: A History of Indian-White Relations in Canada (3 ed.)*. Toronto: University of Toronto Press.
- Milne, A. R., and J. H. Ganton (1964). Ambient Noise under Arctic-Sea Ice. *Journal of the Acoustical Society of America*, 36 (855).
- Mitchell, C., and M. Boyd (Directors). (2011). *A Concise History of the Origins of Cinema* [Motion Picture].
- Mitson, R. B., and H. P. Knudsen (2003). Causes and effects of underwater noise on fish abundance estimation. *Aquatic Living Resources*, 16, 255-263.



- Morrison, W. R. (2006). *Arctic sovereignty*. (Historica Foundation) Retrieved February 2, 2015, from The Canadian Encyclopedia:  
<http://www.thecanadianencyclopedia.ca/en/article/arctic-sovereignty>
- Nedwell, J. R., B. Edwards, A. W. H. Turnpenny, and J. Gordon (2004). *Fish and marine mammal aoudiograms: A summary of available information*. Hampshire: Subacoustech Ltd.
- Nichols, B. (1991). *Representing Reality Issues and Concepts in Documentary*. Bloomington and Indianapolis: Indiana University Press.
- Ophuls, M. (Director). (1988). *Hotel Terminus* [Motion Picture].
- Picciulin, M., L. Sebastianutto, A. Codarin, A. Farina, and E. A. Ferrero (2010). In situ behavioural responses to boat noise exposure of *Gobius cruentatus* (Gmelin, 1789; fam. Gobiidae) and *Chromis chromis* (Linnaeus, 1758; fam. Pomacentridae) living in a Marine Protected Area. *Journal of Experimental Marine Biology and Ecology*, 386, 125-132.
- Plato. (360 B.C.E.). *Critias*. Retrieved January 27, 2016, from Benjamin Jowett, Trans.:  
<http://classics.mit.edu/Plato/critias.html>
- Popper, A. N., M. E. Smith, P. A. Cott, B. W. Hanna, A. O. MacGillivray, M. E. Austin, and D. A. Mann (2005). Effects of exposure to seismic airgun use on hearing of three fish species. *Journal of the Acoustical Society of America*, 117, 3958-3971.
- Popper, A. N., A. Kane, M. B. Halvorsen, D. L. Miller, M. E. Smith, J. Song, P. Stein, and L. E. Wysocki (2007). The effects of high-intensity, low-frequency active sonar on rainbow trout. *Journal of the Acoustical Society of America*, 623-635.

- Popper, A. N., and R. R. Fay (2011). Rethinking sound detection by fishes. *Hearing Research*, 25-36.
- Popper, A. N., and M. C. Hastings (2009). Effects of anthropogenic sources of sound on fishes. *Journal of Fish Biology*, 75, 455-489.
- Richardson, B. (1993). *People of Terra Nullius: Betrayal and Renewal in Aboriginal Canada*. Vancouver: Douglas and MacIntyre.
- Riefenstahl, L. (Director). (1935). *Triumph of the Will* [Motion Picture].
- Russell, I. C., A. Moore, S. Ives, L. T. Ives, and R. O. Stonehewer (1998). The migratory behaviour of juvenile and adult salmonids in relation to an estuarine barrage. *Hydrobiologia*, 321-333.
- Sandstrom, A., B. K. Eriksson, P. Karas, M. Isæus, and H. Schreiber (2005). Boating and Navigation Activities Influence the Recruitment of Fish in a Baltic Sea Archipelago Area. *Ambio*, 34 (2), 125-130.
- Scholik, A. R., and H. Y. Yan (2001). Effects of underwater noise on auditory sensitivity of a cyprinid fish. *Hearing Research*, 152, 17-24.
- Shafiei Sabet, S., K. Wesdorp, J. Campbell, P. Snelderwaard, and H. Slabbekoorn (2016). Behavioural responses to sound exposure in captivity by two fish species with different hearing ability. *Animal Behaviour*, 116, 1-11.
- Sims, D. W., E. J. Southall, N. E. Humphries, G. C. Hays, et al. (2008). Scaling laws of marine predator search behaviour. *Nature*, 451, 1098-1102.
- Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A. N. Popper (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution*, 25, 419-427.

- Smith, N., and J. Rock (2014). Documentary as a statement: defining old genre in a new age. *Journal of Media Practice*, 58-62.
- Sousa, W. P. (1984). The role of disturbance in natural communities. *Annual Review of Ecology and Systematics*, 15 (1), 353-391.
- Stahl, M. (2014). *PJR2014-3 Max Stahl on Timor-Leste and 'Reconciliation' (PMC)*. Retrieved March 2, 2015, from YouTube:  
<https://www.youtube.com/watch?v=99jwylm6fwg>
- Submarine Force Museum. (2013). *History of USS NAUTILUS (SSN 571)*. Retrieved February 22, 2016, from Submarine Force Museum:  
<http://www.ussnautilus.org/nautilus/index.shtml?museumNautilus>
- Taylor, M. D., and A. Ko (2011). Monitoring acoustically tagged king prawns *Penaeus (Melicertus) plebejus* in an estuarine lagoon. *Marine Biology*, 158, 835–844 .
- The Communication Initiative. (2007). *World congress on communication for development: lessons, challenges and the way forward*. Retrieved March 3, 2015, from Food and Agriculture Organization of the United Nations:  
<http://www.fao.org/3/a-ai143e.pdf>
- UC Berkeley. (2016). *Chronology of documentary history*. Retrieved March 2, 2016, from UC Berkeley: <http://www.lib.berkeley.edu/MRC/docexhibit/docuchron.htm>
- University of Calgary. (2016). *Arctic Expedition: CGS Arctic*. Retrieved February 22, 2016, from University of Calgary:  
<http://www.ucalgary.ca/arcticexpedition/icebreakers/cgs-arctic>

- US Energy Information Administration. (2012). *Today in Energy*. Retrieved February 20, 2015, from Energy Information Administration:  
<http://www.eia.gov/todayinenergy/detail.cfm?id=4650>
- USCG. (2011). *U.S. Coast Guard Cutter POLAR SEA (WAGB 11)*. Retrieved February 22, 2016, from United States Coast Guard:  
<http://www.uscg.mil/hq/cg4/cg47/docs/CGC%20POLAR%20SEA%20Hist%20Context%20Rpt-22%20July%202011.pdf>
- Vabø, R., K. Olsen, and I. Huse (2002). The effect of vessel avoidance of wintering Norwegian spring spawning herring. *Fisheries Research*, 58, 59-77.
- van der Oost, R., J. Beyer, and N. P. E. Vermeulen (2003). Fish bioaccumulation and biomarkers in environmental risk assessment: a review. *Environmental Toxicology and Pharmacology*, 57-149.
- Vaudo, J. J., and C. G Lowe (2006). Movement patterns of the round stingray *Urolophus halleri* (Cooper) near a thermal outfall. *Journal of Fish Biology*, 1756-1766.
- Verne, J. (1869). *Twenty Thousand Leagues Under The Seas*. Retrieved January 12, 2016, from The Literature Network: <http://www.online-literature.com/verne/leaguesunder/10/>
- Welch, H. E., M. A. Bergmann, T. D. Siferd, K. A. Martin, et al. (1992). Energy flow through the marine ecosystem of the Lancaster Sound region, Arctic Canada. *Arctic*, 45 (4), 343-357
- Welch, H. E., R. E. Crawford, and H. Hop (1993). Occurrence of Arctic Cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian high Arctic. *Arctic*, 46 (4), 331-339.

- Weston, D. E. (1960). Underwater Explosions as Acoustic Sources. *Proceedings of the Physical Society*, 76 (2).
- White, P. S., and Pickett, S. T. (1985). Natural disturbance and patch dynamics: an introduction. In S. T. Pickett, & P. S. White, *The ecology of natural disturbance and patch dynamics* (pp. 3-9). San Diego: Academic Press.
- Wysocki, L. E., J. P. Dittami, and F. Ladich (2006). Ship Noise and Cortisol Secretion in European Freshwater Fishes. *Biological Conservation*, 128 (4), 501-508.
- Yool, A., E. E. Popova, and A. C. Coward (2015). Future change in ocean productivity: Is the Arctic the new Atlantic? *Journal of Geophysical Research Oceans*. 120(12), 7771-7790, doi:10.1002/2015JC011167.
- Young, O. R. (1987). International Arctic Politics: Arctic Shipping: An American Perspective. In F. Griffiths, *Politics of the Northwest Passage* (pp. 115-133). Kingston & Montreal: McGill-Queen's University Press.

## CHAPTER 2

### SHIPPING ACTIVITY DISTURBS KEY FISH SPECIES IN THE HIGH ARCTIC

\* This manuscript has been co-authored by Steven T. Kessel, Svein Vagle, Mario Espinoza, Montana McLean, Caitlin O'Neill, Justin Landry, Nigel E. Hussey, and Aaron

T. Fisk.

## *Introduction*

With a rate of warming nearly twice that anywhere else worldwide (Bintanja and Selten, 2014; Richardson et al., 2016), the Arctic and its inhabitants are the canary-in-a-coal-mine experiencing a rapidly changing environmental and economic conditions. The extent of melting of the multi-year ice in the Arctic has been increasing since the 1970s (IASC, 2005; Johannessen et al., 2004), and more rapidly since 2000 (Comiso et al., 2008). This has opened up the Northwest Passage (Fig. 2.1) and other areas of the arctic marine environment to ship traffic that were previously only accessible to icebreakers. The Arctic region, previously covered by near year-round ice, include vast coastlines of well over 330,000 kilometers and continental shelves believed to hold significant natural resources. Approximately 40% of Canada's total landmass is in the Arctic with 162,000 kilometers of coast, contributing to about two thirds of the total Canadian coastline (Morrison, 2006). As such, the Arctic is continuously growing in importance for the world's economy and resource development (Cressey, 2011). With receding ice during the summer months, shipping and cruise traffic in the Arctic has increased approximately two-fold over the past 20 years, and research vessels have nearly quadrupled since 2000 (Judson, 2010) (Fig. 2.1). This upward trend will also result in the increase of acoustic noise in the arctic marine environment, a region that has experienced limited anthropogenic noise in the past.

Fish use sound for foraging, predator avoidance, exploration, navigation and communication (Nedwell et al., 2004; Popper and Hastings, 2009; Hastings et al., 1996). All fish studied to date can hear sound (Fay and Popper, 2000; Popper and Fay, 2011; Kasumyan, 2005) and their hearing ranges fall within the same frequency as many

sources of anthropogenic noise (Slabbekoorn et al., 2010). Acoustic anthropogenic disturbance has been demonstrated to cause changes in the behavior of a wide variety of fish species, and can inflict internal injuries including hearing loss, damage to auditory tissues and/or death (Vaudo and Lowe, 2006; Russell et al., 1998; Slabbekoorn et al., 2010; Picciulin et al., 2010; Wysocki et al., 2006; Sandstrom et al., 2005; Caltrans, 2001; Popper et al., 2007; McCauley et al., 2003). Other effects range from reduced reproduction to changes in populations and overall community structure (Naiman et al., 2005; Slabbekoorn et al., 2010).

Presently, little research has been conducted on the effects of acoustic disturbance on arctic fish species. Inuit believe that large ships disrupt fish, in particular the Arctic cod (*Boreogadus saida*), and ultimately, the distribution of marine mammals and seabirds that depend on this key fish species (*personal observation*). Given this, and the pending changes to the arctic, it is important to gain an understanding of how fish species, in particular their movement and behaviour, will be affected by increased ship presence and traffic in the Arctic, in order to effectively conserve and manage this vulnerable ecosystem.

Acoustic telemetry is a tracking technology that uses fixed stations for remote monitoring of aquatic species (Cooke et al. 2013). Station locations are determined based on the research question(s), and allow for a precise detection of tagged species within space and time via triangulation (Hussey et al. 2015). Tags vary in size to accommodate different species and different life stages, and fish are tagged externally or internally. In addition to a horizontal location and time, logging capabilities may include depth, acceleration and temperature.



Arctic cod has circumpolar distribution and is a key species due to its large biomass and role as a conduit of energy and biomass from lower trophic levels to higher trophic level marine mammals and seabirds in the Arctic (Welch et al., 1992 & 1993). Arctic cod are also high in fat and have more energy content than other prey species including those from more temperate regions, such as Capelin (*Mallotus villosus*) (Brekke and Gabrielsen, 1994), and as such are a preferred food source of marine mammals and seabirds. Consequently, changes in the behavior of Arctic cod could have implications for its predators, such as Ringed seals (*Pusa hispida*) and Beluga whales (*Delphinapterus leucas*), as well as the Inuit communities that directly depend on these mammals for subsistence hunting. Given the rapidly changing climate and ice conditions in the Arctic, there is ‘urgent need’ for more studies of anthropogenic effects on fish worldwide (Slabbekoorn et al., 2010), and this is particularly relevant for the Arctic.

Our objective was to quantify the spatial/behavioral response of fish in the high Arctic to ship activity. We used a novel approach that utilized acoustic telemetry to quantify the cod movement in combination with oceanographic metrics and acoustic measurements to produce a sound profile relating to vessel generated noise. We quantified Arctic cod’s home ranges, the extent of spatial habitat used (both at the individual and population levels), and swimming behaviors during times of vessel absence, movement and presence. We hypothesized that vessel movement will elicit a startle response and a school aggregation, thus increasing higher speed swimming patterns and decreasing the core home ranges of cod. Also, we hypothesized that noise generated by ship presence will deter fish from the near vessel habitat resulting in horizontal displacement within the bay.

## *Methods*

### *Study Site*

Resolute Bay, Nunavut (latitude 74.6773°N and longitude 94.8297°W) was chosen as the study site due to its proximity to the Northwest Passage (see Fig. 2.1). Ships are often visitors of the bay and studies have found it to have an accessible Arctic cod population (Graham and Hop 1995, Welch et al, 1993). The bay's depth varies from 0 to 30 m at the head of the bay (Fig. 2.2a). The 243-resident community (Government of Nunavut, 2013) is located to the northeast, where an untreated sewage is released through a pipe into the bay waters. One small river on the west side and two streams on the east contribute to the freshwater input. Common species in the bay are Arctic cod, two sculpin species (*Myoxocephalus spp*), Ringed seals (*Pusa hispida*), Belugas (*Delphinapterus leucas*), Black guillemot (*Cepphus grylle*) and Northern fulmar (*Fulmarus glacialis*).

### *Fish telemetry*

A total of 85 Arctic cod were caught via line-and-hook in three different locations in the bay of Resolute in 2012. Fish were held in a tank with fresh seawater for a minimum of 1h prior to surgery to ensure they were healthy. Each individual was anesthetized in a MS222 solution (0.2mg/L in seawater). Fork and total length were measured and recorded to the nearest 1 mm and mass to the nearest 0.01 g. Pectoral fin clipping was taken for stable isotope analysis (not part of this study). A 10% betadine solution was used for sterilization before the procedure of all instruments, tags and the

location of surgical incision on the individual. An incision was made on the ventral side of the fish to expose the gut cavity enough (~8 mm) for a VEMCO® V6 transmitter to be inserted. The tag to body weight ratio was <2%. Two separate coated Vicryl sutures (Ethicon VCP423, 3-0 FS-2) were used to close the surgical incision. The procedure took between 2 to 4 min. Individuals were allowed to recover fully in fresh water tank for ~1 h, and later released at the capture location.

VEMCO® 180Hz acoustic receiver array consisting of 60 units was used to log cod's movements and associated times in Resolute Bay (Figure 2.3). The array was deployed at the end of July 2012 and recovered Aug. 2013. It was set up at a depth of >15 m due to consideration for ice cover with spacing between individual units from 150 to 300 m. Moorings consisted of anchor rock (~40 kg) attached to a ORE Port ME acoustic release via ~2 m rope, and the receiver and float. Sync tags were attached to 17 receivers across the array and were used for correction of receiver internal clock drift (Espinoza et al., 2011).

#### *Acoustic telemetry data processing*

After downloading data from all the receivers, all raw detections were processed by VEMCO VPS Software (VEMCO, Ltd, Nova Scotia) to generate the VEMCO Positioning System (VPS) data used for further analysis. The exact methods and calculations used by VEMCO for processing are proprietary, however, at least three receiver detections are required to triangulate a position location for each signal received. The transmission detection time difference between receivers is converted into a distance

difference via signal propagation speed allowing for synthesized position calculation of the transmission origin (Smith, 2013). A total of 8 individuals were removed from further analysis due to suspected mortality. Thus, VPS detection data for 77 individuals Arctic Cod was filtered for HPE (horizontal position error - a unitless estimate of the sensitivity of the calculated position (Smith, 2013)) of 19.9, any values larger than 20 were removed from further analysis. Due to vessel traffic being limited only to end of July, August and September, we used detection data from July 27, 2012 to September 30, 2012, thus also avoiding any influences of the formation of ice. A final total of 11,852 positions were used for further analysis.

We used `adeHabitatHR` package (Calenge, 2006) in R to estimate the home ranges and `adeHabitatLT` package (Calenge, 2006) to determine the behaviors of cod with the following vessel variables: 1) vessels were absent from the bay (VA), 2) vessels were present/docked in the bay (VP), and 3) vessels were moving in or out of the bay (VM). During VA the only noise in the bay would be from smaller boats and any noise from machinery equipment on the shore, which for this study was considered a regular background noise that the bay is subjected to in the summer months. During VP, additional noise is produced by the generators of the vessel running to produce and supply it with power, as well as zodiacs or barges transporting passengers or goods to the shore and back. During VM noise is produced by the vessel's propellers, the vessel moving through the water, and also by the dropping or pulling of the anchor. For home range (HR) determination we used Kernel Utilization Distribution (KUD) at 50% and 95%, and Minimum Convex Polygon at 100% (both reported in hectares). The detection data was separated according to vessel variables (see Table 2.1 for number of detections).

Because Arctic cod are schooling fish, we examined the HR KUD at the individual level as well as the population level. An overlap examination was performed using CalcHR.R and Indices.txt (Fieberg, 2005) on 50% and 95% KUD for VP, VA and VM for cod as a population, and mean was taken for all cod individuals of the same indexes.

For cod behavior, trajectories for individual fish were broken into “bursts” based on the time and date of detection with cut off between “bursts” of >30 min between consecutive positions. Doing this allowed for the elimination of prolonged/excessive periods between detections/positions, and thus, the separation of different behaviors. Only “bursts” with 5 or more relocations were used for assessment. PCA was performed to identify un-correlated variables, and variables with correlation greater than 40 were removed from further analysis. Three (3) clusters were identified based on “Within-groups-sum-of-squares” plot. The movement trajectories were categorized into three movement types (clusters) by analyzing the following metric variables: 1) sum of distance; 2) mean rate of movement (ROM; m/s); 3) variance of distance; 4) mean turn angle; and 5) variance in bearing (absolute angle). The performed clustering (here also referred to as behaviors) has a Dunn Fuzziness coefficient (a measure of clustering denoting a position between hard and fuzzy partition, with 1 being hard and 0 fuzzy partitioning) of 0.542. Clusters were then subset into the three vessel variables and proportions of each cluster (movement pattern) exhibited in each vessel variable, calculated from the frequency of the movement patterns. A chi-squared test was performed for all proportions using VA as the expected values. A t-test was performed between each separate behavior/cluster for VA, VP and VM to determine the actual differences.

### *Presence and movement of ships in Resolute Bay*

Satellite AIS (Automatic Identification System) archive data from 2012 was used to determine the times of vessels absence, presence and movements. An assumption was made for vessels (n=2) with incomplete AIS data for either docking or leaving time that these would transmit a position and time 0.5hrs after docking or 1hrs before leaving, as this was consistent with other vessels with more detailed AIS and as is required by NORDREG, the Northern Canada Vessel Traffic Services Zone, according to which vessels are required to report before entering, while operating and upon exiting northern Canadian waters (Tulaktarvik Inc., 2014). The times it took a vessel to move in and out of the bay via the two tracks were cross-referenced with time-lapse footage set at 10 s intervals from 2014 for passenger vessels and cargo vessels, and these were determined to be 10 and 30 min, respectively, for vessels going in and 15 and 30 min for vessels going out. Passenger vessels utilize the western track and cargo vessels utilize the eastern track (see Fig. 2.2a). Extra 5 min was added at the end of moving in and before start of leaving to account for noise generated by dropping or pulling of the anchor, respectively.

### *Results and Discussion*

#### *Quantification of ship noise*

Acoustic disturbance inherently is based on sound originating from a source and its propagation. In aquatic environments the propagation is influenced by the environmental conditions, such as salinity, temperature, depth, pressure, frequency and

other factors, which determine the gradual loss of sound energy with increase in distance, i.e. the sound transmission losses (STL) (Mellen, 1984). A STL model provides a baseline for the calculation of actual noise levels. In this study, STLs of a vessel entering the bay along the eastern and western tracks were modeled based on the bathymetry of the study site, Resolute Bay (Fig. 2.2a and c). Based on the model, the area of residence of Arctic cod is shielded from noise until the vessel reaches the mouth of the bay. Compared to the bow, approximately 3 dB higher levels of noise are observed at the rear and 13 dB higher at the sides of the vessel (Fig. 2.2b).

In the Arctic Ocean ice cover is known to influence ambient noise and that may affect the noise levels produced by shipping activity and potentially the organisms living there. In the summer and early fall when ice cover is low ambient sound is higher than in months with ice coverage (Roth et al., 2012). Our study was restricted to the ice-free periods in the Arctic eliminating any large variations in the ambient noise levels due to ice coverage. Roth et al. (2012) reported ambient levels of 80-83 dB ( $11\text{Pa}^2/\text{Hz}$ ) at 20–50 Hz in the Chukchi and Beaufort Seas for periods of no ice coverage with decrease of ~5 dB/octave above 50 Hz. These levels may be reflective of Resolute Bay as well, however caution should be exercised here, because noise levels are also dependent on the bottom type of the bay especially in shallow water (Zakarauskas et al., 1990). Pine et al. (2016) estimated an increase above ambient noise in the range of  $54 \pm 5.7$  dB and  $80 \pm 3.0$  dB for 0.1 to 5 kHz for various ships travelling at various speeds in the Hauraki Gulf, New Zealand, where ambient levels varied based on inner and outer gulf and frequency from ~65 dB to ~114 dB  $1 \mu\text{Pa}$  at 0.1 to 5 kHz. Picciulin et al. (2010) reported an increase in noise of 13 dB above ambient levels due to tourist ferry activity in a Northern Adriatic

Sea marine reserve where they considered the ambient noise to be fairly high (measured at ~135 dB re 1  $\mu$ Pa; below 1.5 kHz). Further more, Pine et al. (2016) also reported estimated source levels for medium and large sized ships to be between 159 and 198 dB re 1  $\mu$ Pa @ 1m. Although inference for Resolute Bay based on other studies, especially studies that are not located in the Arctic region, should be treated with caution, a general trend could be inferred that ship noise exceeds ambient noise levels in marine environments and thus, increases the background noise to various degrees. Therefore, our STL model provides circumstantial evidence regarding the likelihood that ship noise affects habitat important to Arctic cod.

#### *Disruption of Arctic cod spatial distribution*

Home ranges are important indicators of habitat use by species, and core areas often indicate habitat of critical importance. Using Kernel Utilization Distribution core home range area (50% KUD), we found that Arctic cod favor the northwestern part of the deeper depression at the head of Resolute bay when vessels were absent (VA), but relocated to the northeastern part when vessels were present (VP) and contracted to the northern part when vessels were moving (VM) (Fig. 2.4). Hurlbert's index of overlap (Hurlbert, 1978) for the 50% KUD between VA and VP is 0.31, for VA and VM is 0.45, and for VP versus VM is 0.20 (Fig. 2.4, Table 2.2)). The shift in the home ranges of Arctic cod when vessels are present (VP) and absent (VA) occurs for the area where a vessel would be typically docked and in the surrounding areas where STL values are between 0 and -15 dB. Arctic cod also exhibit low overlap for the 50% KUD at the individual level, where mean 50% KUD of Hurlbert's overlap index for VA vs. VP is



0.24. These changes occurred with the species maintaining their overall core area within the >20 m depth zone.

Our findings suggest that this species is not habituated (Fréon et al., 1993) to the noise produced by generators of the vessel and associated activity of the servicing tenders, and are moving away from the docked vessel to areas with lower noise levels. The observed 50% KUD during VM indicates that cod aggregated in the deepest part of the bay where depth extends to 30 m. This is further supported by the observation of low overlap with the natural 50% KUD. Studies have shown that fish species exhibit a sudden dive and school compression reaction when subjected to high noise from vessels (Vabø et al., 2002; Handegard et al., 2003; Fréon et al., 1993). The greatest noise levels produced by vessels are during periods of transit, and are influenced by the type and condition of the propellers, speed of the propeller shaft and of the vessel (Mitson and Knudsen, 2003). Arctic cod favor shallow embayments with deep depressions (Welch et al., 1993; Kessel et al., 2015) likely to avoid detection by echolocation from toothed whales; and an aggregating behavior in schooling fish is linked to predatory events and boat noise (Fréon et al., 1993; Mitson and Knudsen, 2003) as a defense mechanism due to perceived predation risk increase (Shafiei Sabet et al., 2016), during which they experience high levels of stress (Archard et al., 2012). Tropical and temperate studies have shown a change in the hearing threshold of different fish species at high noise levels (Scholik and Yan, 2001; Codarin et al., 2009), and Wysocki et al. (2006) demonstrated that ship noise doubled cortisol production in European perch (*Perca fluviatilis*), common carp (*Cyprinus carpio*) and gudgeon (*Gobio gobio*), and was independent of the actual hearing

sensitivity of the fish species. Thus, our results during VP and VM indicate that Arctic cod perceive ship noise as a threat.

Another metric of spatial use is the Minimum Convex Polygon (MCP), which shows the extent of the habitat used. We observed a significant decrease in the MCP for all Arctic cod individuals between VA and VP. Mean of MCP changed significantly from  $0.456 \pm 0.008$  (mean  $\pm$  1 standard error) for VA to  $0.335 \pm 0.009$  ha for VP (t-test p-value  $< 0.001$ ) (Fig. 2.5a and b). The decrease in MCP areas at the individual level during vessel presence suggests that cod were less exploratory during ship presence, remaining within a smaller range and may be cautious in their behavior similar to what would be expected during periods of increased predation risk (Fréon et al., 1993; Shafiei Sabet et al., 2016).

Alternative reason for shift and decrease in the spatial use of Arctic cod may be due to predator presence or prey resource relocation. Single predators (seals) were present for only eight out of more than 60 days in Resolute Bay and their presence was evenly distributed between VA and VP, thus any effects would also be evenly distributed across the home ranges for VA and VP. Marine mammals were recorded on three of the days of VM out of 14 total VM days. However, considering that marine mammals show avoidance behavior to moving vessels in the high Arctic (Richardson & Wursig, 1997), it is unlikely these were actively feeding during the exact times of vessel entering and exiting the bay. Thus, influences of marine mammals on the shift or special use extent during VA, VP and VM of cod seem insignificant. On the other hand, prey resource relocation due to noise as the possible cause for the observed shift in 50% KUD home range seems plausible. Zooplankton exhibit vertical migrations to avoid predators (Hays,

1995; Benoit et al., 2010), such as cod, however, we were not able to find studies on effects of acoustic anthropogenic disturbance on zooplankton. Thus, at the present time it is hard to infer whether any prey relocation occurs, and thus, whether it may be a cause for the observed home range shift.

### *Disruption of Arctic cod swimming behavior by ship noise*

Defining the occurrence and movement patterns of animals is crucial to understanding their spatial use in regards to the motivations driving their movements, as well as assessing any effects of anthropogenic disturbances. Three different movement patterns (MP) were identified for Arctic cod in Resolute Bay; i) MP 1 – characterized by medium rate of movement, low turning angle, medium to large sum of distance and medium variance of distance; ii) MP 2 – characterized by winding, slow (low rate of movement) movement, low overall distance travelled (sum of distance) and low variance of distance; and iii) MP 3 – characterized by fast rate of movement, large variance of distance, very low turn angles (Fig. 2.6a). Using the proportion values of VA as our expected proportions, significant differences were observed in VA and VP overall MP proportions ( $\chi^2 = 200.42$ ,  $p < 0.001$ ), and VA and VM overall MP proportion ( $\chi^2 = 15.2101$ ,  $p < 0.001$ ) (Fig. 2.6b). To examine where the actual changes in the MPs occur we compared the means; we found that exhibited MPs 1 and 3 were significantly different between VA and VP (p-values were 0.006 and 0.003, respectively, one tailed distribution; Fig. 2.6b). Proportions for MP2 during VA and VP did not change significantly ( $p = 0.40$ ). Furthermore, mean proportions for MP 2 and 3 during VM as

compared to VA also changed significantly, with MP 2 decreasing ( $p = 0.003$ ) and MP 3 increasing ( $p < 0.001$ ). MP 1 did not change significantly ( $p = 0.18$ ).

The three basic movement patterns identified in this study based on their rate of movement, total distance and turning angles have been identified for other species as typical of searching for optimal resources, feeding, and travelling, respectively (McLean et al., 2014). The identified MP 1 is typical of fish searching for food with medium rate of movement (Coughlin et al., 1992); MP 2 is typical of feeding, nesting, or mating with very tortuous trajectory and slow movements (Kasumyan, 1999); and MP 3 is typical of fish in transit, travelling, fleeing or dispersing with straight trajectories and fast rate of movement (Zollner and Lima, 1999; McLean et al., 2014). In this study we show that the natural movement pattern proportions identified were altered during vessel presence and movement. The changes observed in the proportions of each MP show that significantly more time is spent travelling greater distances at a fast rate of movement when ships are present. This is a tradeoff that carries implications for the overall energetics of the individuals (Ydenberg and Dill, 1986) especially during the summer months, when cod exploitation of the abundance of food resources may be interrupted (Hop et al., 1997). Carbonara et al. (2010) showed that energy stores took on average 1 hr to replenish post-exercise, and Booth et al. (1995) showed that re-synthesis of glycogen (used by white muscles in fish for high-speed exhaustive swimming bursts (Zupa et al., 2015)) took 12 hrs or more, lactate recovery took  $\geq 4$  hrs and muscle pH returned to normal within 2 hrs. This suggests that over time a decrease in the physiological condition of the individuals exposed to ship noise may be observed. Whiteley et al. (2006) reported that plasma cortisol levels in resting Arctic cod were  $3 \pm 2 \text{ ng ml}^{-1}$  compared to  $26 \pm 16 \text{ ng ml}^{-1}$  after

stress activity. Thus, the pronounced increase in MP 3 may also indicate increased stress, further affecting cod's energetic levels and body condition (Wright, 2007). Studies have shown that fish swimming speeds decrease based on prior exposure to a stressful event (or elevated cortisol levels), thus, lowering that individual's ability to cope with adverse conditions (Carbonara et al., 2010; Bintanja and Selten, 2014) or to escape approaching predators. In addition, Simpson et al. (2016) showed that fish species living in noisy habitats have increased susceptibility to predation due to diminished response or inability to hear approaching predators. This could be very significant for Arctic cod that deal with a number of predators that use echolocation to find prey.

Alternative factors may affect the behavior of Arctic cod, such as the presence of marine predators. A GLMM model showed no relationship between the two (Table 2.4), likely due to the presence of single individuals for only eight days out of more than 60 days of observations, with equal distribution of mammal presence during VA and VP. We also examined other environmental variables and none showed significant relationships (Table 2.4). Arctic cod exhibit diel migration and diet patterns during the winter and spring months, however, these are not observed in the summer months (Benoit et al., 2010) during which our study took place, thus the observed changes in MP proportions are not likely due to diel influences. Tidal cycles may affect distribution and availability of prey species (Chew et al., 2015), thus may be hypothesized as a cause for the observed decrease in MP2 during VM. However, vessels did not seem to follow a particular pattern in time of entering or leaving the bay and these occurred at any morning, evening or night hours regardless of the tidal cycle, thus decrease in MP2 during VM could not be attributed to tidal influences on prey availability.

*Broader implications of Arctic cod displacement for the high Arctic region*

Spatial shifts during disturbance events, such as the ones highlighted here, indicate that the species are being affected (Fréon et al., 1993; Vabø et al., 2002), and considering the importance of Arctic cod in the arctic marine food web, such shifts will play a major role in the distribution of predators and their availability and accessibility for Inuit subsistence. The results of this study indicate that with increase of vessel traffic into Resolute Bay over the summer months Arctic cod will avoid specific areas in response to ship noise. This could lead to changes in the community structure by changes in the species composition and food web interactions within the system similar to these observed at lower altitudes. Sandstrom et al. (2005) showed that navigation and boating activities significantly changed the recruitment of Pike (*Esox lucius*) and Bleak (*Alburnus alburnus*) in the Baltic Sea, and Richardson and Wursig (1997) showed that cetaceans completely leave a site for a few days. However, due to lack of alternative pelagic fish in the higher altitudes of the Arctic (Bradstreet et al., 1986), cascading effects are likely for marine predators, such as Northern fulmar (*Fulmarus glacialis*), Beluga whales, Polar bears (*Ursus maritimus*) and Ringed seals. Studies have shown that lack of cod affects negatively seabird body condition due to unstable foraging conditions and replacement with a lower quality prey (Gaston et al., 2012).

A disturbance of Arctic cod by increasing ship traffic will also influence the presence of marine mammals in the area with implications for local Inuit over half of whose diet consists of subsistence hunted Ringed seals, Beluga whales, Narwhals (*Monodon monoceros*) and Polar bears. This food is referred to as *niqituinnaq*, meaning *real food* (personal interviews; Wenzel, 1991 & 2009). Inuit use leftovers to feed their

sled dogs, or to share in the community with others in need; they make any inedible parts into jewelry and accessories, and sell to generate extra income (personal interviews; Wenzel, 2009). Thus, Inuit's income and expenses for food will be affected if increasing ship traffic disturbs Arctic cod.

Future studies should include the construction of an audiogram for Arctic cod, which at the present time is lacking, and experiments on recovery times after vessel noise disturbance. Our study lacked depth measurements, thus a three-dimensional analysis of Arctic cod behaviors with depth as the third component would be highly relevant to help establish the pattern of the movement behavior in the water column as influenced by sound propagation.

### *Conclusion*

The increase in vessel traffic in the high Arctic is already evident as ice recedes and interest in natural resources and cruises grows, and with that an increase in the underwater noise is expected. Our results accentuate ecologically and socially important, but previously unstudied effects of acoustic disturbance due to vessel traffic on Arctic cod in the high Canadian Arctic. This is the first documentation of Arctic cod noise-induced spatial avoidance via horizontal displacement and change in behavior due to ship traffic in its natural environment, and as such, it greatly advances our understanding of this species and its ecology, and contributes key information for the prediction of trends, management and conservation of the rapidly changing Arctic ecosystem.

## BIBLIOGRAPHY

- Anderson, P. J., and J. F. Piatt (1999). Community reorganization in the Gulf of Alaska following ocean climate regime shift. *Marine Ecology Progress Series*, 189, 117-123.
- Archard, G. A., R. L. Earley, A. F. Hanninen, and V. A. Braithwaite (2012). Correlated behaviour and stress physiology in fish exposed to different levels of predation pressure. *Functional Ecology*, 26, 637-645.
- Benoit, D., Y. Simard, J. Gagne, M. Geoffroy, and L. Fortier (2010). From polar night to midnight sun: photoperiod, seal predation, and the diel vertical migrations of polar cod (*Boreogadus saida*) under landfast ice in the Arctic Ocean. *Polar Biology*, 33, 1505-1520.
- Bintanja, R., and F. M. Selten (2014). Future increases in Arctic precipitation linked to local evaporation and sea-ice retreat. *Nature*, 509, 479-483.
- Booth, R. K., J. D. Kieffer, K. Davidson, A. T. Bielak, and B. L. Tufts (1995). Effects of late season catch and release angling on anaerobic metabolism, acid-base status, survival, and gamete viability in wild Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences*, 52, 283-290.
- Bradstreet, M. S. W., K. J. Finley, A. D. Sekerak, W. B. Griffiths, C. R. Evans, M. F. Fabijan, and H. E. Stellard (1986). Aspects of the biology of Arctic cod (*Boreogadus saida*) and its importance in Arctic marine food chains. *Canadian Technical Report of Fisheries and Aquatic Sciences 1491*. viii +193p.
- Brekke, B., and G. W. Gabrielsen (1994). Assimilation efficiency of adult Kittiwakes and Brunnich's Guillemots fed Capelin and Arctic Cod. *Polar Biology*, 14, 279-284.



- Calenge, C. (2006) The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modeling*, 197, 516-519.
- Caltrans. (2001). *Pile Installation Demonstration Project Fisheries Impact Assessment*. Retrieved January 12, 2016, from nrc.gov:  
<http://www.nrc.gov/docs/ML1434/ML14345A579.pdf>
- Carbonara, P., I. Corsi, S. Focardi, G. Lembo, S. Rochira, M. Scolamacchia, et al. (2010). The effects of stress induced by cortisol administration on the repeatability of swimming performance tests in the European sea bass (*Dicentrarchus labrax* L.). *Marine and Freshwater Behaviour and Physiology*, 43 (4), 283-296.
- Chew L., V. C. Chong, A. L. Ooi, and A. Sasekumar (2015). Vertical migration and positioning behavior of copepod in a mangrove estuary: Interactions between tidal, diel light and lunar cycles. *Estuarine, Coastal and Shelf Science*, 152, 142-152.
- Codarin, A., L. E. Wysocki, F. Ladich, and M. Picciullin (2009). Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy). *Marine Pollution Bulletin*, 58, 1880-1887.
- Comiso, J. C., C. L. Parkinson, R. Gersten, and L. Stock (2008). Accelerated decline in the Arctic sea ice cover. *Geophysical Research Letters*, 35 (L01703).
- Cooke, S. J., J. D. Midwood, J. D. Thiem, P. Kimley, M. C. Lucas, E. B. Thorstad, J. Eiler, C. Holbrook, and B. C. Ebner (2013). Tracking animals in freshwater with electronic tags: past, present and future. *Animal Biotelemetry*, 1:5.

- Coughlin, D. J., J. R. Strickler, and B. Sanderson (1992). Swimming and search behaviour in clownfish, *Amphiprion perideraion*, larvae. *Animal Behaviour*, 44 (3), 427-440.
- Cressey, D. (2011). Open water: As Ice melts, fresh obstacles confront Arctic researchers. *Nature*, 478, 174-177.
- Espinoza, M., T. J. Farrugia, D. M. Webber, F. Smith, and C. G. Lowe (2011). Testing a new acoustic telemetry technique to quantify long-term, fine-scale movements of aquatic animals. *Fisheries Research*, 108, 364-371.
- Fay, R. R., and A. N. Popper (2000). Evolution of hearing in vertebrates: the inner ears and processing. *Hearing Research*, 149, 1-10.
- Fieberg, J. R. (2005). *Home range overlap indices implemented using kernel density estimators with plug-in smoothing parameters and Program R*. Retrieved June 15, 2015, from Data Repository of University of Minnesota:  
<http://dx.doi.org/10.13020/D6G59W>
- Fréon, P., F. Gerlotto, and M. Soria (1993). Variability of *Harengula* spp. school reactions to boats or predators in shallow water. *ICES Marine Science Symposium*, 196, 30-35.
- Gaston, A. J., P. A. Smith, and J. F. Provencher (2012). Discontinuous change in ice cover in Hudson Bay in the 1990s and some consequences for marine birds and their prey. *ICES Journal of Marine Science*, 69 (7), 1218-1225.
- Government of Nunavut. (2013). *Resolute Bay*. Retrieved February 23, 2016, from Government of Nunavut:

<http://www.gov.nu.ca/sites/default/files/files/Resolute%20Bay%20Profile%20new%20layout.pdf>

Graham, M., and H. Hop (1995). Aspects of Reproduction and Larval Biology of Arctic Cod (*Boreogadus saida*). *Arctic*, 48 (2), 130-135.

Handegard, N. O., K. Michalsen, and D. Tjøstheim (2003). Avoidance behaviour in cod (*Gadus morhua*) to a bottom-trawling vessel. *Aquatic Living Resources*, 16, 265-270.

Hastings, M. C., A. N. Popper, J. J. Finneran, and P. J. Lanford (1996). Effects of low-frequency underwater sound on hair cells of the inner ear and lateral line of the teleost fish *Astronotus ocellatus*. *Journal of the Acoustical Society of America*, 1759-1766.

Hays, G. C. (1995). Diel vertical migration behaviour of *Calanus hyperboreus* at temperate latitudes. *Marine Ecology Progress Series*, 127, 301-304.

Headland, R. K. (2015). *Transits of the Northwest Passage to end of the 2015 navigation season*. Cambridge: Scott Polar Research Institute.

Hop, H., H. E. Welch, and R. E. Crawford (1997). Population structure and feeding ecology of Arctic cod schools in the Canadian high Arctic. *American Fisheries Society Symposium*, 19, 68-80.

Hurlbert, S. H. (1978). The measurement of niche overlap and some relatives. *Ecology*, 59 (1), 67-77.

Hussey, N. E., S. T. Kessel, K. Aarestrup, S. J. Cooke, P. D. Cowley, A. T. Fisk, R. G. Harcourt, K. N. Holland, S. J. Iverson, J.F. Kocik, J. E. Mills Flemming, and F. G.

- Whoriskey (2015). Aquatic animal telemetry: A panoramic window into the underwater world. *Science*, 348 (6240), 1221-1231.
- IASC. (2005). *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*. Retrieved February 20, 2015, from Arctic Climate Impact Assessment: <http://www.acia.uaf.edu/pages/overview.html>
- Johannessen, O. M., L. Bengtsson, M. W. Miles, S. I. Kuzmina, V. A. Semenov, G. V. Alekseev, et al. (2004). Arctic climate change: observed and modelled temperature and sea-ice variability. *Tellus. Series A, Dynamic meteorology and oceanography*, 56 (5), 328-341.
- Judson, B. (2010). Trends in Canadian Arctic Shipping Traffic – Myths and Rumours. *Proceedings of the Twentieth (2010) International Offshore and Polar Engineering Conference* (pp. 1292-1299). Beijing: The International Society of Offshore and Polar Engineers (ISOPE).
- Kasumyan, A. O. (1999). Olfaction and taste senses in sturgeon behaviour. *Journal of Applied Ichthyology*, 15, 228-232.
- Kasumyan, A. O. (2005). Structure and function of the auditory system in fishes. *Journal of Ichthyology*, S223-S270.
- Kessel, S. T., N. E. Hussey, R. E. Crawford, D. J. Yurkowski, C. V. O'Neill, and A. T. Fisk (2015). Distinct patterns of Arctic cod (*Boreogadus saida*) presence and absence in a shallow high Arctic embayment, revealed across open-water and ice-covered periods through acoustic telemetry. *Polar Biology*, 39, 1057-1068.

- MacFarlane, J. M. (2012). *Full Transits of the Canadian Northwest Passage*. Retrieved February 22, 2016, from Nauticapedia.ca:  
[http://nauticapedia.ca/Articles/NWP\\_Fulltransits.php](http://nauticapedia.ca/Articles/NWP_Fulltransits.php)
- McCauley, R. D., J. Fewtrell, and A. N. Popper (2003). High intensity anthropogenic sound damages fish ears. *Journal of the Acoustical Society of America*, 638-642.
- McLean, M. F., C. A. Simpfendorfer, M. R. Heupel, M. J. Dadswell, and M. J. Stokesbury (2014). Diversity of behavioural patterns displayed by a summer feeding aggregation of Atlantic sturgeon in the intertidal region of Minas Basin, Bay of Fundy, Canada. *Marine Ecology Progress Series*, 496, 59-69.
- Mellen, R. H. (1984). Sound absorption in seawater. *Physics Today*, 37 (1), S4-S5.
- Mitson, R. B., and H. P. Knudsen (2003). Causes and effects of underwater noise on fish abundance estimation. *Aquatic Living Resources*, 16, 255-263.
- Morrison, W. R. (2006). *Arctic sovereignty*. (Historica Foundation) Retrieved February 2, 2015, from The Canadian Encyclopedia:  
<http://www.thecanadianencyclopedia.ca/en/article/arctic-sovereignty>
- Naiman, R. J., H. Decamps, and M. E. McClain, (2005). *Riparia: ecology, conservation and management of streamside communities*. Elsevier Inc.
- Nedwell, J. R., B. Edwards, A. W. Turnpenny, and J. Gordon (2004). *Fish and marine mammal audiograms: A summary of available information*. Hampshire: Subacoustech Ltd.
- Picciulin, M., L. Sebastianutto, A. Codarin, A. Farina, and E. Ferrero (2010). In situ behavioural responses to boat noise exposure of *Gobius cruentatus* (Gmelin, 1789; fam. Gobiidae) and *Chromis chromis* (Linnaeus, 1758; fam.

- Pomacentridae) living in a Marine Protected Area. *Journal of Experimental Marine Biology and Ecology*, 386, 125-132.
- Pine, M. K., A. G. Jeffs, D. Wang, and C. A. Radford (2016). The potential of vessel noise to mask biologically important sounds within ecologically significant embayments. *Ocean & Coastal Management*, 127, 63-73.
- Popper, A. N., and R. R. Fay (2011). Rethinking sound detection by fishes. *Hearing Research*, 25-36.
- Popper, A. N., and M. C. Hastings (2009). Effects of anthropogenic sources of sound on fishes. *Journal of Fish Biology*, 75, 455-489.
- Popper, A. N., M. B. Halvorsen, A. Kane, D. L. Miller, M. E. Smith, J. Song, et al. (2007). The effects of high-intensity, low-frequency active sonar on rainbow trout. *Journal of the Acoustical Society of America*, 623-635.
- Richardson, M., K. Cowtan, E. Hawkins, and M. B. Stolpe (2016). Reconciled climate response estimates from climate models and the energy budget of Earth. *Nature Climate Change*, 1-6.
- Richardson, J. W. and B. Würsig (1997). Influences of man-made noise and other human actions on cetacean behavior. *Marine and Freshwater Behaviour and Physiology*, 29, 183-209.
- Roth, E. H., J. A. Hildebrand, S. M. Wiggins, and D. Ross (2012). Underwater ambient noise on the Chukchi Sea continental slope from 2006-2009. *Journal of the Acoustical Society of America*, 131, 104-110.

- Russell, I. C., A. Moore, S. Ives, L. T. Kell, M. J. Ives, and R. O. Stonehewer (1998). The migratory behaviour of juvenile and adult salmonids in relation to an estuarine barrage. *Hydrobiologia*, 321-333.
- Sandstrom, A., B. K. Eriksson, P. Karas, M. Isæus, and H. Schreiber (2005). Boating and Navigation Activities Influence the Recruitment of Fish in a Baltic Sea Archipelago Area. *Ambio*, 34 (2), 125-130.
- Scholik, A. R., and H. Y. Yan (2001). Effects of underwater noise on auditory sensitivity of a cyprinid fish. *Hearing Research*, 152, 17-24.
- Shafiei Sabet, S., K. Wesdorp, J. Campbell, P. Snelderwaard, and H. Slabbekoorn (2016). Behavioural responses to sound exposure in captivity by two fish species with different hearing ability. *Animal Behaviour*, 116, 1-11.
- Simpson, S. D., A. N. Radford, S. L. Nedelec, M. C. Ferrari, D. P. Chivers, M. I. McCormick, et al. (2016). Anthropogenic noise increases fish mortality by predation. *Nature Communcations*, 1-7.
- Slabbekoorn, H., N. Bouton, I. van Opzeeland, A. Coers, C. ten Cate, and A. N. Popper (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution*, 25, 419-427.
- Smith, F. (2013). Understanding HPE in the VEMCO Positioning System (VPS). VEMCO.
- Tulaktarvik Inc. (2014). *Submission to the tanker safety expert panel (Phase II – 'North of 60')*. Iqaluit: Tulaktarvik Inc.
- Vabø, R., K. Olsen, and I. Huse (2002). The effect of vessel avoidance of wintering Norwegian spring spawning herring. *Fisheries Research*, 58, 59-77.

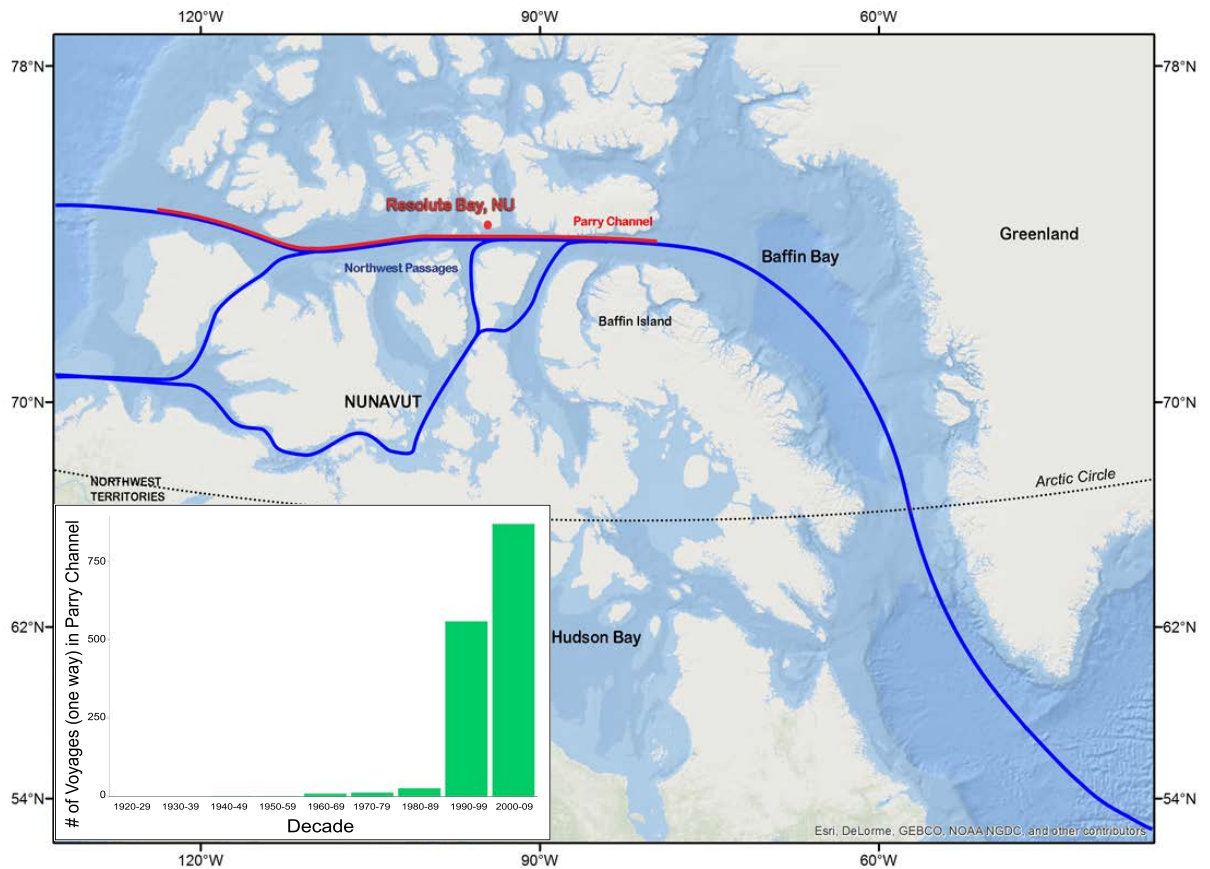
- Vaudo, J. J., and C. G. Lowe (2006). Movement patterns of the round stingray *Urobatis halleri* (Cooper) near a thermal outfall. *Journal of Fish Biology*, 1756-1766.
- Welch, H. E., M. A. Bergmann, T. D. Siferd, K. A. Martin, M. F. Curtis, R. E. Crawford, et al. (1992). Energy Flow through the Marine Ecosystem of the Lancaster Sound Region, Arctic Canada. *Arctic*, 45 (4), 343-357.
- Welch, H. E., R. E. Crawford, and H. Hop (1993). Occurrence of Arctic Cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian high Arctic. *Arctic*, 46 (4), 331-339.
- Wenzel, G. W. (1991). *Animal Rights, Human Rights: Ecology, Economy, and Ideology in the Canadian Arctic*. Toronto, Buffalo: University of Toronto Press.
- Wenzel, G. W. (2009). Canadian Inuit subsistence and ecological instability— if the climate changes, must the Inuit? *Polar Research*, 28, 89-99.
- Whiteley, N. M., J. S. Christiansen, and S. Egginton (2006). Polar cod, *Boreogadus saida* (Gadidae), show an intermediate stress response between Antarctic and temperate fishes. *Comparative Biochemistry and Physiology, Part A* 145, 493-501. doi: 10.1016/j.cbpa.2006.08.023.
- Wright, A. J. (2007). Anthropogenic Noise as a Stressor in Animals: A Multidisciplinary Perspective. *International Journal of Comparative Psychology*, 20, 250-273.
- Wysocki, L. E., J. P. Dittami, and F. Ladich (2006). Ship Noise and Cortisol Secretion in European Freshwater Fishes. *Biological Conservation*, 128 (4), 501-508.
- Ydenberg, R. C., and L. M. Dill (1986). The economics of fleeing from predators. *Advances in the Study of Behaviour*, 16, 229-249.



Zakarauskas, P., D. M. F. Chapman, and P. R. Staal (1990). *Journal of the Acoustical Society of America*, 131, 2064-2071.

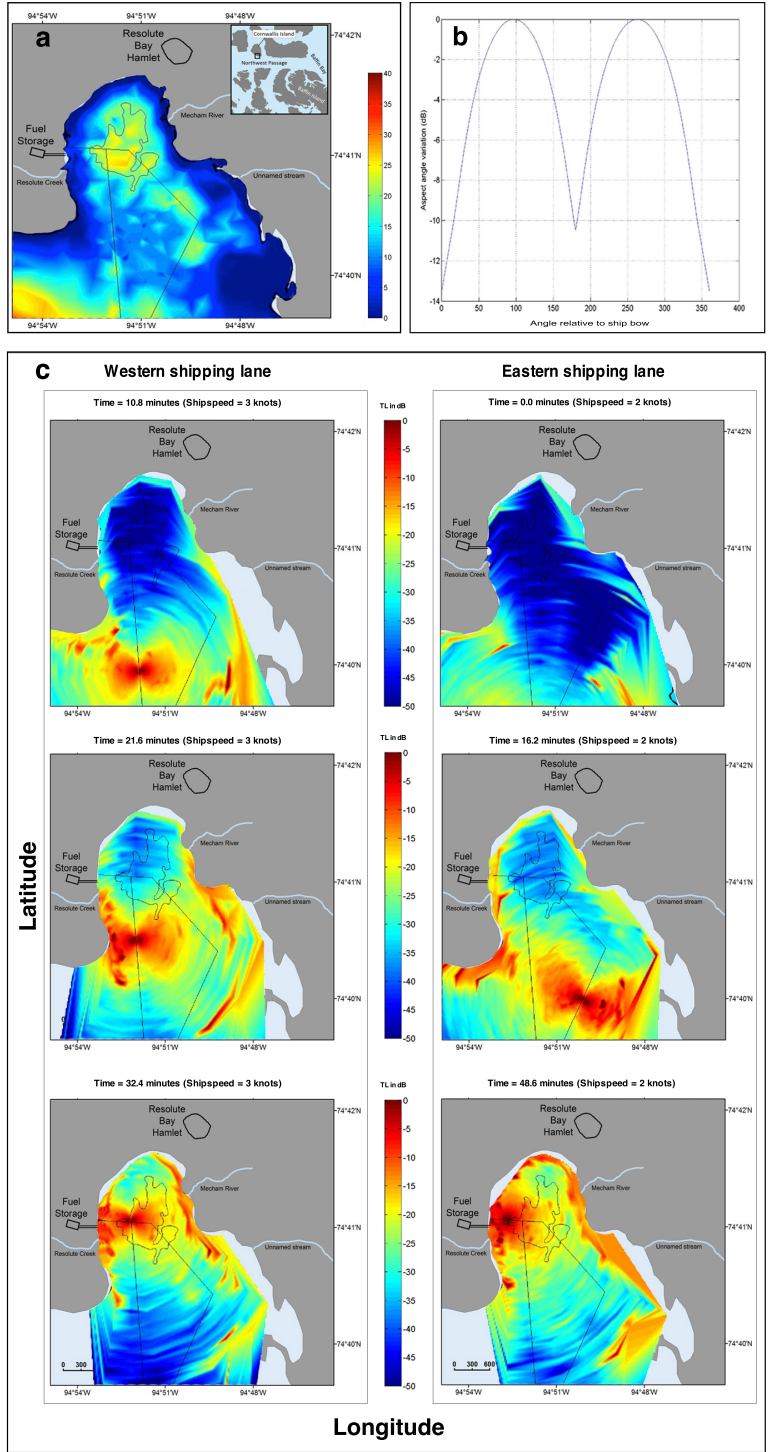
Zollner, P. A., and S. L. Lima (1999). Search Strategies for Landscape-Level Interpatch Movements. *Ecology*, 80 (3), 1019-1030.

Zupa, W., P. Carbonara, M. Spedicato, and G. Lembo (2015). Modelling swimming activities and energetic costs in European sea bass (*Dicentrarchus labrax* L., 1758) during critical swimming tests. *Marine and Freshwater Behaviour and Physiology*, 48, 341-357.



**Figure 2.1** | Map of Northwest Passage routes (in blue) and location of Resolute Bay, Nunavut (latitude 74.6773°N and longitude 94.8297°W). The Parry Channel is shown in red along a route of the Northwest Passage. Base map used in this figure is from the public domain Natural Earth and is freely available for personal, educational and commercial uses. See <http://www.naturalearthdata.com/about/terms-of-use/> for more details. **(Inlay)** Number of one-way ship voyages in the Parry Channel per decade (excludes yachts and other vessel <50m). Information was obtained from Canadian Coast Guard Services (1995 to 2009), Headland (2015) and MacFarlane (2012). Vessel one-way voyages were defined as follows: i) vessels that had as an aim to cross partially or fully the Northwest channel were counted as a single voyage unless they performed a

return trip, which in that case was counted as a second voyage; ii) each port-to-port trip in directions east-to-west, west-to-east, south-to-north and north-to-south, performed by vessels, such as cargo or ice-breakers, if these were known or distinguished from data set, was counted as a separate voyage; and iii) if a vessel discontinued reporting everyday at 1600 hrs as is regulated by NORDREG, was considered to have left the NORDREG zone and thus the Parry Channel. Only vessels with length of over 50 m were used, thus tug boats and yachts <50 m were excluded; submarines were excluded as well.

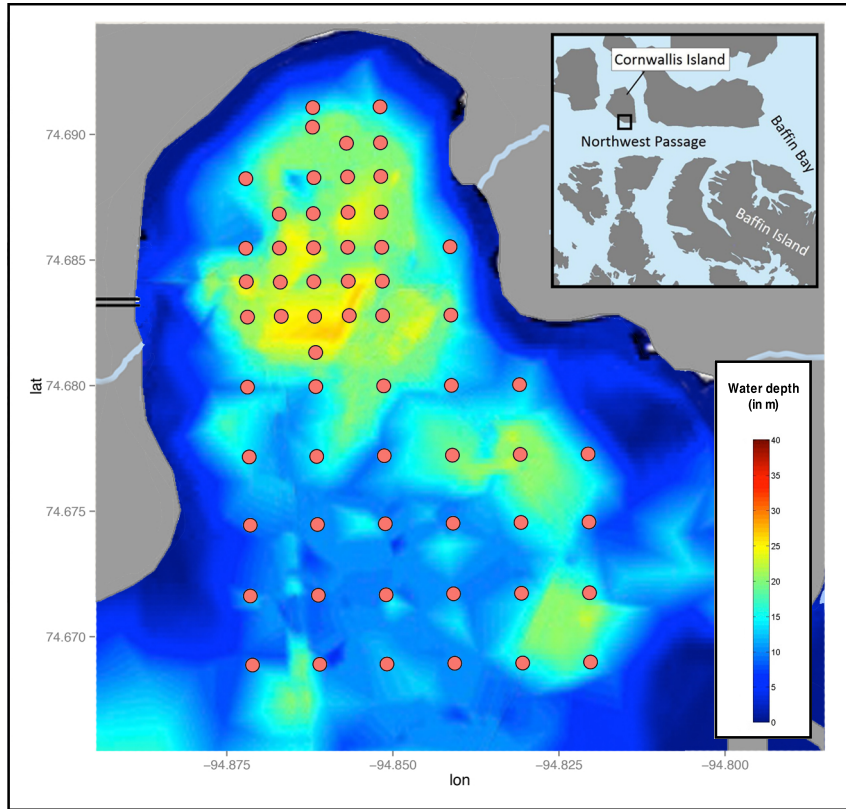


**Figure 2.2** | (a) Bathymetry of Resolute bay in meters (dark blue is 0-5 m and yellow to orange 25-30 m); straight black lines denote vessel navigation lanes, and curved black

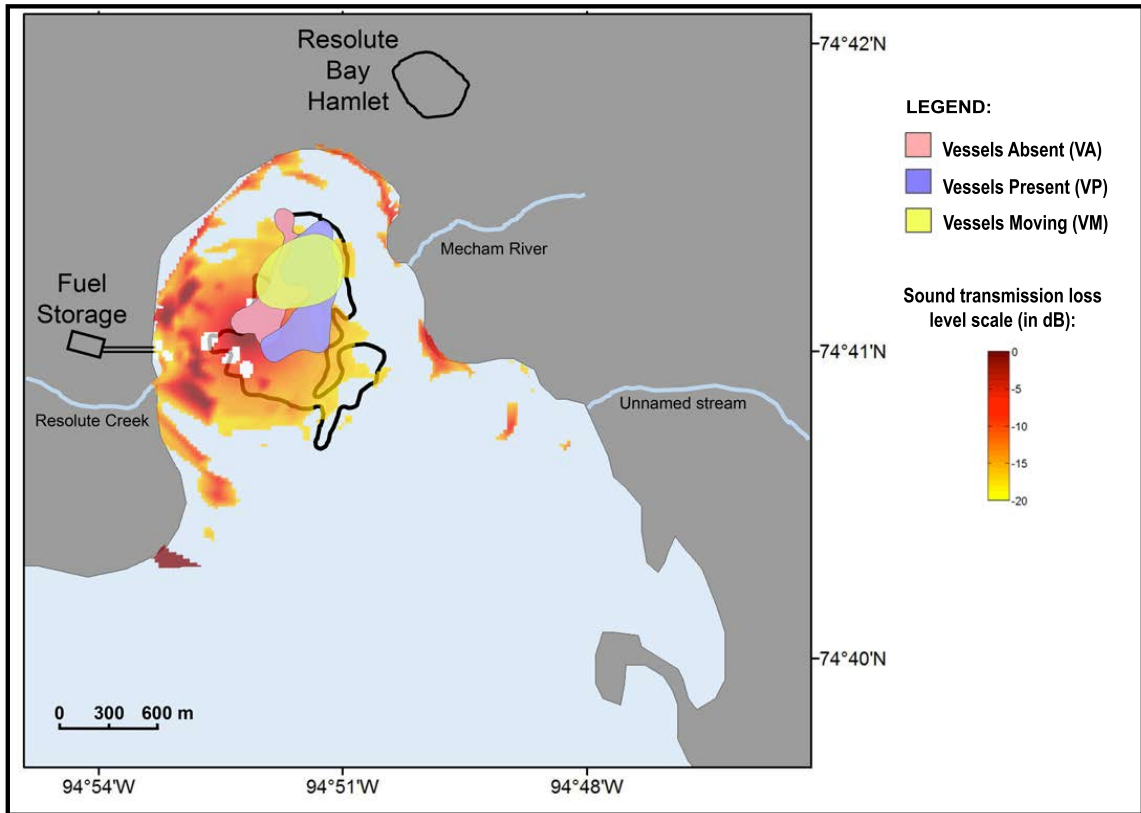
line denotes depth of 20 meters and up.

**(b)** Noise-field directionality around a vessel (0 and 360 degrees are the bow and 180 degrees is straight behind); There are 3 dB and 13 dB higher noise levels at the rear and the sides of the vessel, respectively, compared to the bow.

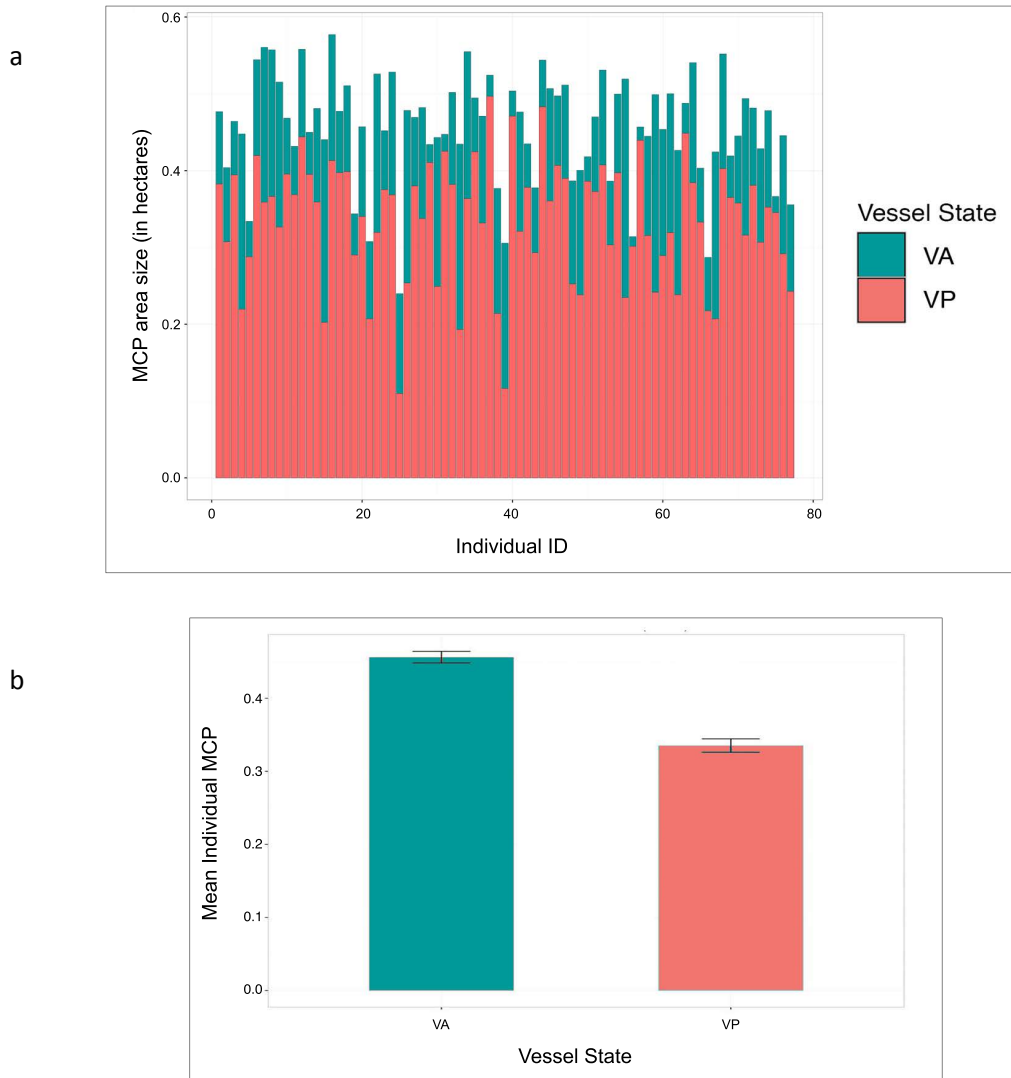
**(c)** Transmission losses (TL; in decibels) of vessels entering the bay along the Eastern and Western shipping lanes with relative sound field 1 m above the seafloor and speed of 3 kts for the western shipping lane and 2 kts for the eastern lane.



**Figure 2.3** | VEMCO 180kHz acoustic receiver array (red circles) are mapped on a bathymetry map of the bay of Resolute, Nunavut (latitude 74.6773°N and longitude 94.8297°W).

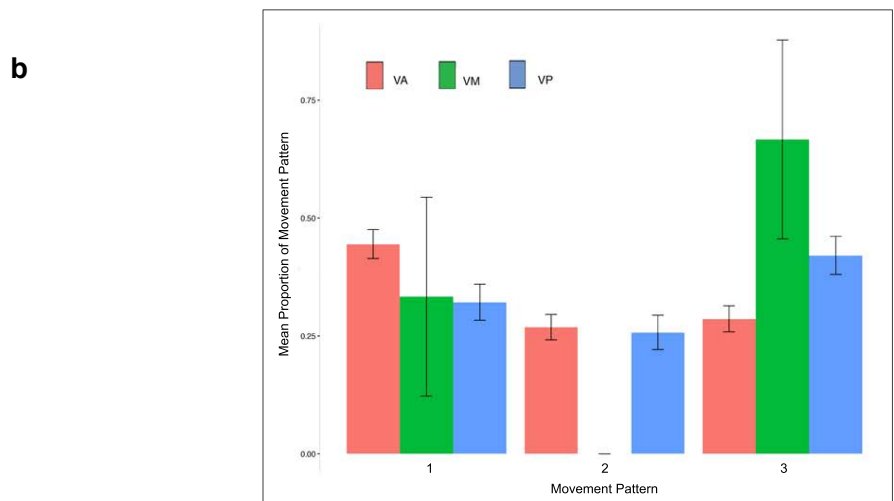
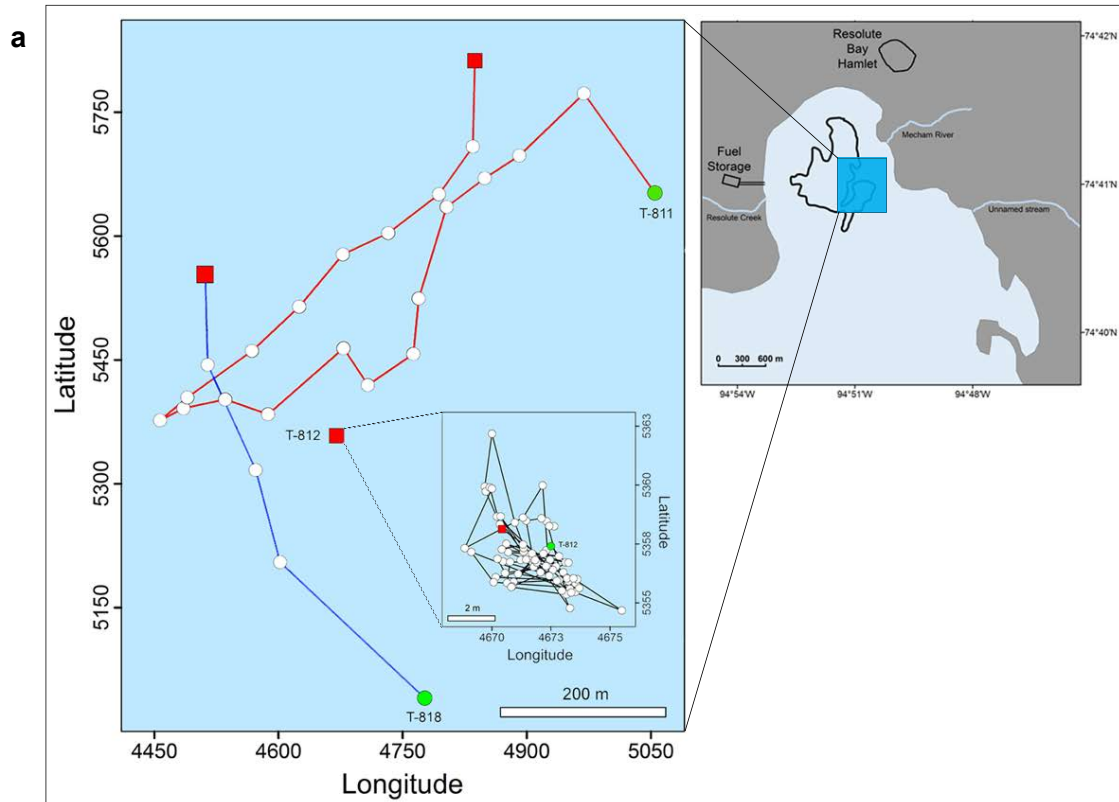


**Figure 2.4** | VA (red), VP (purple) and VM (yellow) 50% KUD home ranges of Arctic Cod are plotted over sound transmission losses (STL) with values of 0dB to -18dB. The STL is centered at the most common large vessel docking location (dark red in middle). Black line denotes the area of the bay that is with depth 20 to 30m.



**Figure 2.5 | (a)** Minimum Convex Polygon (MCP) area sizes are shown for all Arctic Cod individuals when vessels are present in bay (VP) (red) and when vessels are absent from the bay (VA) (blue/green). VP is overlapped on top of VA. **(b)** Mean values for MCP area sizes (in hectares with plotted SE bars) of Arctic Cod individuals when vessels are present in bay (VP) (blue/green, 0.335 ha) show significant decrease ( $p < 0.001$ ) compared to when vessels are absent from the bay (VA) (red, 0.456 ha).





**Figure 2.6** | (a) Movement Patterns (MP). An example of MP 1 is shown with red movement path: individual 811 travelled a total distance of 1539.75 m, had mean ROM 0.1566 m/s, mean turning angle 0.03337, mean distance between relocations 76.99 m and variance of distance 898.12m. An example of MP 2 is shown in Inlay with black

movement path: individual 812 travelled a total distance of 114.87 m with mean distance between relocations 1.53 m, mean ROM 0.0038m/s and variance of distance of 1.4554.

An example of MP 3 is shown with blue movement path: individual 818 travelled a total distance of 604.95m, mean distance between relocations of 151.24, mean ROM 0.3304 m/s, variance of distance 3676.84m, and mean turn angle 0.01649. Black line on general bay map denotes the area of the bay that is with depth 20 to 30m.

**(b)** Proportions of MP 1, 2 and 3 for Arctic cod are plotted for each of the three vessel states: Vessels absent (VA) (red), Vessels Present (VP) (blue) and Vessels are moving (VM) (green). Using VA as expected proportions, significant differences were observed in VA and VP overall MP proportions ( $\chi^2 = 200.42$ ,  $p < 0.001$ ), and VA and VM overall MP proportion ( $\chi^2 = 15.2101$ ,  $p < 0.001$ ). Examining different MPs for each vessel state, we found that exhibited MPs 1 and 3 were significantly different between VA and VP (p-values were 0.006 and 0.003, respectively, one-tailed distribution); proportions for MP2 during VA and VP did not change significantly ( $p = 0.40$ ); mean proportions for MP 2 and 3 during VM as compared to VA changed significantly, with MP 2 decreasing ( $p = 0.003$ ) and MP 3 increasing ( $p < 0.001$ ), while MP 1 did not change significantly ( $p = 0.18$ ).

**Table 2.1 | Number of positions used in the estimation of Kernel utilization**

**distribution home ranges and MCP.** Listed below are the numbers of positions for each vessel state used in the determination of Arctic cod spatial use. HR stands for Kernel utilization distribution home ranges and MCP for minimum convex polygon.

	# of positions used for HR and MCP analyses
<b>Vessels Absent (VA)</b>	7975
<b>Vessels Present (VP)</b>	3843
<b>Vessels Moving in bay (VM)</b>	34

**Table 2.2 | Overlap metrics for Arctic cod home ranges as a population.** This table shows core (50%) and extended (95%) home range (KUD) overlap values when vessels are absent (VA; considered in this study to be the natural state and size of the home ranges) compared to when vessels are present (VP), and to when vessels are moving in and out of the bay (VM). HR denotes the percent overlap or proportion of the VA home range that is overlapped by the VP or VM home range and vice versa. PHR denotes the volume of overlap or the probability of the VA home range being located in the VP or VM home range and vice versa. Hurlbert index is measure of general overlap, with value of zero denoting no overlap, and 1 denoting complete overlap and uniform distribution.

	<b>VA &amp; VP</b>		<b>VA &amp; VM</b>	
<b>KUD %</b>	<b>50%</b>	<b>95%</b>	<b>50%</b>	<b>95%</b>
<b>Volume Intersection</b>	0.48	0.78	0.52	0.61
<b>HR 1,2</b>	0.54	0.96	0.82	0.77
<b>HR 2,1</b>	0.50	0.89	0.46	0.68
<b>PHR 1,2</b>	0.54	0.94	0.53	0.73
<b>PHR 2,1</b>	0.58	0.98	0.85	0.89
<b>Hurlbert Index</b>	0.31	0.99	0.45	0.79

**Table 2.3 | Frequency (Freq) and proportion (Pr) values of movement patterns (MP)**

**1, 2 and 3.** Frequency and proportion values of each of the three movement patterns are shown below as separated by vessel state. VA stands for vessels absent; VP for vessels present and VM for vessels moving.

	<b>VA Freq</b>	<b>VP Freq</b>	<b>VM Freq</b>	<b>VA Pr</b>	<b>VP Pr</b>	<b>VM Pr</b>
<b>MP 1</b>	1889	616	8	0.468	0.359	0.381
<b>MP 2</b>	1052	374	0	0.261	0.218	0
<b>MP 3</b>	1093	724	13	0.271	0.422	0.619

**Table 2.4 | Influences of environmental variables on movement patterns.** A

generalized linear mixed model (glmmadmb in R) was run with Poisson response distribution and a random factor for the number of different IDs detected that day to examine any influence of the environmental variables listed below on the proportions of movement patterns. The values show that there is no significant influence of any of these environmental variables on the movement pattern proportions. Daily DO stands for daily dissolved oxygen.

	<b>Estimate</b>	<b>St. Error</b>	<b>z-value</b>	<b>Pr(&gt; z )</b>
<b>Mammal Presence</b>	0.328	0.957	0.34	0.73
<b>Daily DO</b>	-0.034	0.047	-0.71	0.48
<b>Water Temperature (°C)</b>	-0.061	1.705	-0.04	0.97
<b>Salinity</b>	-0.979	4.45	-0.22	0.83
<b>Mean Wind Speed</b>	-0.013	0.036	-0.35	0.73
<b>Mean Wind Direction</b>	-0.015	0.041	-0.37	0.71

## CHAPTER 3

“AN ICE-FREE SUMMER”

The documentary film produced as part of chapter 3 has been co-produced by A.T. Fisk

## *Synopsis*

Inuit's life in the Arctic community of Resolute Bay, Nunavut, has been possible because of their reliance on subsistence hunting. Mark Amarualik, a middle-aged hunter who grew up there, shares that Inuit diet consists of more than 50 percent marine mammals. Other citizens of the community are also concerned with the changes occurring in the Arctic ecosystem, the change of migration routes of marine animals due to decrease in their food source, Arctic cod, and that ships coming into the bay are affecting the cod negatively. The concerns are well founded, because food security in the village is an issue due to skyrocketing grocery prices. Science experts confirm Inuit's observations of decrease of multi-year ice and change in weather patterns, and they undertake a research project to find out whether Arctic cod, the primary marine mammal prey, are indeed affected by ships. Researchers track the fish using novel instrumentation and record underwater noise made by vessels. Although researcher findings support Inuit's observations that cod are displaced by vessel noise, all this work has taken place amidst Inuit dislike for anyone bothering the animals and tagging them. Scientists are understanding of Inuit's sensitivity on the issue, but are hopeful that in the future, Inuit and the traditional ecological knowledge they possess will be key components in the science in aid of conservation and management.

## *Methods*

The pre-production for the film took place during 2014 (Aug. 11, 2014 to Sept. 10, 2014) and 2015 (Aug. 7 to Sept. 1, 2015) field seasons. The production had an



overlap with pre-production during the 2014 season and thereafter between the two seasons, and was completed during the 2015 field season. We used one Blackmagic Cinematic Production 4K camera, Canon 60D (season 2014) DSLR, Canon 70D (season 2015) DSLR, a variety of zoom and prime lenses (18-200mm, 18-135mm, 70-300mm with a 2x converter, 35mm, 85mm, 100mm), Canon XF100 Camcorder (kindly donated for our use by the Resolute Bay Hamlet and the Government of Nunavut, Social Services Department), two GoPro Hero 3 and one GoPro Hero3+ cameras to capture all interviews and action. Sound was recorded via four Rode lavalier microphones, one Rode NTG1 directional microphone (also kindly donated for our use by the Resolute Bay Hamlet and the Government of Nunavut, Social Services Department), one Zoom H4N recorder and four Zoom H1N recorders. Between the two field seasons, interviews were recorded and lab work captured with key researchers to help provide insight into the research projects and issues facing the Arctic. During the 2015 season in Resolute Bay we interviewed local Inuit to help us establish the background, history and culture of the Arctic region, and to capture the traditional ecological knowledge they possess of the Arctic ecology. More interviews were recorded with researchers during 2016 to help us complete the image and understanding of the Arctic in the public eye, and to explore the researchers views on Inuit traditional ecological knowledge (TEK).

As part of our efforts to strengthen our relations with the local community and promote collaboration, during the 2014 season we organized a community meeting to gain insight and understand issues the local community is facing and to gain their support. As requested by the local community and in an effort to empower them and enable them to communicate effectively, in 2015 we organized a workshop to teach local

students and interested individuals different photography, video-capture and video-editing techniques. A second workshop was organized the same year to introduce the complementation of TEK with modern research techniques and to promote environmental engagement and stewardship. A presentation featuring clips and work on the documentary film was done in Essex, Ontario in 2016 to inform and engage the general public of the issues facing the Arctic and the complementary use of TEK in science.

For the film, I made use of narrative to help lead the story and convey information that would have remained hidden from audiences not versed in the science and/or subject if a non-narrative approach was used. Dynamic shots were used as much as possible to convey the changes occurring in the Arctic environment and with that, inevitably, in Inuit way of life. Filming under natural light conditions was used to help establish the inherent lack of pretense surrounding that region and the science. Native throat singing along with modern tunes were chosen as metaphors of connections, and to complement some of the ideas behind the film, such as collaboration between Inuit and researchers, complementation of TEK with high tech research, and modernization and development of the Canadian Arctic.

#### *Film main topics, goals and impact*

The main topic of “An ice-free summer” is Inuit reliance on the environment for survival, and how vessels are affecting this. Food security is already an issue in these remote communities, and it is of even greater concern when the environment is changing with such rapidity. This change is driven by climate change (a subtopic of the film) and

the retreat of ice that has facilitated the increase of vessel traffic in the Arctic region. Another main topic examined in the film is the Traditional Ecological Knowledge (TEK) that Inuit possess, its accuracy and complementation with scientific research. As subtopic to that, the necessity of collaboration between Inuit and scientists is highlighted as the pathway to conservation and sustainable management of the Arctic ecosystem.

There are two overall goals and sought impacts of the film. 1) To communicate the above-mentioned issues/topics to audiences beyond the scientific and, as impact, to generate discussion and interest among these audiences. These will be accomplished with the selected distribution of the film and via private viewings followed by discussions. 2) Another goal is to show that non-Inuit researchers care about the Arctic environment and the Inuit way of life and culture, and that Inuit and non-Inuit scientists working together could improve management and conservation endeavors. The impacts are improvement of the working relationships and communication between researchers and Inuit, and facilitation of future collaborations. The film accomplishes that by presenting the views of the Inuit alongside those of researchers highlighting the similarities of opinions and understanding of the environment, and also, by showcasing that TEK and modern science complement each other.

#### *Description of film process*

The film was conceived during a conversation in November 2013 with Dr. Aaron Fisk regarding a master's degree in the Arctic, which was to combine natural, and social sciences. Over the months of December 2013 to July 2014 the project's theme, some

content and points-of-view (POV) were established. The strongest influence for the themes and POVs used were from “Chasing Ice”, a film by Jeff Orlowski (2012) in which a scientist doing photography work on the glaciers is leading the narration/story of the film in a self-reflexive manner. Originally, my film was aiming for a similar approach, i.e. using self-reflection to allow for inclusion of anything that influences the Arctic environment and the Inuit, such as contaminants in the bodies of marine mammals, and the connectivity between the land and the ocean, and between the Arctic and the rest of the world. The main themes at that point were the research on Arctic Cod and the Inuit reliance on the environment, and the sub-theme, complementation of Inuit TEK with modern science. With the self-reflexive approach and main themes in mind, my presence in some scenes, such as interviews and doing scientific work, was appropriate. However, as the focus of the film shifted (removing research from being a main theme) rendering the self-reflexive approach unsuitable after all production had already been completed in Resolute, these scenes could not be re-filmed and had to be inserted as available. Thus, Max Stahl and his approach to finding the most important overarching issue after all filming was completed and only then edited, became the inspiration for the final version of my film.

Due to the nature of the Arctic environment, and the lack of experience of any of the crew, including me, in Resolute Bay, Nunavut, some of the pre-production was left until I was on location. Examples are meetings and set up of interviews, community meeting organization, and finalized filming schedule and shot list.

The pre-production in Resolute Bay went better than expected. Looking for permission to film in the community from the Hunters and Trappers Association, I asked

for a meeting with them. The summary of my project and approval request was met by complete silence. Speaking to the secretary the following day, she said I was granted approval. I set up a community meeting for Aug. 18, 2014 and hired an interpreter to make sure the purpose of my project was understood by everyone, to facilitate dialog with members of the community for whom Inuktitut was a more comfortable way of expression, and to avoid misunderstandings and misinterpretations due to language barriers. Since my arrival, I spend every evening in the community (after all my scientific work for the day was completed) talking to residents in an effort to learn more about their culture, to understand their way of life, and to build a relationship for any future interviews and filming. The community responded in a fairly open manner, although many were unwilling to have their opinions filmed and preferred to offer these in private conversations. Those who agreed to be filmed, however, shared very similar opinions to all I talked to, thus I believe the interviews were representative of the community's attitudes. Shooting schedule and shot list had to be modified daily, usually every morning, according to the scientific work that would be done that day, or based on any developments with the community from the night prior. For the 2015 production season shooting schedule was established prior to arrival in Resolute, and I scheduled all interviews in the first 2 days after arrival in the community.

Some of the equipment brought in 2014 proved ineffective and unsuitable for use in the Arctic outdoor conditions. For example, concerns for malfunction due to dust prevented the crew from using the Movi stabilizer, similar concerns for water or dust damage prevented most of the use of the two BlackMagic cameras, and wind prevented the use of the drone for aerial filming. The equipment used for filming in the 2014 was

largely one DSLR camera and one GoPro. Once filming crew left (Aug. 23, 2014; two weeks after arrival), one BlackMagic, one DSLR and one GoPro were left at my disposal. On August 26, I used the BlackMagic to film an army cultural training and all SSD memory was used up. Without attachment to download the footage and no additional memory, the camera could not be used further. Thus, after a water accident with the DSLR on August 25, which left the camera in need of repair, I used an iPhone 5S and the GoPro as the primary cameras until I was able to obtain a camcorder from the community of Resolute Bay in the beginning of September. In the 2015 production season, I encountered a single issue near the end of the season – a malfunction of one of the two GoPro gymbals. This was not a problem since we were able to continue work uninterrupted with the second gymbal only.

Due to high expenses for flights and stay in Resolute Bay, a limited crew was assigned to go for 2 weeks out of the planned 5 weeks of ecology field work in 2014. The crew that year consisted of a cinematographer and camera assistant/sound technician, in addition to myself. Due to the low number of crew and my active participation in research and discussion during the community meeting, tripod use was impractical during the community meeting and near impossible during outdoor filming of scientific research. Tripods were only utilized for time lapse (not including bay time-lapse, the set up of which will be explained below). In the 2015 season, crew consisted of one cinematographer in addition to myself. The filming in that season went flawlessly and all work was done as planned. The equipment used in 2015 consisted of two DSLR cameras, three GoPros, two GoPro gimbals and one camcorder. For the 2014 season outdoor sound and conversations between researchers were captured using the DSLR camera with no

external microphones and a single lavalier microphone attached to an iPhone 5S as the recorder. For the 2015 filming season, sound was captured by four lavalier microphones, each attached to a Zoom H1 handy recorder. Some additional footage for both seasons, 2014 and 2015, was obtained from researchers and from a teacher in the community.

A full year of time-lapse of the bay was desirable between August 2014 and August 2015, and thus, a location with good unobstructed view that provided access to constant power source was established. All permits by local officials and owners of the building were obtained and the mounting was done on August 21, 2014. The camera was mounted on a city maintenance building's hydro pipe at height of ~4 m above the ground. A local teacher was recruited on a voluntary basis to clean the camera box window from snow during the fall, winter and spring season, and change the memory card in March 2015.

As mentioned above, final pre-production was getting done during actual production in the 2014 season, and although a shot list and a shooting schedule were established prior to arrival in Resolute, these had to be modified daily based on weather, circumstances and scientific work to be completed for that day. Thus, a challenge for the director and crew that season was the filming of unplanned events that occurred during prolonged scientific work (>3 hrs), such as a Ringed seal 2 meters away from the research boat. The problem was resolved with me carrying a DSLR camera at all times and filming as necessary.

My discussion with Inuit during the community meeting and its capture on film were imperative for this film. Neither me nor my crew had seen the location in which the

community meeting was to take place; all we knew was that it would be in the gym. The set up for filming took place about an hour before the meeting was scheduled to commence. As the organizer of the meeting, I also had to provide instruction to the interpreter and set up snacks. Thus, my direction to the filming crew, knowing they were experienced filmmakers, was to capture on camera anything the Inuit said. Considering one crewmember was required to operate a boom microphone to ensure we had good sound of any Inuit speaking, we only used one camera (BlackMagic) to film everything. The lens used was a 35mm prime lens and thus, as mentioned earlier, use of tripod was unfeasible. Perhaps tripod could have been used had we had a dolly, and had we used a zoom lens instead. In general however, the meeting went well and the shoot was considered successful because most of what was said was captured on camera.

Interview with hunter Mark Amarualik was scheduled at first opportunity upon arrival in Resolute Bay in 2015. The local ATCO hotel was retained as the location due to considerations for interruptions and weather elsewhere. The set up consisted of two cameras (one frontal wide angle, and one on tripod facing the interviewee) and two lavalier microphones. Before the interview, I picked Mark up at his house although the hotel is a walking distance away. This gave us an opportunity to chat and catch up on events regarding the research, something he was interested in, and thus, help to relax him for the actual interview. While setting up the equipment, we continued conversing and I used this time to explain that what I was about to ask him was pretty much everything we had talked about in all of our other conversations. We also took breaks during the interview to ensure he was comfortable. One regret I have regarding the set up of the interview was that right next to Mark there was an Arctic wolf taxidermy, which we



placed to be well visible in the wide angle, but not in the medium angle shots. In retrospect, we should have lifted the wolf onto a table and moved back to make visible in all shots.

Throat singing was set up to take place in the local school due to best acoustics and quietness. I had met one of the sisters previously for a throat-singing lesson and an interview, so she was comfortable around the camera and me. I ensured that the second sister was comfortable too by leading a prolonged conversation with both of them about my throat-singing lesson before any set up and filming. I was the only crew, thus reducing any additional noise and distractions for the singers. To capture video and audio I used a single camera with attached external microphone and two lavalier microphones, one on each throat singer. The filming and recording went flawlessly and were considered a success.

Overall, the influences of Orlowski and Stahl helped me resolve or deal with the challenges faced during the making of this film. Orlowski's film combined with Stahl's approaches allowed me to stand not only in front of the camera, but also behind it, thus facilitating the shift of focus of the film. Stahl showed that cut-and-dry paths don't work in all situations (something highly applicable to working in the Arctic), and filming what is available, rather than staging, is an approach worthwhile.

#### *Description of film element choices*

Filming, sound and editing techniques used in "An ice-free summer" were selected for their value of expression to convey faithfulness to reality, based on Max

Stahl's documentary work in Timor-Leste, which is being recognized as a World Heritage by UNESCO. He employed long-takes when filming and minimalistic editing style to make "Reconciliation" (2014), with a premise to stay "faithful to the moment" and convey the uncertainty and confusion of the conflict or moment. In addition, the conception of the film and the storyline, were accomplished after the actual filming of the events:

"...we have 4000 hours of material at present. We don't know entirely what the story will be; we don't do what one would normally do. We try to understand what the themes of significance are—they are not necessarily all political... .

When you get an opportunity, when there is a moment, when there is an audience, then you make a film from this archive of a history" (Stahl, 2014).

This approach not only allowed the filmmaker to address the issues he wanted to focus on, but also to create a documentary that would come as close as possible to being faithful to what actually happened. In this project, I employed long takes in the field and filmed unplanned events as these presented themselves, rather than staging the filming, allowing me to capture real key events in the work of researchers, such as the measurement of underwater sound or capture of fish (Fig. 3.1) and the everyday life of Inuit, such as a hunting trip and skinning a seal (Fig 3.2). Subsequently, this approach allowed for a focused edit of these actual events in the final version. This film's structure and choice of footage for editing were done after all footage was completed, allowing us to concentrate on the overarching issue of Inuit reliance on the Arctic ecosystem and how it's being affected by vessel activity. This approach also allowed us to provide for as

honest and faithful expression of the issue as possible while also including key components contributing to it, such as the changes of ice-cover, and exploring sub-themes of the value of TEK and the importance of its inclusion in further scientific studies. In addition, we avoided image stabilization in post-production and emphasized the use of dynamic shots, for example, general scenery is presented from a moving boat perspective (example in Fig. 3.3). This was done to emanate the uncertainty of the situation facing the community featured, their way of life and the changes occurring in the Arctic ecosystem (see chapter 2 and film). Furthermore, artificial sound effects were not employed (example in Fig. 3.4), other than music and throat singing, allowing the film to stay true to its documentary nature and to reality.

Music is used in film to convey a mood, and/ or a state of character's mind, such as these in *Samsara* (Fricke, 2012) and *Into the mind* (Auclair, 2013), or to enhance visual elements, as in *Blackfish* (Cowperthwaite, 2013). In "An ice-free summer", music and throat singing were used as an auditory metaphor (in addition to narration; see paragraph on narration below) to establish the current state of perceived segregation between Inuit and researcher's interests by complementing the visual and auditory content concerning the two parties. For example, in the edit, music was used during research and interviews with scientists and throat singing during Inuit interviews (Fig. 3.5).

I used interviews to reinforce the position and views of both Inuit and researchers. I incorporated both common and pseudo-dialogue interviews. The common interview was used with researchers because it allowed for a structured extraction of key scientific information, which was then used as tool to showcase the researchers' point of view and

contribute to the larger theme of the film. The pseudo-dialogue interview was used with Inuit to help break any feeling of uneasiness on their part while being interviewed so that they wouldn't feel pressured and would open up; and to communicate that sense of honest conversation to the audience, by allowing them to sit in on the 'conversation'.

Narration allows for summarization of a large quantity of information and in this project was used when an interview or other means of presenting the given information would have distracted the viewer from the main focus. For example, presenting the location and brief introduction of Resolute Bay are relevant enough to merit a few seconds, but no more (example in Fig. 3.6). In narration, a "great deal of the charm and spice is derived from irregularity" says Dyrenforth (1951), who explains how accents and different pitches are considered a burden during casting for a narrator, when what is important is the meaning these may bring out. Dyrenforth proclaims narration to be an art, which "defies all cut-and-dried systems and rules" (1951). In this work, I, the author of the research, complete the narration. This was done for two reasons: i) I am well versed and involved via my research in the subject matter, and according to Dyrenforth (1951) this should be a rule when choosing a narrator; and ii) I have an eastern European background and English is not my native language. An accent in the narrator's voice creates an artistic parallel with the Inuit subjects most affected by the events in question. The parallel is drawn to convey the severity that a situation of difference in culture, traditions, values, opinions and even miscommunication may pose when dealing with environmental problems that encompass different nations and have impacts beyond the particular village in the film. For example, the accent suggests a different cultural background of the narrator, creating a parallel to the uniqueness of the Inuit culture, but

also precludes that the Arctic extends beyond Canadian territory to other nations worldwide. Thus, such parallel allows the film to transcend the boundaries of one nation or culture, and illuminate the need for collaboration between researchers, Inuit and stakeholders from all nations. In addition, my role in the research, and extended knowledge of the subject matter and problem presented, provide even more weight on the problem discussed.

#### *Rationale for editorial structure choices*

The goal behind the way the film begins is to establish the extent of Inuit reliance on the environment. Presenting something as basic as food is also meant to establish instant connection with the audience. Introducing the drivers that influence this style of life next, gives key information to the viewers to be able to understand and put into context the seriousness of this food security issue. This introduction incorporates not only the scientifically available information, but also the Inuit TEK. The idea behind this approach was to introduce and examine the complementation of science with TEK on the sublevel, and, just as importantly, to show the two sides as seeing the same changes. The later part of the middle section (6:33 to 8:15 min) included scientific research on an important fish species. The research was used as a tool to support the knowledge of the Inuit and their belief that ships were scaring away the animals, but more importantly it was used to showcase the complementation of TEK with science and the potential these two carry if used together.

The ending of the film (9:10 min to end) has the purpose of showcasing the existing segregation between Inuit and scientists as barrier to conservation and sustainable management. At a first glance it seems as though scientists disrespected the wishes of the Inuit regarding tagging animals. In reality, this project would not have been possible without the Inuit permission to work in their community, and scientists do and should respect that. So, even though Inuit agree for the research to take place, because they understand the value of it, they don't necessarily like all the methods employed. Thus, I left the explanation out in order to gain discussion around this segregation and call upon the curiosity and desire of the audience to find and understand the answer. The concluding statements were chosen to be by scientists instead of Inuit, because these showcase the scientists' sincere concern with the issues facing the Inuit and the Arctic. In addition, these conclusions prelude to the necessity for action by more than just the Inuit.

### *Reflections/Conclusion*

“An ice-free summer” is a documentary film examining some of the little known effects climate change brings to the Arctic ecosystem. The increase in ship traffic due to decreasing ice cover in the summer months is seen as a threat by Inuit hunters not only to the relatively pristine arctic environment, but also to the individuals living there, because of their heavy reliance on subsistence hunting. The stakes are high for Inuit, because their food security is an issue if subsistence hunting of marine mammals cannot be relied upon due to vessel traffic. Non-Inuit researchers working there share the same concern for the wellbeing of the arctic ecosystem, but this is often misunderstood by the Inuit. Inuit believe researcher interest is only driven by profit gains. As this project has shown

however, researchers could do much to help and initiate conservation work, but this can only happen when collaboration is present. “An ice-free summer” also shows that Inuit TEK could be used as a valuable resource and should be incorporated into any future research efforts.

This film and the work involved in its creation accentuate environmental problems facing these arctic communities, such as the decrease of multi-year ice and changes occurring due to increased ship activity, and emphasize the need for collaboration and understanding in order to conserve and manage sustainably this highly vulnerable ecosystem, and preserve Inuit culture and way of life.

Future goal for the film is to be entered into festivals worldwide to generate interest and discussion around the topic and issues of the Arctic. Any recognition by festivals will aid in the dissemination of the film to further audiences. A subsequent release to online audiences is planned after festival showcasing ends. To facilitate the publicizing of the project online, the use of an existing platform is most desirable, thus, the film will be offered for use to climate change NGOs in their existing campaigns, such as Greenpeace and their campaign “Fighting Global Warming”. To accomplish the aim of disseminating information directly to decision-makers, I am looking to locate funds to set up a private viewing of the film in Ottawa for members of the parliament after which a discussion will follow. Also, a resident in Resolute Bay will be recruited to organize a viewing of the film for the community and decision-makers.

## BIBLIOGRAPHY

Auclair, J. P. (Director). (2013). *Into the Mind* [Motion Picture].

Cowperthwaite, G. (Director). (2013). *Blackfish* [Motion Picture].

Dyrenforth, H. O. (1951). Narration—The Cinderella of Radio and Filmm. *Western Speech*.

Fricke, R. (Director). (2012). *Samsara* [Motion Picture].

Orlowski, J (Director). (2012). *Chasing Ice* [Motion Picture].

Stahl, M. (2014). *PJR2014-3 Max Stahl on Timor-Leste and 'Reconciliation' (PMC)*.

Retrieved March 2, 2015, from YouTube:

<https://www.youtube.com/watch?v=99jwylm6fwg>





**Figure 3.1** | Still image examples from footage of key events in the work of researchers obtained using unplanned non-staged long takes.

(a) In this scene, researchers are preparing the equipment for underwater sound measure while speeding in a Zodiac to the location where the measurement is going to take place. The whole process from setting up all the equipment to performing measurements by the

researchers to moving from location to location was filmed in one take. This is also an example of dynamic footage used in the film.

(b) In this scene, a researcher is preparing to take off a fish that was just captured by line-and-hook. The whole process from dropping the lines to pulling in the captured fish and storage of it until shore was filmed again in one take.

a



b



c



**Figure 3.2** | Still image examples from footage of the everyday life of Inuit hunters obtained using unplanned non-staged long takes.

(a) Filming of the scene was done after the director and cameraman saw the hunt take place from a distance. Upon reaching the location where the hunters were docked on the bay, the film crew saw the Inuit skinning a Ringed seal and after obtaining permission, filmed the process.

(b) The director of the film was invited to a seal hunt and the filming of this scene took place during an unplanned docking on a floating island in Barrow Strait.

(c) The filming of this scene took place during a trip to film scenery around Cornwallis Island. The hunters' boat appeared while the crew was filming moving ice. The Inuit were searching for marine mammals beyond the bay of Resolute.

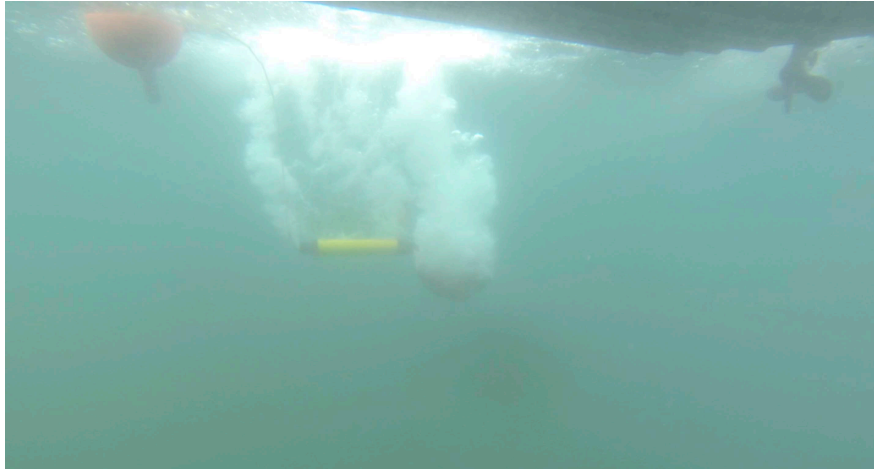


**Figure 3.3** | Still image example from dynamic footage in which general scenery is presented from a moving boat perspective.

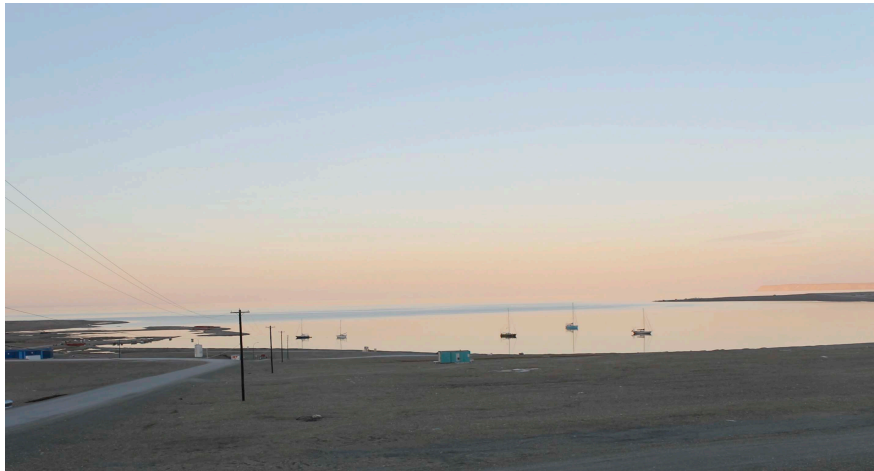




**Figure 3.4** | Still image example from footage in which artificial sound effects were not employed. Sound in this scene is from the camera used in the recording of the video, and is only cleaned up from background noise and amplified to match the film's volume.



a



b

**Figure 3.5** | Still image examples from footage in which music is used as a metaphor.

(a) During background information, research and researchers interviews modern mainstream music is used to complement the cutting-edge technology technologies used for the research.

(b) During Arctic scenery and Inuit interviews and life, throat singing is used to complement the unique traditions, culture and way of life of the Inuit and the uniqueness of the arctic ecosystem.



**Figure 3.6** | Still image example from footage in which narration is used to present the location and briefly introduce Resolute Bay.



## CHAPTER 4

### CONCLUSIONS: CONTEXT AND RECOMMENDATIONS

In recent years acoustic anthropogenic disturbance has become a concern worldwide, and as tracking technology improves, a number of studies are being published on noise disturbance and the effects on fish species in temperate and tropical climates, yet Arctic studies are lacking. The arctic ecosystem is unique not only because of the species inhabiting it, but also because the impact of climate change is amplified with changes occurring at a much greater rate than anywhere else on Earth (Bintanja and Selten, 2014). As ice-free periods get longer, government and industry vessels gain more access for exploration and exploitation, adding a yet another stressor to this ecosystem. The Arctic's human inhabitants, the Inuit, rely heavily on the predictability of the Arctic ecosystem and have a localized decision-making power, and are thus, key stakeholders. Their active involvement is key to enabling future high quality studies of the unique ecology of this ecosystem that incorporates centuries of unrecorded Inuit traditional ecological knowledge as a baseline. An understanding of the spatial and temporal distributions of arctic animals and how different stressors, such as changes due to increasing acoustic disturbance, affect these will lead to sustainable and effective management by both local and regional governments.

The overall objectives of this research were to quantify the impact of vessel activity in the high Arctic on the spatial use of key forage fish, involve local Inuit in the creation of a documentary film in order to disseminate key information about the changes in the arctic ecosystem and complementation of Inuit traditional ecological knowledge (TEK) with modern research. The ecological study provides the first evidence of displacement of Arctic cod (*Boreogadus saida*) due to vessel activity in the high Arctic,

and the documentary film highlights the value of Inuit TEK, and communicates that the displacement of cod is affecting Inuit food security, culture and way of life.

Chapter 2 focused on Arctic cod, and how their behavior and habitat use were affected by large ship activity. Due to its large biomass and lack of an alternative pelagic fish in the high altitudes of the Arctic, Arctic cod is a key prey for marine mammals and sea birds (Welch et al., 1993). Thus, any inconsistencies in its behavior and spatial use carry consequences far beyond the individuals of its species. Using acoustic telemetry to track cod, our results were consistent with Inuit observations of a change in Arctic cod behavior due to vessel presence. Arctic cod shifted and decreased their horizontal spatial use in response to noise levels. The proportion of swimming patterns also changed; slow tortuous behavior by individuals related to foraging decreased while faster larger distance transit behaviors increased in response to ship presence. These results indicate that effects of vessel noise in the high Arctic should not be underestimated, and merit further investigations.

Chapter 3 focused on the documentary film, the approach of the filmmaker and what techniques were used to highlight the issues facing the Inuit, the value of their TEK and the importance of TEK inclusion in future studies in the region as a baseline through collaboration between local populations and southern researchers. In its core the film examines the little known effects of climate change on the arctic ecosystem, such as the Inuit dependence on marine mammals and predictability of their migrations in time and space, and the indirect effects of vessels on their livelihood and traditions. However, metaphoric accents throughout the film, such as dynamic shots, and music selection, emphasize the harsh reality facing both inhabitants and governing bodies: the arctic

ecosystem is encountering multiple stressors and the way forward is through collaboration.

### *Arctic Ecosystem Changes*

The Arctic as an ecosystem has less species diversity than temperate and tropical climates, and thus, its resilience to disturbances is lower (Piatt and Anderson, 1996). Climate change carries a myriad of consequences with it: i) multi-year ice is disappearing and more areas at high altitudes are experiencing longer ice-free periods; ii) studies have already documented invading species, such as Capelin (*Mallotus villosus*) at lower altitudes (Gaston et al. 2012); iii) invading transient and subarctic species have higher contaminant levels in their tissues (McKinney et al., 2012); iv) an increase in the amount of precipitation is expected (Bintanja and Selten, 2014); and v) the last 30 years have seen a steady increase in human activity in the high Arctic (Judson, 2010). All these reflect that arctic regions are beginning to experience multiple stressors, and that it would be difficult to predict the exact effects of these stressors.

### *Contributions*

This study addressed two components of the issues facing the Arctic and the people managing it – anthropogenic disturbance by vessel activity, and explored the need for an approach that includes Inuit TEK and relies on collaboration. The ecological study on acoustic disturbance revealed a sensitivity of Arctic cod to ship noise, suggesting a likely disruption and displacement of this fish over time in areas of increased vessel

activity. Thus, this study provided advancement in our understanding of Arctic cod spatial use and swimming behavior patterns during periods of no disturbance and acoustic disturbance, which are crucial in the prediction of trends associated with the ecology of this species. Also, it yielded critical baseline information for future studies in the region and on the topic.

The second component addressed the suitability of an inclusive approach that incorporates Inuit TEK and collaboration via a documentary film, and the need to communicate the issues facing the arctic ecosystem. The resulting documentary film serves as a disseminator of critical information on multiple issues facing the Inuit and the Arctic in a time when attention of the general public as well as governing officials needs to be drawn to the severity of the changes happening, and the urgent need for collaboration and conservation action.

### *Suggestions for future research, social science and collectively*

The importance of Arctic cod as a key prey species in the high Arctic should not be ignored or underestimated. Thus, anything that may affect their well-being and their ecology should be considered if management and conservation efforts in the Arctic ecosystem are to be effective. Understandably, more research is required on this species, from hearing audiogram to incorporating different environmental stressors to establishment of prime spawning locations. An integrative approach should be used in future studies, incorporating behavioral responses to acoustic disturbance with physiological metrics at the individual level, and at population and community levels by

focusing on early life stages effects and changes in interactions with other species through context, time and space, respectively.

This study showed that the importance of this species extends well beyond the marine mammals and seabirds that they feed and managerial or conservation initiatives should reflect that. Marine planning should be considered and used proactively before noise pollution due to shipping becomes a problem, for example designating the key habitats and spawning areas of Arctic cod as marine protected areas with restriction on vessel activity, would help limit the anthropogenic effects on this species. Also, vessels moving at a slower speed produce less noise, thus a limitation of the speed at which vessels are allowed to operate could be put in place. Further more, conservation managers and local indigenous inhabitants should set guidelines on what consists allowable harm to wildlife and the ecosystem.

The issues facing the Arctic ecosystem and the Inuit merit an examination of present day collaborative effort and involvement of Inuit in research projects through inclusion of TEK. To date few studies have incorporated TEK as a component of the research, yet such studies have shown promise (Emery et al., 2014). Our study supported Inuit observations of Arctic cod and showed that TEK can provide valued guidelines, inputs and can add another level of rigor to future research. In addition, by collaboration with Inuit and integration of their knowledge we ensure that the right questions are asked and research and management address Inuit needs as well as those of other stakeholders. Monitoring is essential for continued managerial success of conservation initiatives and thus, we suggest that Inuit occupy a central role. However, Inuit TEK could also benefit from such collaborative projects, by adding key details to their observations. For

example, this study provided key information on Arctic cod's spatial use and behavior when ships are present, absent and moving, thus supplementing Inuit observations that ships are affecting cod.

An engagement of a diversity of audiences via communication is a fruitful way towards effective conservation and sustainable management (William et al., 2015), thus this study's combination of natural and social sciences allows for the dissemination of crucial scientific information to audiences beyond the scientific journal scene. As the film goes into festivals and is being shown to audiences, it will generate interest and open discussion opportunities that allow for exploration of engagement with the issue and identification of solution opportunities.

Overall, this project furthers our understanding of acoustic disturbance on key fish species in the high Canadian Arctic and the value of Inuit TEK, and it aids in communicating these findings to audiences with different backgrounds.

## BIBLIOGRAPHY

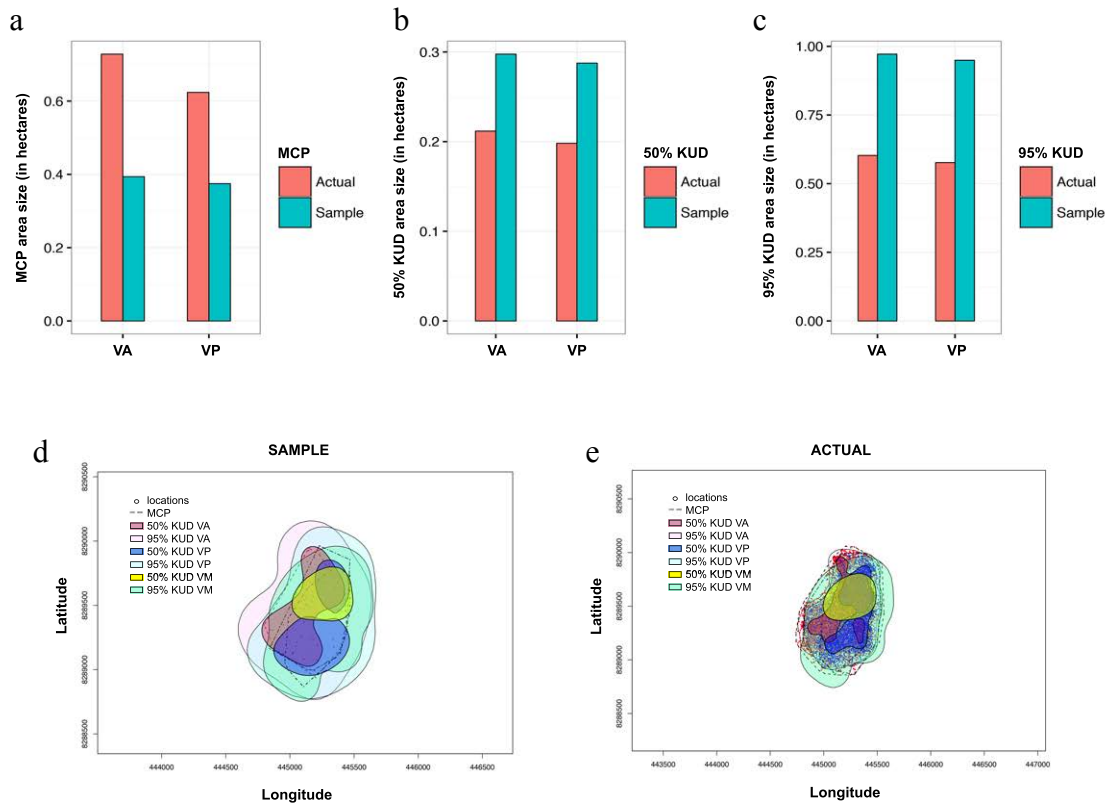
- Bintanja, R., and F. M. Selten (2014). Future increases in Arctic precipitation linked to local evaporation and sea-ice retreat. *Nature*, 509, 479-483.
- Emery, M. R., A. Wrobel, M. H. Hansen, M. Dockry, W. K. Moser, K. J. Stark, and J. H. Gilbert (2014). Using traditional ecological knowledge as a basis for targeted forest inventory: paper birch (*Betula papyrifera*) in the US Great Lakes Region. *Journal of Forestry*, 112 (2), 207-214.
- Gaston, A. J., P. A. Smith, and J. F. Provencher (2012). Discontinuous change in ice cover in Hudson Bay in the 1990s and some consequences for marine birds and their prey. *ICES Journal of Marine Science*, 69 (7), 1218-1225.
- Judson, B. (2010). Trends in Canadian Arctic Shipping Traffic – Myths and Rumours. *Proceedings of the Twentieth (2010) International Offshore and Polar Engineering Conference* (pp. 1292-1299). Beijing: The International Society of Offshore and Polar Engineers (ISOPE).
- McKinney, M. A., B. C. McMeans, G. T. Tomy, B. Rosenberg, et al. (2012). Trophic Transfer of Contaminants in a Changing Arctic Marine Food Web: Cumberland Sound, Nunavut, Canada. *Environmental Science & Technology*, 46, 9914-9922.
- Piatt, J. F., and P. Anderson (1996). Response of Common Mures to the Exxon Valdez oil spill and long-term changes in the Gulf of Alaska Marine Ecosystem. *American Fisheries Society Symposium*, 18, 720-737.
- Welch, H. E., R. E. Crawford, and H. Hop (1993). Occurrence of Arctic Cod (*Boreogadus saida*) schools and their vulnerability to predation in the Canadian high Arctic. *Arctic*, 46 (4), 331-339.



William, R., A. J. Wright, E. Ashe, L. K. Blight, et al. (2015). Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. *Oceans & Coastal Management*, 115, 17-24.

## APPENDICES

### Appendix A Supplementary material for Chapter 2



**Appendix Figure 2.1** | (a-c) Actual sizes are plotted against random sample sizes of MCP, 50% and 95% KUD for Arctic cod. To validate the low number of detections for VM, we took a random sample (n=34, same as VM number of detections) for both VA and VP and compared the sizes of the home ranges of these with the actual. The actual results are shown in red and the sample results are shown in turquoise. (See Appendix Table 2.1 with values.)

**(d-e)** Sample and actual home ranges are mapped for spatial location comparison.

Mapping for VM on sample graph was done only for reference purposes. Red, blue and yellow denote 50% KUD for VA, VP and VM, respectively; light pink, baby blue and

light green denote 95% KUD for VA, VP and VM, respectively. MCPs are shown with dotted lines, and detection locations with red, blue and green points for VA, VP and VM, respectively.

**Appendix Table 2.1 | Values for sample versus actual MCP, 50% and 95% KUD area sizes (in hectares).** Random samples taken from VA and VP were based on the number of detections in VM (n=34).

	SAMPLE MCP	MCP	SAMPLE 50% KUD	50% KUD	SAMPLE 95% KUD	95% KUD
VA	0.39375065	0.728068103	0.297602575	0.211768632	0.971665925	0.602586262
VP	0.37474194	0.623730053	0.287573724	0.198179126	0.94943923	0.576707908

## Appendix B Co-author letters of permission

### Chapter 2 Permissions:

**From:** Silviya Ivanova ivanovas@uwindsor.ca  
**Subject:** Declaration of Co-authorship for Thesis  
**Date:** August 5, 2016 at 9:26  
**To:** Aaron Fisk afisk@uwindsor.ca, Steve Kessel skessel80@gmail.com, Justin Landry landry9@uwindsor.ca, Svein Vagle sveinvagle@gmail.com, Mario Espinoza marioespinozamen@gmail.com, Montana McLean montana.mclean@gmail.com, Caitlin O'Neill caitlin.v.oneill@gmail.com, Nigel Hussey nehussey@uwindsor.ca

---

Hello co-authors,

Part of my MSc thesis paper includes data and results that will be published in the following paper:

Title:

***"Shipping activity disturbs key fish species in the high Arctic"***

Authors:

***Silviya V. Ivanova, Steven T. Kessel, Svein Vagle, Mario Espinoza, Montana McLean, Caitlin O'Neill, Justin Landry, Nigel E. Hussey, Aaron T. Fisk.***

Status:

In preparation for submission.

I need to include a permission from each of you in my thesis that you agree (or not) to inclusion of this data and results in my thesis. I am requesting from each of you as the co-authors, permission to use these results and findings in my thesis as part of my Chapter 2. Please make it clear in a simple email response that you (be sure to include your name) give me permission (or not).

If you have any questions, please let me know.

Many thanks,  
Silviya

**Mario Espinoza**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

August 5, 2016 at 9:46  
[Hide Details](#)

---

Hi Silviya,

No problem. I Mario Espinoza give Silviya permission to use the data presented in Chapter 2 as part of her thesis.

If you have any questions do not hesitate to ask,

Mario

**Nigel Hussey**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

August 5, 2016 at 9:47  
[Hide Details](#)

Dear Sylvia,

I Nigel Hussey give permission to use the data and results in your thesis chapter.

Sincerely,

Nigel Hussey

**Montana McLean**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

August 5, 2016 at 10:00  
[Hide Details](#)

Hi Silviya, congratulations on the completion of your thesis!

I, Montana F. McLean, give you permission to use the results and findings from our collaboration in your thesis Chapter 2.

All the best,

Montana

☆ **Steve Kessel**  
To: Silviya Ivanova  
RE: Declaration of Co-authorship for Thesis

August 5, 2016 at 10:40  
[Hide Details](#)



You have my permission

Steven T Kessel  
Research Associate  
Dept. of Fisheries and Wildlife  
Michigan State University

☆ **Svein Vagle**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

August 5, 2016 at 11:58  
[Hide Details](#)



Hi Silviya,  
I, Svein Vagle, give you permission to use the results and findings in

Title:

***"Shipping activity disturbs key fish species in the high Arctic"***

Authors:

***Silviya V. Ivanova, Steven T. Kessel, Svein Vagle, Mario Espinoza, Montana McLean, Caitlin O'Neill, Justin Landry,***

***Nigel E. Hussey, Aaron T. Fisk.***

Status:

In preparation for submission,  
in your thesis.

**Justin Landry**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

August 6, 2016 at 8:48  
[Hide Details](#)

---

Hey Silviya,

I, Justin Landry agree to the inclusion of the use of the data and results in your paper "***Shipping activity disturbs key fish species in the high Arctic***"

**Caitlin O'Neill**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

August 6, 2016 at 13:55  
[Hide Details](#)

---

Hi Silviya,

I, Caitlin O'Neill, give you permission.

Caitlin

**Aaron Fisk**  
To: Silviya Ivanova  
Re: Declaration of Co-authorship for Thesis

September 7, 2016 at 5:22  
[Hide Details](#)

---

Yes you have my permission.  
Aaron

---

Aaron T. Fisk  
Professor and Canada Research Chair in Trophic Ecology  
Great Lakes Institute for Environmental Research  
University of Windsor  
401 Sunset Ave  
Windsor, ON N9B 3P4

## VITA AUCTORIS

NAME: Silviya Vasileva Ivanova

PLACE OF BIRTH: Sofia, Bulgaria

YEAR OF BIRTH: 1978

EDUCATION: University of Windsor, B.Sc. in Biological  
Sciences and Communications, Media and Film,  
Windsor, ON, 2014

University of Windsor, M.Sc. in Environmental  
Science, Windsor, ON, 2016