INTERACTIONS BETWEEN SEALS AND ATLANTIC SALMON (SALMO SALAR) IN RIVERS AND ESTUARIES OF NEWFOUNDLAND AND LABRADOR

CRYSTAL C. LENKY

INTERACTIONS BETWEEN SEALS AND ATLANTIC SALMON (*SALMO SALAR*) IN RIVERS AND ESTUARIES OF NEWFOUNDLAND AND LABRADOR

by

© Crystal C. Lenky

A thesis submitted to the
School of Graduate Studies
in partial fulfillment of the
requirements for the degree of
Master of Science

Biology Program
Memorial University of Newfoundland
St. John's, Newfoundland and Labrador, Canada

December 2007

ABSTRACT

The causes for the decline in some Atlantic salmon (*Salmo salar*) stocks in eastern Canada are uncertain but many resource users consider predation by seals in rivers and estuaries to be a contributing factor. During the 1990s, the Department of Fisheries and Oceans (DFO) received reports from resource users of increased seal-salmon interactions on several rivers in Newfoundland and Labrador. To address these concerns, semi-directed interviews (n=57) were conducted from 2004 to 2006 with resource users on 29 rivers throughout the Province. Respondents were requested to comment on any changes in the relative abundance, timing of migration, habitat use and foraging behavior of seals frequenting the area during the last 5 years (2000-2005), during the 1990s, and 1980-1990. Starting in the mid 1990s, harp seals (*Pagophilus groenlandicus*) increased their residency time in some rivers and estuaries by 1-3 months. Potential harp seal predation on salmon was considered to be high for half of the 16 rivers frequented by harp seals on the northeast coast of Newfoundland and southern coast of Labrador. In 6 of these rivers, the reported increase in the occurrence and relative abundance of seals was concurrent with the migration or spawning of pelagic forage fish (e.g. capelin) in the area. One river was influenced by variable local ice conditions during late spring, and one river was affected by both of these conditions. The presence and relative abundance of harbour seals (*Phoca vitulina*) in some rivers and estuaries increased during the 1990s; potential predation was considered to be high on 10/24 of these rivers. In the case of grey seals (*Halichoerus grypus*), relative abundance has increased in some Labrador rivers since 2000, with 3 rivers considered to have high potential predation.

A directed harp seal diet study was carried out in 2005 and 2006 on the Campbellton River, one of the rivers considered to have high potential for predation during the smolt salmon run. A total of 122 seal stomachs were analyzed and no evidence was found that seals were feeding on salmon. Capelin, an energy-rich forage fish, was the major prey component in both years. Although information from resource users suggested that the potential for harp seal predation on salmon had increased since the mid-to late 1990s, the diet component of the project indicated that they were not necessarily feeding on salmon when these species co-occurred. Similar investigations on other seal species and rivers with high potential will be necessary before it can be concluded that harp, grey or harbour seal predation of salmon stocks is not occurring.

ACKNOWLEDGEMENTS

I would like to extend my sincere thanks to my supervisor, Dr. Becky Sjare, for giving me the opportunity to work on this project. It is important for me to acknowledge your excellent advice and guidance throughout this journey, and for improving my scientific and writing skills. Thank you to my co-supervisor, Dr. Ted Miller, for our critical thinking and grammar sessions and providing me with a great working environment. I'm sure you are looking forward to re-claiming your lab.

I would also like to acknowledge support and guidance from many people including my thesis committee member, Dr. Ian Fleming, and the research staff at the Department of Fisheries of Oceans (DFO). Thank you for taking the time to answer all my questions, and the enjoyable experience of working in the field and fish lab. Special thanks go to Dave McKinnon, Dr. Jack Lawson, Bonnie Stockwood, Wayne Penney, Dennis Wakeham and Dr. Garry Stenson. I would also like to thank Peter Downton for all his help on the Campbellton River portion of this project. This project was funded by a grant to Becky Sjare from Natural Resources Canada: Climate Change Impacts and Adaptations Fund.

I am forever indebted to all the resource users who shared their knowledge and experience with me. I would not have been able to complete this project without your support. Special thanks go to Gilb Budgell, Wayne Dove, Pearce Manuel, Dan Taylor, and Calvin Frances for collecting seals and their help with surveys. Thanks also go to the St. Lewis and Cartwright fishery officers who provided office space and logistic support in Labrador. I must also thank the Curl family for taking me into

their home and making me feel as part of their family during my two summers in Labrador. I will never forget your hospitality.

My time in Newfoundland and Labrador was an experience that I will never forget, and was made possible by my close friendships with many people. Thank you to Jenn Guy, Tanya Bowen, Cari Eggleston, Alain Lusignan, everyone from Ultimate Frisbee, and countless others. I will miss you all.

And last but not certainly not least, I must thank my parents (Melodi and Paul), my brother Ted, my grandparents, and all my friends for their unconditional love and support that gives me the strength to follow my dreams and live life to its fullest.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Overview and study rationale

Environmental and oceanographic conditions play an important role in determining the distribution and abundance of marine predators and their prey (e.g. Trillmich and Ono 1991; Ballance et al. 2006; Trites et al. 2007). Given that marine mammals are top predators in marine ecosystems, they may be good indicator species for monitoring climate-related ecosystem changes (Tynan and Demaster 1997). Variations in the availability or access to food supplies are both factors that can lead to changes in the nutritional status, reproductive success, geographic range, and migration patterns of some predator species (Tynan and Demaster 1997; Bowen and Siniff 1999; Le Boeuf and Crocker 2005). These changes may be observed in association with oceanographic regime shifts over decadal temporal scales (Springer 1998; Benson and Trites 2002; Weimerskirch et al. 2003) or short-term perturbations (months to a few years) (e.g. Trillmich and Ono 1991).

Researchers are just now beginning to understand the ecological consequences of long and short-term climate variations and their effects on marine mammal foraging behaviour. There are several well-documented cases of altered predator-prey relationships where access to, or the abundance of prey has important ecological consequences. For example, long-term declines in the extent of sea ice not only influence the distribution of polar bears (*Ursus maritimus*), but also directly influence the availability and access that bears have to their major prey, the ringed seal (*Pusa hispida*) (Stirling and Derocher 1993). Polar bears are dependent on sea ice for traveling between foraging and denning areas, and for hunting ringed seals. These seals forage near the ice edge and rely on ice to provide a platform for pupping and nursing their young (Smith and Stirling 1975; Finley and Renaud 1980; Burns et al. 1981). Over the last two decades (1981-1998), the decline in the condition of polar bears coming ashore in western Hudson Bay has been linked to early breakup of sea ice and reduced access to seals (Stirling et al. 1999). Early spring is the most important hunting period for polar bears because they need to accumulate enough fat stores to fast on land during the ice-free season (Stirling and McEwan 1975). Warmer fall temperatures are also thought to have delayed the timing of ice freeze-up, thereby limiting bears' access to seals in the fall and prolonging their fasting period (Derocher et al. 2004). The effects of climate warming on ringed seals are still uncertain, but a reduction in available habitat may alter their distribution and overall productivity, resulting in changes to polar bear distributions (Derocher et al. 2004).

Short-term perturbations such as El Niño events (e.g. 1982-83 and 1997-98) have impacted the foraging behavior of several pinniped populations along the coasts of South and North America (Trillmich and Ono 1991; Crocker et al. 2006). El Niño is a climatic phenomenon that occurs periodically in the tropical Pacific, but its effects are often widespread. During an El Niño, increased sea surface temperatures, decreased upwelling, and a depressed thermocline contribute to decreased primary and secondary productivity in areas where many pinnipeds forage. South American fur seals (*Arctocephalus australis*) off Peru feed mainly on anchovies (*Engraulis ringens*). Reduced availability of these prey species during the 1982-83 El Niño resulted in females not being able to find enough food, even though they spent extended periods of time at sea foraging. Reduced growth in fur seal pups was observed during those years, compared to years when anchovy stocks were plentiful (Maljuf 1991). Longer foraging trips were also observed in female Galapagos fur seals (*Arctocephalus galapagoensis*), but the impact on pups was more severe. Most perished due to starvation and those that survived were 10% lighter than those in non-El Niño years (Trillmich and Dellinger 1991). Poor body condition in northern elephant seals (*Mirounga angustirostris*) was related to reduced prey availability during the 1982-83 and 1997-98 El Niño events (Le Boeuf and Reiter 1991; Crocker et al. 2006). During El Niño years, female elephant seals exhibited a marked decline in mass gain rate related to a reduction in foraging success and time spent in prey patches.

In the Northwest Atlantic, significant climate-related ecosystem changes took place from the late 1980s through the early 1990s (Colbourne et al. 1994; Drinkwater 1996, 2004; Parsons and Lear 2001). During this period, the ecosystem transitioned from one dominated by demersal fish species, most notably Atlantic cod (*Gadus morhua*), to one dominated by crustaceans (Lilly and Carscadden 2002). Although all the underlying causes for this transition are not fully understood, changes in the distribution, abundance and reproductive biology of many species were concurrent with the onset of cold oceanographic conditions (Rose et al. 1994; Hutchings 1996; Carscadden and Nakashima 1997; Bryant et al. 1999; McAlpine et al. 1999; Lacoste and Stenson 2000). Changes in the marine ecosystem were reflected in the distribution, migration patterns, and diet of harp seals (*Pagophilus groenlandicus*) as well as in the distribution and abundance of some of their major prey, capelin (*Mallotus villosus*) and Arctic cod (*Boreogadus saida*) (McAlpine et al. 1999; Lilly and Simpson 2000; Parsons and Lear 2001) (see Chapter 2 for further details). Harp seals were also observed moving into Newfoundland waters earlier in the fall and staying later into the summer, as well as frequenting river and estuarine habitats more often. Also during this period, Atlantic salmon (*Salmo salar*) stocks declined throughout its range in the northwest Atlantic, including stocks in Newfoundland and Labrador rivers. Resource users expressed concern about the possible negative impact that harp seals frequenting coastal waters could have on some depressed salmon stocks around the Province. However, most observations of seal-salmon interactions were anecdotal, and information on the spatial dynamics of both species and on the diet of seals are needed to fully quantify those interactions.

The two general objectives of this research were to determine whether there has been an increase in the potential for seal predation on salmon in some rivers and estuaries in Newfoundland and Labrador, and for rivers that exhibited a high potential for predation, to document the importance of salmon in seal diets. To accomplish this, the research approach included two components. The first was to use local ecological knowledge (LEK) to document relevant changes in the distribution, habitat use, and migration patterns of seals, changes in the presence and spawning times of forage fish, and the occurrence of seal-salmon interactions on a river-by-river basis (Chapter 2). The second was to investigate the diet of seals, particularly harp seals, on rivers considered to have a high potential for seal predation during the smolt or adult salmon run (Chapter 3). Understanding how seals use river or estuarine habitats when salmon are migrating will allow us to evaluate the potential impact seals may have on commercially and recreationally important salmon stocks. A summary of key findings and recommendations for future research is given in Chapter 4.

The following text provides relevant background information on environmental conditions and ecosystem changes that occurred in the northwest Atlantic during the late 1980s through the mid 1990s. It also provides an overview of the life histories and ecology of harp seal and salmon populations in Newfoundland and Labrador, and a general overview of the local ecological knowledge research approach used in this study.

1.2 Environmental conditions in the northwest Atlantic

The North Atlantic Oscillation (NAO) is the recurrent mode of atmospheric activity influencing weather and climate over the North Atlantic Ocean (Hurrell et al. 2003). The NAO is dominated by two atmospheric pressure patterns: the Azores High, a sub-tropical high pressure system centered over Bermuda; and the Icelandic Low, a low pressure system centered between Greenland and Iceland. The NAO occurs year round but is most intense in winter, and therefore exerts a greater influence on the environment during this time. The difference in pressure strengths between the Azores High and Icelandic Low varies from year to year and is known as the NOA index. A high index (positive phase) corresponds to an intense High and deep Low, producing cool, dry conditions across the Northwest Atlantic, while warm and wet conditions prevail in the Northeast over western Europe. The opposite occurs during a low index (negative phase) (Hurrell et al. 2003).

Changes in these phases produce considerable variability in the physical environment, including effects on wind speed, sea surface temperatures, and prevalence and intensity of winter storms (Hurrell et al. 2003). During the last several decades of the twentieth century, the NAO switched from a low to a predominately high index, producing considerable variability in climate over Newfoundland and Labrador. Warm winters and minimal sea ice cover occurred throughout the 1950s and 1960s until a variable but general cooling trend started in the 1970s (Colbourne 2004). A positive phase persisted from the late 1980s until early 1990s, producing strong northwesterly winds over the Labrador Sea (Colbourne et al. 1994; Drinkwater 1996, 2004; Colbourne 2004). These winds brought cold Arctic air further south across Newfoundland and Labrador, resulting in decreased winter air temperatures, extreme cold water temperatures, heavier ice conditions, and greater sea ice formation in the Newfoundland and Labrador shelf region and Grand Banks (Colbourne et al. 1994; Drinkwater 1996). During this time period, water temperatures over the Grand Banks were generally 0.5°-2.0°C degrees colder than the 30 year norm and the extent of sea ice coverage exceeded the decadal averages recorded since the early 1960s (Drinkwater 1996; Colbourne 2004). In 1996, the NAO began to weaken, and the latter half of the decade was characterized by air temperatures that were warmer than the 30 year norm and by sea ice coverage that was minimal compared to previous decadal averages (Drinkwater 2004).

1.3 Harp seals

There are three harp seal populations in the North Atlantic region including those in the White Sea, Greenland Sea (near Jan Mayen Island), and the Northwest Atlantic. The Northwest Atlantic population is the largest with a current abundance estimate of approximately 5.9 million animals (Anonymous 2005), making them the most numerous pinniped frequenting Newfoundland and Labrador waters. Estimates of seal abundance declined from approximately 3.0 million in the 1950s to 1.8 million animals by the early

1970s. From 1980-1996, the population steadily increased to approximately 5.5 million animals and then stabilized in more recent years (Anonymous 2005). This harp seal population is the most migratory of the three, with seals undertaking extensive annual fall and spring migrations (Sergeant 1965, 1991). Harp seals leave western Greenland and the Canadian Arctic in late fall, and migrate south along the Labrador coast ahead of forming local pack ice (Figure 1.1). The population reaches the Strait of Belle Isle by late November or December and splits into two components. Approximately 70% of seals stay off the coast of Newfoundland and Labrador, while the remaining animals move into the Gulf of St. Lawrence. During January and February, adult harp seals are dispersed over the continental shelf off Newfoundland. This period is a time of heavy feeding, especially for females who must accumulate fat stores in preparation for reproduction (Lavigne and Kovacs 1988).

Females aggregate on the pack ice off southern Labrador (the "Front"), and in the southern and northern Gulf of St. Lawrence (the "Gulf"), forming large whelping patches to give birth to their pups in late February to mid March (Lavigne and Kovacs 1988). After weaning and mating (late March), females disperse to feed before joining juvenile animals and adult males on the pack ice to undergo their annual molt (mid April). Once the moult is complete, adult harp seals generally begin their northern migration in May to summer feeding grounds in the Canadian Arctic. Pups migrate north independently of adults, with the majority spending their first summer along the west coast of Greenland (Sergeant 1991).

Harp seals in Newfoundland and Labrador waters feed on a wide range of prey, yet only a few species compose the bulk of their diet. The relative importance of these species varies seasonally, between years, and among geographic locations (Lawson et al. 1995; Lawson and Stenson 1997; Wallace and Lawson 1997). Stomach content analyses indicate that Arctic cod is a large component of harp seal diet in nearshore waters off Labrador and northeastern Newfoundland, and capelin is a preferred prey item in offshore areas (Lawson and Stenson 1997; Lawson et al. 1998a; Stenson and Perry 2001). Harp seals off western Newfoundland feed primarily on capelin, herring (*Clupea harengus*), Atlantic cod, and redfish (*Sebastes* spp.), whereas the latter two species are the main prey of seals along the south coast of Newfoundland (Lawson et al. 1995).

The above text describes the harp seal's traditional distribution, migration patterns and diets. However, in recent years, the timing of migration, distribution and habitat use has changed for some segments of the population (Chapter 2). Understanding the possible impacts of these changes on Atlantic salmon was a key component of this study (Chapter 3).

1.4 Atlantic salmon

The present range of salmon in the Northwest Atlantic includes rivers from the northeastern United States to Ungava Bay in northern Quebec (Klemetsen et al. 2003). Atlantic salmon are anadromous fish that migrate from the ocean into rivers to spawn. Pre-spawning salmon usually enter rivers between May and November, and consist of either grilse (salmon that have spent one year at sea) or multiple-sea-winter salmon (Klemetsen et al. 2003). With the exception of a few rivers on the southwest coast of Newfoundland, the majority of salmon stocks in Newfoundland and Labrador are composed of grilse (Dempson et al. 1986). Spawning usually occurs in October or

November, and after spawning, male and females are called kelts or "spent fish". Most male salmon die after spawning, but females may survive and become repeat spawners (reviewed in Fleming 1996). Kelt salmon may return to sea after spawning or overwinter in the river and return the following year (Mills 1989).

Juvenile salmon (parr) remain in freshwater from four to eight years before reaching the smolt stage, at which time they migrate downstream in early spring (April to June) (Mills 1989). When smolt depart their natal rivers, they are thought to move quickly out to sea, usually staying within the estuary for a few days to a month (Reddin 1988; Lacroix et al. 2004; Gudjonsson et al. 2005). Post-smolts that leave Newfoundland and Labrador rivers migrate north to feed and mature in areas off western Greenland and in the Labrador Sea (Reddin 1988). Salmon at sea feed on a variety of prey, including capelin, herring, amphipods, and euphausids. In coastal waters off Newfoundland, they feed primarily on capelin and herring (Reddin 1988).

Starting in the mid 1980s, Atlantic salmon stocks declined throughout much of its range in the North Atlantic, including some stocks in the United States, Canada and Europe (ICES 1999). The factors responsible for the decline and whether they occurred during the freshwater or marine stage are uncertain. Some studies have shown a correlation between the decline in marine survival and growth of salmon and reduced sea surface temperatures in the North Atlantic (Friedland et al. 1993, 1998), but several other factors have been hypothesized, including habitat loss, predation, disease, and pollution (Cairns 2001).

1.5 Local ecological knowledge (LEK)

Traditional ecological knowledge (TEK) and local ecological knowledge (LEK) are derived from a person's or group of people's long term, experiences and interactions with their surrounding environment (Huntington 1998, 1999; Neis et al. 1999a; Usher 2000). This knowledge can be useful in complementing Western science and is often incorporated into environmental assessment and resource management studies (e.g. Ferguson and Messier 1997; Neis at al. 1999a, 1999b; Usher 2000). The primary difference between TEK and LEK is often the longer temporal scale upon which TEK is based upon. Some researchers use TEK to indicate aboriginal knowledge and LEK to indicate the knowledge of commercial fishers or local resource users (Neis et al. 1999a, 1999b). Information collected from resource users in this thesis refers to the knowledge of retired and current inshore fishers, seal hunters, federal and provincial fishery officers, aboriginal fishery guardians and recreational salmon anglers. Therefore, both TEK and LEK would be appropriate, but given that most of the information collected pertains to the last 20 years, the term local ecological knowledge will be used throughout this thesis.

Resource users often acquire detailed information about their surroundings and environment, so that while one species may be their primary focus, a wide range of other knowledge is invoked to understand the species of interest. LEK has been useful for collecting detailed information about wildlife because it is often passed down through generations, so compared to most scientific studies, LEK is able to provide data over a longer temporal scale (Fischer 2000). For example, Huntington (1999, 2000b) documented knowledge from hunters about beluga whale (*Delphinapterus leucas*) migrations, feeding behaviour, and distributions in several Alaskan communities. The hunters' knowledge was largely consistent with existing information from the published literature, but they were able to provide information on beluga ecology over a longer temporal scale. Ferguson and Messier (1997) used TEK of Inuit hunters to collect historic information on the ecology of a caribou population on southern Baffin Island. Their goal was to integrate aboriginal and scientific knowledge for the development of management and conservation initiatives. From a climate change perspective, Nichols et al. (2004) documented Inuit knowledge regarding various aspects of sea ice (e.g. freeze-up and breakup times) in the western Canadian Arctic. Understanding changing sea ice conditions is necessary for Inuit from a subsistence hunting, travel safety and cultural perspective. Their observations complemented scientific knowledge where climate data were temporally and spatially limited (Nichols et al. 2004). LEK is also useful for providing information on endangered species when field work is logistically difficult to carry out (Mallory et al. 2003). In remote areas where populations are hard to monitor, LEK may be the only source of information regarding a species distribution and abundance changes, and the ecological factors that could be influencing these changes.

Incorporating LEK allows resource users and scientists to share their expertise and collaborate on future research projects. This cooperation between different groups of individuals can lead to new management strategies, improved data collection, and new testable hypotheses. Several other studies utilized LEK for acquiring information on wildlife and have incorporated this information into resource management (Ferguson et al. 1998, Neis et al. 1999a, 1999b).

Figure 1.1 Distribution and migration patterns of Northwest Atlantic harp seals (taken from DFO 2000, Science Stock Status Report E1-01).

CHAPTER TWO: EVALUATING THE POTENTIAL FOR SEAL PREDATION ON SALMON IN RIVERS AND ESTUARIES: INSIGHTS FROM LOCAL ECOLOGICAL KNOWLEDGE

2. 1 Introduction

Atlantic salmon (*Salmo salar*) have a well-documented history of commercial, recreational and subsistence exploitation by coastal communities in Newfoundland as well as by aboriginal peoples in coastal Labrador (Brice-Bennett 1977; Taylor 1985). Prior to the mid 1980s, Newfoundland and Labrador salmon populations were considered healthy. However, by the 1990s their abundance had declined to such low levels that moratoria were placed on the Newfoundland commercial salmon fishery in 1992 followed by the Labrador fishery in 1997 (Dempson et al. 2004). River closures and recreational fishing restrictions have been implemented since that time. Reasons for the decline in salmon abundance are not fully understood, but over-fishing, habitat loss, aquaculture, environmental conditions, mortality at sea, and seal and seabird predation are some of the factors that have been attributed as possible causes (Cairns 2001).

Evaluating the importance of seal predation is difficult given how little is known about their diet, habitat use and distribution in rivers and estuaries of Newfoundland and Labrador during salmon runs. In the case of harp seals (*Pagophilus groenlandicus*), this data gap is mainly due to the fact that diet studies have focused on late fall and winter feeding periods of this species (Lawson and Stenson 1995; Lawson et al. 1995; Lawson and Stenson 1997). Relatively few spring and summer samples were collected from coastal waters when harp seals are most likely to prey on salmon. Limited diet information is available for harbour (*Phoca vitulina*), grey (*Halichoerus grypus*), ringed (*Pusa hispida*) and bearded seals (*Erignathus barbatus*), which also frequent Newfoundland and Labrador waters. However, predation of salmon by harbour and grey seals has been well documented in other parts of their range (Brown and Mate 1983; Roffe and Mate 1984; Carter et al. 2001; Orr et al. 2004).

Coincident with declining salmon populations in Newfoundland and Labrador, there were major changes in the Northwest Atlantic ecosystem (Colbourne et al. 1994; Drinkwater 1996; Carscadden et al. 2001). Colder than normal water temperatures from the late 1980s to the mid 1990s are thought to have affected the biology, biomass and distribution patterns of many species, including schooling forage fish (e.g. capelin (*Mallotus villosus*), Atlantic herring (*Clupea harengus*) and Arctic cod (*Boreogadus saida*)) and harp seals (Frank et al. 1996; McAlpine et al. 1999; Lacoste and Stenson 2000; Parsons and Lear 2001). Capelin and Arctic cod are important prey for seals in the northwest Atlantic, especially the harp seal (Lawson et al. 1995, 1998a; Hammill and Stenson 2000). Capelin are also a primary prey of adult salmon migrating into coastal waters (Reddin 1988). During the early 1990s, acoustic surveys estimating capelin populations in offshore areas showed a significant decline in their abundance (Carscadden and Nakashima 1997). At the same time, capelin distributions shifted south to occupy areas on the Flemish Cap and Scotian Shelf (Frank et al. 1996). In nearshore waters, the average capelin length was smaller compared to the 1980s, beach spawning was delayed by one to two months, or in some locations did not occur at all (Carscadden and Nakashima 1997; Carscadden et al. 2001). At the same time, Arctic cod exhibited a southerly shift in its distribution from Arctic and Labrador waters into nearshore areas of Newfoundland (Lilly et al. 1994), and replaced capelin as the dominant prey item for harp seals in coastal areas of northeastern Newfoundland during the 1990s (Lawson and Stenson 1995; Lawson et al. 1995). Concurrent with these changes, there were anecdotal reports from resource users to the Department of Fisheries and Oceans (DFO) regarding increased numbers of harp seals frequenting coastal waters during the late spring and summer, suggesting a change in seasonal migration patterns and distribution for a segment of the population. Although oceanographic conditions have warmed since 1996 (Drinkwater 2004), capelin distribution and spawning times have remained variable or delayed (Carscadden et al. 2001), harp seals' use of coastal waters during the late spring and summer has continued to remain high compared to historical times, and there has been no sustained recovery of some salmon stocks (Dempson et al. 2006).

Documenting the response of a single marine species to large-scale ecosystem change and oceanographic perturbations is difficult; attempting to understand multi-species interactions is an even greater challenge. This is particularly true when the feeding habits of harp seals, a highly mobile and adaptive apex predator, are a research focus. The task is further complicated because knowledge of climate-related changes in the distribution, relative abundance and spawning behavior of key forage fish species in many parts of Newfoundland and Labrador is fragmentary. In this study, local ecological knowledge (LEK) was used to document the seasonal presence, habitat use, and relative abundance of harp seals and key forage fish species in selected salmon rivers and estuaries over a 20 year time period when the Northwest Atlantic marine ecosystem was undergoing significant change. This approach was adopted because resource users often acquire extensive knowledge about the species they depend on and interact with (Neis et al. 1999a; Huntington 2000a). This knowledge is then passed down through generations, enabling resource users to provide information on the status of certain species when other data sources are limited or logistically difficult to collect (Mallory et al. 2003).

The specific objectives of this study were to first identify rivers and estuaries where there has been a change in the temporal and spatial overlap between harp seals, forage fish and salmon, and second to evaluate the potential for seal predation on salmon in those river and estuaries. This research focused primarily on harp seals, but five other seal species frequent Newfoundland and Labrador waters and all have been reported to feed opportunistically on salmon; therefore relevant data are reported for these species as well.

2. 2 Methods

Interviews were conducted from March 2004 to August 2006 with 57 resource users regarding their knowledge of salmon rivers in Newfoundland and Labrador (Appendix A). A total of 29 rivers were studied; 19 were located in Newfoundland (northeast coast n = 3; south coast n = 5; west coast n = 11) and 10 in southern Labrador (Figure 2.1; Table 2.1). They were chosen because most are regulated, or scheduled salmon rivers, and in many cases they have been the focus for salmon research and management initiatives in the past. The resource users interviewed included active and retired inshore fishermen, recreational salmon anglers, seal hunters, fishery officers, and aboriginal river guardians. Some of the respondents were recommended by DFO research personnel based on their expertise and contributions to previous departmental research programs in their community, and the others were selected using a snowball sampling technique (Huntington 1998; Neis et. al 1999a). This is a method where people within a community who have the most knowledge on a particular topic are identified by their peers. Respondents were then selected based on the number of recommendations they received from local community members; those with two or more recommendations were contacted for an interview.

Interview protocol followed a semi-directive procedure (Nakashima and Murray 1988; Huntington 1998, 2000a). A set of questions was used for the interview, but respondents were given the opportunity to bring up topics of concern and address recent environmental changes they felt were relevant to the research (Appendix B). Respondents were contacted by phone a day or two ahead to set up a time and location for the interview. The majority of interviews took place in the respondent's home or at the local fishery detachment office.

At the start of each interview, a marine mammal identification guide was shown to identify seal species and clarify common name usage between the interviewer and respondent. Each respondent was asked to fill out a short questionnaire regarding their fishing or hunting background (Appendix C). Interviews of approximately one hour were recorded with the permission of the participant and later transcribed. Locational information, including seal migration routes, seal haul-out and foraging sites, forage fish spawning areas (including capelin beaches), important physical characteristics of the river or estuary, and areas of local ice coverage were marked on 1:50,000 and 1:250,000 topographic maps. Maps were digitized and locational information was transferred into a geographic information system (GIS) database using ArcView software. Each respondent was assigned an identification number to ensure confidentiality when data were marked on demographic sheets and maps. In most cases, three or more individuals with extensive knowledge of their area were interviewed for each river, or group of rivers. Follow-up interviews, by telephone or in-person interviews, were conducted with approximately 42% of the respondents to confirm information (e.g. locations, dates).

Interviews focused on three time periods: 1980-1989 (historic), 1990-1999 (recent past), and 2000-2005 (present). The interview questions were designed to: 1) examine changes in the distribution, relative abundance, and habitat use of seals in an area; 2) document changes in the timing and seasonal presence of forage fish in or near estuaries; and 3) provide a general overview of any observed changes in the local marine environment in relation to anthropogenic or large scale ecosystem changes that occurred during the study period. For questions relating to the occurrence and relative abundance of seals in a coastal area, respondents were asked to comment on whether seals were observed daily (common), once or twice per week (occasional), less than once per week (rare), or never observed during smolt or adult salmon runs. They also commented on whether seals were observed as single animals, small sculls of 3-5, 5-15, or larger sculls of >15. For questions focusing on forage fish, respondents commented on spawning times, spawning areas, and trends in relative abundance.

Documenting direct evidence of seal predation on salmon is difficult given the mobility and foraging behavior of the predator and the aquatic habitat of the prey. For the purposes of this study, *potential seal predation on salmon* refers to the opportunity for a predation event or predator-prey interaction to occur given that there is spatial and temporal overlap of predators (seals) and prey (salmon) in a river or estuary. Seal-salmon interactions were defined as direct if a seal(s) was observed chasing and consuming a salmon. Indirect seal-salmon interactions included scenarios when seals were observed foraging in the vicinity of salmon migration corridors or feeding areas, when there was evidence that seals were removing salmon from nets and when distinctive claw or tooth marks were observed on salmon.

The current status for potential seal predation on salmon at each river was evaluated using the following three criteria: 1) the occurrence and relative abundance of seals during the smolt or adult salmon run, 2) observations of either direct or indirect seal-salmon interactions in the river and estuary, and 3) ecological or physical habitat characteristics of the river that may attract seals to the area as well as increase the susceptibility of salmon to predation (e.g. warm water temperatures and low flow rates, light spring ice conditions, or physical river features that enhance salmon aggregation). An examination of the criteria across the three time periods of the study provided a perspective on the direction, magnitude and general timing of changes in potential seal predation on salmon in each river.

Based on these criteria, a river was categorized as having a high, moderate or low potential for seal predation on salmon. High predation potential occurred when seals were commonly sighted during a salmon run, there were observations of direct or indirect seal-salmon interactions, and there was evidence of an ecological or physical habitat feature that increased the susceptibility of salmon to seal predation. Moderate potential occurred when seals were occasionally sighted during a salmon run, there were observations of indirect seal-salmon interactions, and there was evidence of an ecological or physical habitat feature that increased the susceptibility of salmon to seal predation. Low potential occurred when seals were rarely or never observed during a salmon run, there was no evidence of seal-salmon interactions, and there were no ecological or physical habitat features that increased the susceptibility of salmon to seal predation.

2.3 Results

2.3.1 General Comments

The long-term seasonal occupation of rivers and estuaries by seals during salmon migrations varied both by seal species and geography (Table 2.1). Prior to 1990, harp seals were rarely observed during salmon runs at rivers along northeastern Newfoundland and southern Labrador. In the recent past, there was a notable increase in occurrence and relative abundance that has continued to the present. Harbour seals were occasionally observed in rivers along the south and west coast of Newfoundland prior to 1990, and have increased their presence on a number of rivers throughout the duration of the study. The occurrence and relative abundance of grey seals in southern and central Labrador rivers has increased in recent times. Observations of direct and indirect interactions between seals and salmon varied between rivers; direct observations of predation were rare (Table 2.2). Most evidence of indirect interactions involving harp seals occurred when large sculls were observed foraging (usually for capelin) in the vicinity of salmon migration pathways or salmon feeding areas near the headlands of an estuary (St. Lewis Sound and Sandwich Bay rivers, Figure 2.1; locations 4-10) or when individual seals were seen chasing salmon in a river (Gander and Campbellton, Figure 2.1; locations 1-2).

Harbour and grey seals were more often observed taking salmon from fishing nets or foraging at the river mouth (e.g. Paradise River in southern Labrador, St. George's Bay in western Newfoundland). The ecological or physical habitat features most commonly reported to be important in determining the susceptibility of salmon to seal predation could be grouped into three categories: 1) factors that appeared to attract more seals into an area (e.g. alternative prey sources, spring ice conditions), 2) habitat features that compromised the anti-predator evasive tactics of salmon (e.g. warm water temperatures, low river flow rates), and 3) natural or man-made habitat features that caused salmon to aggregate, making them more accessible to seals (e.g. waterfalls, bridges and causeways) (Table 2.3).

Potential harp seal predation on salmon was evaluated to be high for 8/16 rivers frequented by the species on the northeast coast of Newfoundland and southern coast of Labrador (Table 2.4 and Figure 2.1: locations 1, 2, 4-9). Of these rivers, potential seal predation on six were associated with increased spatial and temporal overlap with forage fish in the area, one with variable ice conditions during the late spring, and one with both conditions. Rivers on the west coast located in St. George's Bay, and those inland on the southern coast of Newfoundland (Figure 2.1: locations 17-29) were more susceptible to potential harbour seal predation with 10/24 rivers being considered to have high predation potential (Table 2.5). Potential grey seal predation on salmon was considered to be high at 3/11 rivers during the adult run in southern Labrador and moderate for the Torrent River on the western coast of Newfoundland (Table 2.6). Harp, harbour and grey seals co-occurred during salmon runs at eight rivers in southern Labrador and three in western Newfoundland (Table 2.1 and Figure 2.1: locations 4-11, 14-16). For these rivers, potential seal predation was evaluated for each species individually (Tables 2.4-2.6). Ringed, hooded (*Cystophora cristata*), and bearded seals were observed near several rivers around the Province but were rarely or never observed during salmon runs. Details of the interviews are summarized below beginning with rivers reporting harp seal-salmon interactions followed by those reporting interactions with harbour and grey seals. Quotations from resource users in the following text are given using an individual's identification number and year the interview took place.

2.3.2 Harp seals

Labrador

At the St. Lewis Sound rivers, there was an increase in both the relative abundance and residency time of harp seals starting in the mid to late 1990s (Table 2.1, Figure 2.1: locations 4-6). Historically, harp seals would migrate north by the end of May or early June passing by the area, but in the recent past, they have been observed in large sculls during July and August (n=5/5 respondents). Two noted that:

> "One time they (harp seals) would move on through fairly quick up north again but its not taking place…I mean they are here pretty well mid-summer, they are hardly gone actually." 1:2004

> "Years ago you would never see a harp in July. Once May, June came they would be gone" 3:2004

Scull sizes ranged from 15-20 to hundreds of animals with varying age class composition. Most were a mixture of beater (young of the year seal aged <6 months) and bedlammer (immature seal aged 1-4) harp seals (n=4/5). Only one respondent indicated the sculls were composed mainly of adult harps.

Although it was not possible to obtain information on the residency time and movements of individual seals or sculls in and out of the estuary, the occurrence and activity of seals while in the estuary appeared to be influenced by the presence of capelin in the area (n=4/5). One commented that:

> "Last year (2004) when we were on the water during the salmon fishery which was mid-July, there was some capelin in the area which brought together bigger packs (of seals)…" 1:2004

Capelin disappeared from the area in the early 1990s, but started to return in 2001 and 2002 (n=5/5). However, spawning and migration times were still highly variable compared to the 1980s (n=4/5). Capelin traditionally spawned in late June, but now this activity occurs anytime from mid July up to November. These changes in spawning times and the increased residency time of harp seals have resulted in an overlap in the occurrence of harp seals, capelin and adult salmon migrations into the St. Lewis, St. Mary's and St. Charles rivers. The presence of seals in St. Lewis Sound during this time period also overlaps with the subsistence salmon fishery for aboriginal and Labrador residents in the area. Two of the respondents who were involved with the commercial salmon fishery never had problems with seals removing salmon from their nets. However, one fisherman noted that harps were starting to become a nuisance for the fishery in the mid 1990s (the fishery ended in 1997). This coincides with the time that harp seals were first observed to increase their summer residency (Table 2.1). When the subsistence fishery started in 2000, all respondents reported problems with harp seals at their nets.

"Well very seldom would you see seals in the 1990s when there was a commercial fishery, but now…say from 1995 up till now, you pretty well see them every year." 5:2005

In Sandwich Bay, the occurrence and relative abundance of harp seals started to increase in the late 1990s (Table 2.1, Figure 2.1: locations 7-10). Concurrently, the summer residency period for harp seals increased by 1-2 months, extending into July and August (n=7/7). Capelin essentially disappeared from the area during the 1960s but returned in 2002. Migrations and abundance were delayed and variable and peak capelin activity occurred from July to August (n=7/7). Changes in the seasonal occurrence of capelin appeared to have influenced harp seals' movements in the vicinity of Sandwich Bay in recent years. Four respondents have observed harp seals foraging on capelin along the headlands at the entrance of Sandwich Bay during July and early August. Two noted:

"Last few years they (harp seals) have been getting more numerous in the summertime, especially when the capelin comes around. See sculls chasing capelin" 17:2005

"Seems like when the capelin comes, you got seals that start following them right in around the headlands. They don't follow them up into the bay. Huge sculls of old harps mostly." 26:2005

Although this seal foraging activity occurred in the vicinity of adult salmon migration routes into the Bay, respondents felt that harp seals were not a serious concern for returning adult salmon because they rarely frequented inside Sandwich Bay during this time. Instead, all respondents felt that harbour and grey seals were a greater threat to salmon (Table 2.5 and 2.6). One noted:

"For salmon, they (harps) are not that much of an issue." 26:2005.

Newfoundland

At Campbellton River, there was an increase in the relative abundance and residency time of harp seals starting in the late 1990s (Table 2.1, Figure 2.1: location 2). Historically, the majority of seals left this area by early May, but in recent years respondents have observed beaters and adult seals until the end of June with occasional observations in July and August (n=4/4). Single or small sculls of 2-3 beaters were most commonly observed; however, sculls of 5-15 adult seals also frequented the area. Both capelin and herring occur in the estuary and there is also a run of smelt (*Osmerus mordax*) from the river. Although capelin still spawn in the estuary, their relative abundance has declined (n=3/4). Two respondents noted that abundance had decreased over the last five years, one over the last ten years, and one respondent commented that capelin has been gradually decreasing over the last twenty years. All agreed that spawning times were delayed by 1 to 2 months and in some years did not occur at all on certain beaches (in recent years spawning occurs from July to August). Herring abundance has been declining since the mid 1990s and there has been no spawning inside the estuary since 2000 (n=2/2 that were knowledgeable about herring). The increased residency time of seals in the estuary overlaps with the migrations of smolt and kelt salmon, the concurrent smelt run from the river, the beginning of capelin spawning, and the onset of the adult salmon run. There have been verified reports of beaters chasing and consuming kelt salmon by DFO research personnel and two respondents have observed seals chasing adult salmon in the estuary.

In addition to the presence of late spawning capelin and other forage fish species in the estuary, increasing light and variable ice conditions were also important factors in explaining the increase in seal numbers during the smolt run. Prior to 1990 harp seals remained in more offshore waters and rarely frequented the estuary because ice usually impeded access to the area during the late winter and early spring (n=2/4). The extent and duration of local ice has gradually decreased since the late 1990s. The timing of freeze-up prior to and during the 1990s occurred by December, but in recent years has been delayed until February. The timing of spring breakup in the past used to occur in late April but is now one month earlier. Young seals that moved into the area in early spring tended to remain in the area until late June or July. The absence of ice was reflected in changes to local hunting practices over the last 5 years. Three respondents commented that hunting seals was easier because they were able to leave their boats in the water longer in the winter, and start hunting earlier in the spring.

In Gander Bay and River, there was an increase in the relative abundance and residency time of harp seals starting in 2000 (Table 2.1, Figure 2.1: location 1). Individual and small groups of seals were observed hauled out on rocks near the mouth of the river and 4 -5 km up the main stem throughout the smolt and adult salmon runs (n=6/6). The identification of these species was not certain (n=6/6); however, based on the haul out behaviour, it is likely they were mixture of immature harp seals and harbour seals (Wayne Penney, personal communication, 2007). Unidentified seals, most likely to be harbour seals, were also sighted in Gander Lake, approximately 30 km from the river mouth. Two respondents have observed seals feeding on adult salmon, while others (n=3/6) have seen salmon with their stomach cavities ripped open and believe this could have been caused by a seal (Table 2.2).

Similar to the situation at Campbellton River, respondents (n=4/6) noted that late winter and spring ice conditions allowed harp seals access to Gander Bay throughout the winter and early spring. Since 2000, an increased number of seals have been frequenting an open water area created by a causeway at the river mouth, and gaining access to the river during spring thaw. Four respondents thought seals were able to travel under the ice from the causeway to areas of open water inside the river. During the last decade, Gander Bay has experienced intermittent mild winters; ice extent and duration of coverage have varied significantly in recent years (n=4/6). Freeze-up has been delayed by 1-2 months and ice thickness is notably less compared to the 1980s and early 1990s (n=4/6). Two respondents believed that there had been no warming trend and that ice coverage just varied each year. The peak time that seals (1-35 animals at a time) frequented the causeway was from late December to February. Several respondents acknowledged seals may be present before freeze-up but are not as noticeable until they move onto the ice. One respondent noted that seal abundance at the causeway appeared to be linked to the amount of ice cover within Gander Bay. He noted:

"If all of Gander Bay is frozen, you see very few seals. Now three years when I counted 20 odd at this location, it was frozen but there was a lot of open water." (12:2005).

There has been no increase in the spatial or temporal overlap of harps seals and salmon on the Humber, Torrent and Lomand Rivers in Newfoundland, or the Forteau Brook and Pinware River in southern Labrador (Figure 2.1: locations 12-16). There has been an increase in harp seal relative abundance since the mid 1990s, but they have not increased their residency time during the summer nor has the timing of their northward migration changed. In the past, sightings of individual seals have been reported in the Humber River, but this was not a yearly occurrence and the species of seal was not known (n=2/2). In the case of the Torrent River, there have been rare sightings of lone beaters in some years during June and July in the estuary. However, seals were not observed in the Torrent River or at the river mouth (n=4/4). No harp seals frequented Forteau Brook or Pinware River during salmon runs even though capelin and herring spawning both coincided with adult salmon migrations (n=5/5). Harp seals were not observed during salmon migrations at rivers in St. George's Bay or at rivers located in southern Newfoundland.

2.3.3 Observations on other seal species

This study focused primarily on harp seals, but there were several rivers where a spatial and temporal overlap of salmon occurred with other seal species. Rivers on the western and southern coasts of Newfoundland were more susceptible to potential harbour seal predation (Table 2.5), while rivers in Sandwich Bay, Labrador were susceptible to both harbour and grey seal predation (Table 2.6). The relative abundance of grey seals frequenting St. Lewis Sound, the Pinware River, Forteau Brook and the Torrent River during the adult salmon run has increased (Table 2.1).

Harbour seals – Newfoundland

Harbour seals have always been present in St. George's Bay, but the relative abundance of this species increased on 6/8 rivers over the past 15 years (n=9/10; Table 2.1).

"Over the last number of years, the population has really increased. I would say within the last 10 years they really doubled in population." 51:2005

Seals were most often observed at river mouths from March to June, but in recent years have started moving into some rivers. Flat Bay Brook had the highest potential for predation, but seals also frequented the Highlands, Crabbes, Fishchells, Robinsons and Southwest Brook rivers (Table 2.6). At Flat Bay Brook, animals were first observed in March when ice was still present in the estuary. Seals then moved upriver after the spring thaw, concurrent with the seaward migration of smolt from the river. Single seals and small sculls of 2-3 have been observed 1 km upriver (n=2/3 respondents familiar with Flat Bay) and seals have been observed chasing smolt in Flat Bay (n=1/3). Sculls of 2-10 harbour seals were also observed at river mouths on the Highlands and Crabbes Rivers during the smolt and adult salmon runs. Two main haul-out sites were identified, one near Flat Bay and the other south of Highlands River (Figure 2.1: locations 19 and 24). Estimates of scull sizes for seals congregated at the site near Flat Bay Brook ranged from 5-40 animals; however most observations were of sculls with 5-15 seals. Estimates of relative abundance for the site near Highlands River ranged from 100-500 seals. This site is remote and only accessible by boat, therefore respondents did not know if seals occupied it all year round.

The relative abundance of harbour seals has increased in several bays and estuaries on the southern coast of Newfoundland. The majority of these rivers were assessed as having moderate potential for predation (Table 2.5). Harbour seals have always been present near Northeast and Northwest Brook Trepassey (Figure 2.1: locations 28-29); however, relative numbers of seals have steadily increased since 1990 (n=3/3; Table 2.1). A natural waterfall at the mouth of Northeast Brook prevents seals from entering the main stem, but seals were occasionally observed foraging at the river mouth and in the estuary during both the smolt and adult run (n=3/3; Table 2.2). No respondents (n=3/3) observed seals at the mouth of the Collinet River, and only rare sightings of single seals or small sculls have been made at the mouth of the Rocky River (n=1/3) during the adult run (a waterfall prevents seals from accessing the main stem of the river). Although seals are rarely seen at the Rocky and Collinet rivers, they utilize haul-out sites in the estuary during the adult salmon run. Harbour seals and a rare grey seal were commonly observed hauled out on rocks approximately 9 km from both river mouths. Herring and capelin spawn in the estuary, but both species have decreased in abundance over the last 15 years, with variable or no spawning in some years. One respondent noted:

"when everything was plentiful, like we had lots of herring and lots of capelin, it seemed that the seals weren't bothering (salmon) that much, but when everything was scarce they had to have something to eat, so they'd tear the salmon out of your nets" (70:2006).

Harbour Seals – Labrador

Harbour seals were considered the main predator on adult salmon entering rivers in Sandwich Bay. This species has historically been present on the Eagle, White Bear, and Paradise rivers during adult runs (n=7/7). On the Paradise River, seals migrated into the river in June, and left in November before freeze-up (Figure 2.1: location 7). Estimates of local abundance ranged between 50-100 animals, with a steady increase in numbers during the 1990s (n=7/7). Harbour seals were frequently seen around salmon nets during the subsistence fishery and were thought to be responsible for removing salmon and damaging nets. Seals were also sighted in Table Bay near the Sandhill Hill River; however, their distribution and relative abundance in this bay were not known (n=3/3 respondents who were familiar with the area). Harbour seals were rarely observed during smolt or adult salmon runs in St. Lewis Sound, near the Pinware River or Forteau Brook (Table 2.5). The low number of seals in St. Lewis Sound and surrounding are was thought to be caused by heavy hunting pressure in the 1970s (n=4/5).

Grey seals

Grey seals were present on all rivers in southern Labrador, but were most commonly observed frequenting river mouths during the adult salmon run on the White Bear, Eagle and Pinware rivers. Their relative abundance in the Sandwich Bay area increased starting in the mid 1990s, and respondents (n=4/7) identified one haul-out area near the Eagle River. Although grey seals were not observed in St. Lewis Sound until 2000, they were known to be present at St. Peter's Bay, approximately 20 km south of the Sound. The relative abundance of seals in St. Lewis has increased since that time, and they are occasionally observed at salmon nets during the local subsistence fishery (n=3/5). Some of the respondents from the Pinware, Forteau and Torrent rivers considered grey seals to be the 'new' population of seals because they had never observed them before. At the Pinware River, grey seals were rarely observed during the 1990s, but their relative abundance increased starting in 2000 (n=5/5). Seals were observed hauled out on two islands and a sandbar near the river mouth during the adult run. Capelin and herring also spawn in the vicinity of the river mouth. Grey seals were never observed at the Torrent River before 1995, but their relative abundance increased in the late 1990s and continued to increase through the present (n=4/4). There is one haul-out site located along the headlands near the Torrent River where seals congregate from late summer until October. None of the respondents observed seals at the mouth of the Torrent River, and no direct interactions were observed.

2.4 Discussion

Local ecological knowledge collected from interviews with resource users has provided evidence of an increase in the spatial and temporal overlap of seals and salmon on some rivers in Newfoundland and Labrador. Changes in the distribution and extended occupation of some rivers and estuaries by harp seals suggests that potential for harp seal predation on salmon has increased since the mid-to late 1990s on some rivers. Increases in the relative abundance of harbour and grey seals in some rivers over approximately the same time period suggests an increased predation potential by these species as well. Based on these observations, eight rivers frequented by harp seals, nine by harbour seals, and three by grey seals were considered to have high potential for predation. Variation in potential predation from river to river can be partially explained by geography, the ecology of seal species frequenting the area, and migratory behaviour of the predator and prey. Rivers located on relatively exposed coastlines adjacent to late spring feeding areas and migration routes for harp seals were more susceptible to seal-salmon interactions with these species. Those located in well protected inland bays or those located to the south of habitats traditionally used by harp seals in the late spring and summer were frequented more often by harbour or grey seals that had permanent or summer haul-out sites near the river or estuary. Changes in the seasonal distribution and delayed spawning times of forage fish, particularly capelin, also seemed to be an important factor in determining which rivers and estuaries harp seal-salmon interactions occurred. In the recent past, ice conditions in some rivers, bays and coastal areas have become increasingly variable, and in some cases lighter. This allowed harp seals access to coastal habitats that were previously protected by ice during their spring migration. For some rivers, early access by seals was associated with extended residency time and increased spatial and temporal overlap with smolt runs.

The information provided for a river or group of rivers by resource users was remarkably consistent. Those who hunted seals for personal use, subsistence, or had experience in the commercial harp seal hunt were most familiar with the ecology and identification of seals in their area. Most of the respondents from the northeast coast of Newfoundland and Labrador fit this description of expertise. For respondents who were not seals hunters or were from communities where some seals were considered new to the area (i.e. harps seals at Gander River and grey seals at Pinware River), species identification was more difficult. However, most were familiar with local names, and with the aid of photographs and general descriptions, were able to identify the seal species frequenting their area. Call back interviews were used to clarify and validate information if necessary. In rare cases where species identification was inconsistent among respondents for a particular area, their observations were verified by DFO researchers who had experience working in the area.

Less consistent information was found when resource users were asked to identify the age class composition of harp seal sculls migrating into coastal waters. The majority of harp seals reported in coastal waters around Newfoundland in the late 1990s during salmon runs were young animals. Concomitantly, harp seals reported in extralimital areas of their range were also predominantly immature seals (Stevick and Fernald 1998; Harris et al. 2002; Lucas and Daoust 2002). The higher proportion of young seals observed in Newfoundland is consistent with what is known about age segregation during the northern migration. Young seals are usually solitary during this period, and their migration generally follows older animals (Sergeant 1965, 1991). There did not appear to be a problem in the correct identification of immature harp, harbour and grey seals in areas where they co-occurred; however, St. Georges Bay warrants further investigation to confirm that no young grey seals have moved into the area. Confirmation of the species frequenting the Gander River should also be considered. There was little confusion with the identification of immature species of seals in Labrador rivers because respondents were generally familiar with all seal species. Any major discrepancies in the information provided for a particular river could usually be reconciled given that at least three people were interviewed. These findings underscore the importance of establishing species and age class early in the interview process.

Local ecological knowledge of historic harp seal migration patterns and general habitat use was consistent with published information (Sergeant 1965, 1991; Lavigne and Kovacs 1988; Stenson and Kavanagh 1993). This was particularly the case for respondents living in communities along the northeast and northwest coasts of Newfoundland and southern Labrador. The information provided on changes in the timing of seasonal migrations, the use of coastal habitat during the spring and summer, and increasing relative abundance of seals in coastal waters is generally supported by several studies documenting shifts in harp seal seasonal distribution and movement patterns during the 1990s (Stevick and Fernald 1998; McAlpine et al. 1999; Harris et al. 2002; Lucas and Daoust 2002).

Historically, the southern limit of the harp seals' summering range was considered to be the northern coast of Labrador; extralimital sightings of harp seals during the summer period were considered rare (Sergeant 1965). Prior to 1990, reports of harp seals outside their seasonal range (Lavigne and Kovacs 1988; Sergeant 1991) were also relatively rare. McAlpine and Walker (1990) summarized records of harp seals in the Northwest Atlantic and found only 16 occurrences from New Brunswick to Virginia from 1841 to 1989. A general increase in the occurrence of harp seals started in 1994, most notably along the eastern seaboard of the United States (Stevick and Fernald 1998; McAlpine et al. 1999; Harris et al. 2002). Lacoste and Stenson (2000) reported that the winter distribution of harp seals moved southward in 1994 and 1995; concurrently Lucas and Daoust (2002) sighted 1,191 harp seals at Sable Island, Nova Scotia from 1994-1998, a significant increase from the five harp seals observed throughout the 1980s.

The movement patterns and habitat use of 22 harp seals monitored with satellite tags in 1994 and 1995 also indicated that winter distributions had likely shifted southward to the Flemish Cap and northern Scotian Shelf, and that animals were frequenting nearshore habitats most of the year (G. Stenson, personal communication, 2007). LEK has provided a complementary perspective on how harp seal distribution and habitat use was changing in coastal areas during the same time period when offshore changes were taking place.

Resource users were also able to provide a considerable amount of new information regarding the relative abundance and distribution of harbour and grey seals during salmon runs for several rivers around the province. However, validating the LEK information for these species was more difficult because relatively little research has been conducted on them in Newfoundland and Labrador waters. LEK on the general distribution of harbour seals is supported by the early research of Boulva and McLaren (1979). Evidence of increasing relative abundance in some rivers and bays is corroborated by similar findings based on DFO boat surveys of several known harbour seal haul-out sites on the south and northwest coasts of the province (Sjare et al. 2005). Grey seals frequent Newfoundland and Labrador coastal waters in low numbers primarily during the summer (Mansfield 1967). However, there is no current information on their distribution, relative abundance or foraging behaviour in nearshore waters or in rivers and estuaries of this province. Evidence of increased abundances at some rivers and establishment of new haul-out sites near others is consistent with the rapid growth of grey seal populations and distributions on the Scotian Shelf (Bowen et al. 2003) and in the Gulf of St. Lawrence (Hammill et al. 1998). LEK was an effective way to document the movements of these seal species into new areas of the province, map the locations of seasonal haul-out sites, identify pupping locations and monitor the occurrence of seal-salmon interactions.

Local ecological knowledge documenting variable and delayed spawning and changes in the relative abundance of capelin in estuarine habitats is also supported by the literature. A variety of studies including trawl and acoustic surveys, shore-based spawning studies, and fisherman logbook programs conducted during the early to mid 1990s provided evidence of the following: reduced capelin abundance in offshore areas (Carscadden and Nakashima 1997); a shift in capelin distribution south onto the Flemish Cap and Scotian Shelf (Frank et al. 1996); numerous changes in reproductive biology consistent with cool oceanographic conditions; and delayed or lack of beach spawning in many areas of the province (Carscadden and Nakashima 1997; Carscadden et al. 2001). The changes in spawning times, seasonal migration patterns and use of beach and offshore spawning habitat documented by the shore-based and fisherman logbook programs corroborate LEK collected in this study. Unfortunately, because these programs are limited to relatively few sites around the Province, our understanding of finer scale changes in capelin spawning ecology is fragmented. LEK on capelin spawning behaviour collected in this study effectively addressed this problem by providing new information for areas where there has been limited capelin research effort.

In contrast to the detailed LEK available on capelin, none of the respondents interviewed were able to comment on the occurrence, distribution, or changes in the relative abundance of Arctic cod in their areas during the study period. This was surprising and requires additional research focus in future LEK studies. Given the predominance of this species in the diet of harp seals in nearshore waters during the 1990s (Lawson et al. 1995, 1998a), a major change in its distribution was likely important for harp seals. Resource users may not have been familiar with Arctic cod since it has never been commercially fished and it was therefore mistakenly identified as immature Atlantic cod. In addition, Arctic cod abundance was remarkably high in nearshore Newfoundland waters for only a relatively short period of time (1990-1997) and it dropped when ocean temperatures warmed and fish distributions shifted north (Lilly and Simpson 2000). Most respondents probably had limited exposure to the species.

Resource users also reported rare or difficult to document foraging events involving seals, forage fish, other predators, salmon and low water events. Observations of harp seals frequenting rivers and estuarine habitats when capelin was preparing to spawn and when salmon were migrating have not been documented in the literature. In some locations, it appeared that the presence of capelin coupled with delayed spawning behaviour were contributing factors in attracting harp seals into coastal habitats for longer periods of time. There is some evidence in the literature to support this interpretation. The southward shift in distribution of both capelin (Carscadden and Nakashima 1997; Frank et al. 1996) and seals (McAlpine et al. 1999; Lacoste and Stenson 2000; Lucas and Daoust 2002) during the mid 1990s suggested a predator-prey relationship between these species. Another related example of this relationship occurred when there was a mass invasion of harp seals from the Barents Sea into Norwegian coastal waters from 1986-1988 and then again in 1995 (Haug et al. 1991; Nilssen et al. 1998). These 'invasions' of seals were linked to the collapse of forage fish stocks, particularly capelin (Haug and

Nilssen 1995; Nilssen et al. 1998) and illustrate that harp seals will leave traditional feeding areas to seek out alternative areas for foraging. However, it is interesting to note that two salmon rivers, the Pinware and Forteau Brook on the south coast of Labrador, had capelin and herring spawning in their respective estuaries, yet neither river was frequented by harp seals during salmon migrations. There were no conclusive explanations from the information provided by the respondents as to the reason why harp seals passed by these rivers. These rivers require further study. The presence and activity of harbour and grey seals in salmon rivers and estuaries did not appear to be strongly linked with delayed capelin spawning activity in the estuary. The location of haul-out sites and presence of salmon nets appeared to be more important factors. However, until more is known about the basic ecology of harbour and grey seals in coastal waters, particularly their diets, it is difficult to make conclusive statements.

The most important physical habitat characteristic affecting the susceptibility of salmon to predation by seals were variable or light coastal ice conditions, man-made or natural features that caused salmon to aggregate in rivers, and low water levels. On two rivers, changes in local ice conditions due to warmer winters in recent years allowed harp seals increased and earlier access to some rivers and estuaries that were previously protected by ice. Harp seals are well adapted to drifting pack ice in offshore areas, but they are unable to maintain breathing holes in stable coastal ice (Sergeant 1991). If a river estuary is frozen solid, migrating harp seals will not be able to gain access to the river or river mouth even if it is open because of the protective ice cover in the estuary. Structures such as bridges and causeways that create or maintain open water areas can attract and allow seals to remain in these areas for most of the winter and facilitate early access to the river in the spring. In the case of harbour seals that spend most of their life near or onshore close to rivers or estuaries, winter ice restricts their movements to shoreline cracks or to the nearest open water outside the estuary (Boulva and McLaren 1979). Warmer winters and variable coastal ice cover allows all seals greater access to river and estuarine habitats. Based on the findings of this study, LEK is a practical tool for monitoring changes in river and estuarine ice conditions when early access by seals could increase the potential for predation on smolt later in the spring.

In St. George's Bay, six of the rivers are clustered in short proximity to each other, and all have relatively constricted river mouths exposed directly to the bay. These physical features allowed harbour seals to focus their activity at the river mouth where migrating salmon funneled through. On both the White Bear and Eagle rivers in Labrador, there is a waterfall that often delays the migration of adult salmon, making them more susceptible to predation by all seal species as well as other predators. Low water levels in combination with warm water temperatures can exacerbate the effects of these types of habitat features by further restricting the movements of salmon and inducing thermal stress (Dempson et al. 2001). Rivers that exhibit these habitat features and that are prone to low water levels represent potential areas for increased seal predation around the province and require further study. LEK collected for rivers in this study provide a basis for this future work and would also contribute to the development of river-specific salmon management plans. The use of LEK to provide direction and complement both scientific research and management initiatives has been demonstrated in several marine mammal and wildlife studies (Huntington 1999, 2000b; Neis et al. 1999b; Furgal et al. 2002).

In summary, local ecological knowledge was used to evaluate potential predation by seals on salmon in river and estuarine habitats over a 20-year period. The degree of potential predation was based on the occurrence and relative abundance of seals in river and estuarine habitats, direct and indirect seal-salmon interactions, and the presence of ecological or physical habitat characteristics that increased the susceptibility of salmon to predation. This knowledge provided a useful and, in many cases, new perspective on the increased spatial and temporal overlap of seals, particularly harp seals, capelin and salmon in some rivers and estuaries. However, potential predation was based on observations of multiple species co-occurrence in an estuary or river. Quantitative seal diet information and knowledge of seal-salmon relative abundances are required to assess the biological significance of these results from a salmon conservation perspective. This is the research focus of the third chapter.

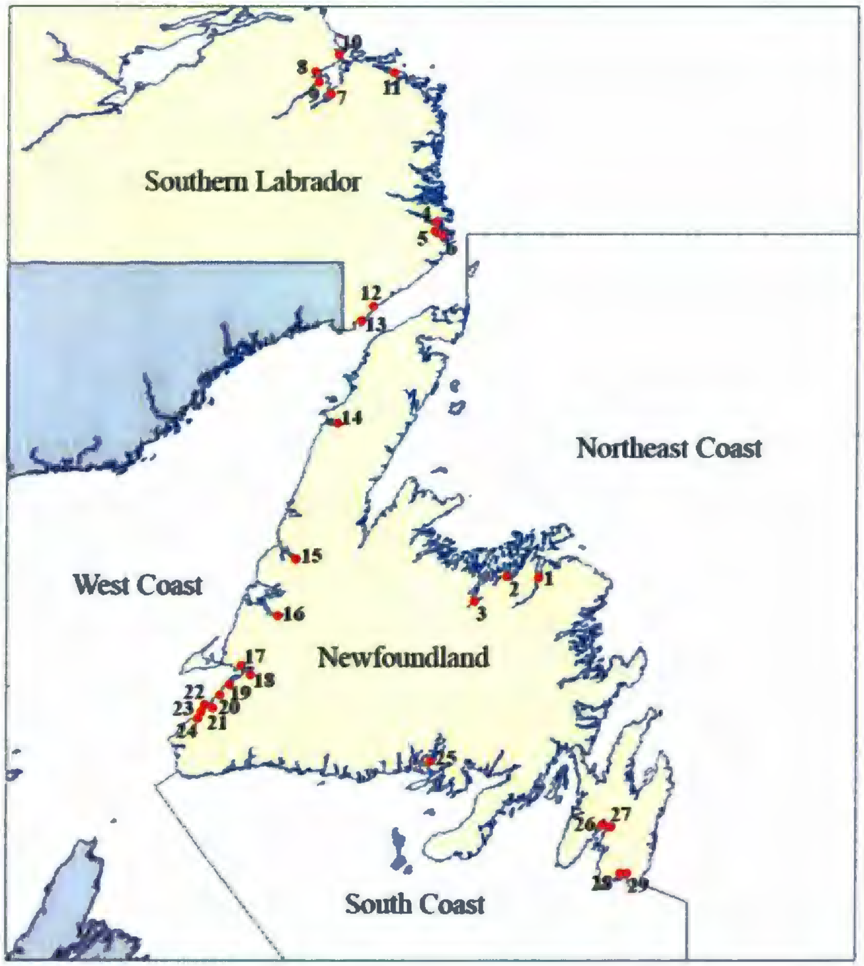

Figure 2.1 Rivers in Newfoundland and Labrador where LEK interviews were conducted between 2004 and 2006. Numbers on map correspond to locations in Table 2.1.

Table 2.1 Occurrence of seals frequenting rivers and estuaries of Newfoundland and Labrador during the smolt or adult salmon run since the 1980s. Seals never observed (-); observed < once per week (+); observed once or twice per week (++); daily (+++).

	Historic (1980-1989)						**Recent Past (1990-1999)**						**Present (2000-2005)**					
	Harp		Harbour		Grey		Harp		Harbour		Grey		Harp		Harbour		Grey	
Location[a]	Smolt	Adult	Smolt	Adult	Smolt	Adult	Smolt	Adult	Smolt	Adult	Smolt	Adult	Smolt	Adult	Smolt	Adult	Smolt	Adult
1. Gander	-	-	-	-	-	-	+++	++	+	+	-	-	+++	++	+	+	-	-
2. Campbellton	-	-	-	-	-	-	++	+	-	-	-	-	+++	++	-	-	-	-
3. Exploits	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
4. St. Lewis	-	-	+	+	-	-	++	+++	+	+	-	-	++	+++	+	+	+	++
5. St. Mary's	-	-	+	+	-	-	++	+++	+	+	-	-	++	+++	+	+	+	++
6. St. Charles	-	-	+	+	-	-	++	+++	+	+	-	-	++	+++	+	+	+	++
7. Paradise	-	-	++	++	+	+	+	+++	+++	+++	++	++	+	+++	+++	+++	++	+++
8. White Bear	-	-	++	++	+	+	+	+++	+++	+++	++	++	+	+++	+++	+++	++	+++
9. Eagle	-	-	++	++	+	+	+	+++	+++	+++	++	++	+	+++	+++	+++	++	+++
10.North	-	-	+	+	+	+	+	+	+	+	+	+	+	+++	+++	+++	+	+
11.Sandhill	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
12.Pinware	-	-	+	-	-	-	-	-	-	-	+	+	-	-	-	-	+	++
13.Forteau	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	+	++
14.Torrent	-	-	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	++
15.Lomand	-	-	+	+	+	+	-	-	+	+	+	+	+	-	+	+	+	+
16.Humber	-	-	+	+	+	+	-	-	+	+	+	+	-	-	+	+	+	+
17.Harry's	-	-	+	+	-	-	-	-	+	+	-	-	-	-	+	+	-	-
18.SW Brook	-	-	+	+	-	-	-	-	+	+	-	-	-	-	+	+	-	-
19.Flat Bay	-	-	+	+	-	-	-	-	+++	+++	-	-	-	-	+++	+++	-	-
20.Fischells	-	-	+	+	-	-	-	-	+++	+++	-	-	-	-	+++	+++	-	-
21.Robinson's	-	-	+	+	-	-	-	-	+++	+++	-	-	-	-	+++	+++	-	-
22.M.Barachois	-	-	+	+	-	-	-	-	+++	+++	-	-	-	-	+++	+++	-	-
23.Crabbes	-	-	+	+	-	-	-	-	+++	+++	-	-	-	-	+++	+++	-	-
24.Highlands	-	-	+	+	-	-	-	-	+++	+++	-	-	-	-	+++	+++	-	-

Table 2.1 cont.

25.Conne	-	-	+	+	-	-	-	-	+	+	-	-	-	-	+	+	-	-
26.Rocky	-	-	+	+	-	-	-	-	++	++	-	-	-	-	+++	+++	-	-
27.Collinet	-	-	+	+	-	-	-	-	++	++	-	-	-	-	+++	+++	-	-
28.NE Brook	-	-	+	+	-	-	-	-	+++	++	-	-	-	-	+++	++	-	-
29.NW Brook	-	-		+	-	-	-	-	+++	++	-	-	-	-	+++	++	-	-

[a] Northeast coast (green); Southern Labrador (blue); West coast (red); South coast (yellow).

Table 2.2 Geographical distribution of seal-salmon interactions in Newfoundland and Labrador rivers and estuaries as reported by resource users. A (+) indicates a direct or indirect seal-salmon interaction and (-) no interaction.

	Historic (1980-89)			Recent past (1990-99)			Present (2000-05)			
Location	Pg	Pv	Hg	Pg	Pv	Hg	Pg	Pv	Hg	Comments
Gander	-	-	-	+	-	-	+	-	-	Consuming adult salmon; scarred salmon.
Campbellton	-	-	-	-	-	-	+	-	-	Foraging in estuary; seals observed chasing salmon; seal with kelt salmon in mouth.
St. Lewis	-		-	+	-	-	+	+	+	Foraging in estuary; damage to salmon nets.
St. Mary's	-	-	-	+	-	-	+	+	+	Foraging in estuary; damage to salmon nets.
St. Charles	-	-	-	+	-	-	+	+	+	Foraging in estuary; damage to salmon nets.
Paradise	-	+	+	+	+	+	+	+	+	Damage to salmon nets; foraging at river mouth and along headlands.
White Bear	-	+	+	+	+	+	+	+	+	Damage to salmon nets; foraging at river mouth, in estuary, along headlands.
Eagle	-	+	+	+	+	+	+	+	+	Damage to salmon nets; foraging at river mouth, in estuary, along headlands.
North	-	-	-	-	-	-	+	-	-	Foraging along headlands.
Pinware	-	-	-	-	-	-	-	-	+	Foraging near herring nets set adjacent to river; haul out on sand bar at river mouth.
Forteau	-	-	-	-	-	-	-	-	+	Foraging near herring nets set adjacent to the river mouth
Torrent	-	-	-	-	-	+	-	-	+	Foraging inside estuary and along headlands.
Flat Bay	-	-	-	-	+	-	-	+	-	Foraging or hauled out in estuary.
Fischells	-	-	-	-	+	-	-	+	-	Foraging near river mouth.
Robinson's	-	-	-	-	+	-	-	+	-	Foraging near river mouth.
M. Barachois	-	-	-	-	+	-	-	+	-	Foraging near river mouth.
Crabbes	-	-	-	-	+	-	-	+	-	Foraging near river mouth.
Highlands	-	-	-	-	+	-	-	+	-	Foraging near river mouth.
NE Brook	-	-	-	-	+	-	-	+	-	Observed near river mouth.
NW Brook	-	-	-	-	+	-	-	+	-	Observed near river mouth.

Table 2.3 Ecological and physical habitat characteristics that may attract seals to a river or increase the susceptibility of migrating salmon to seal predation during the smolt or adult salmon run.

	Forage fish	Proximity to			River characteristics							Estuary Ice		
Location	Δ in spawning time	Harp travel & feeding areas	Harbour haul-out	Grey haul-out	Low water	Warm water	Exposed to open bay	Constricted mouth	Man-made structures	Obstruction	Entrapment pool	Variable conditions	Late winter freeze-up	Early spring breakup
Gander	+	+			+	+		+	+		+	+	+	+
Campbellton	+	+			+	+	+	+	+			+	+	+
St. Lewis	+	+		+				+	+			+		+
St. Mary's	+	+		+	+	+		+	+			+		+
St. Charles	+	+		+		+						+		+
Paradise	+	+	+	+	+	+						+	+	+
White Bear	+	+	+	+							+	+	+	+
Eagle	+	+	+	+							+	+	+	+
North	+	+	+	+			+			+		+		+
Sandhill	+	+	+	+	+									
Pinware	+	+	+	+			+	+				+		
Forteau	+	+		+			+					+		
Torrent	+	+	+	+	+			+	+		+	+		
Flat Bay			+				+	+				+		+
Fischells			+		+	+	+	+				+		
Robinson's			+		+	+	+	+				+		
M. Barachois			+		+	+	+	+				+		
Crabbes			+		+	+	+	+				+		
Highlands			+		+	+	+	+				+		
Rocky			+							+				
Collinet			+											
NE Brook			+							+				
NW Brook			+											

Table 2.4 Evaluation of potential harp seal predation on smolt and adult salmon in Newfoundland and Labrador rivers based on observations from resource users. Low potential (green); moderate (yellow); high (red).

Location	Key Observations	Evaluation	
		Smolt	Adult
Gander	Commonly observed during smolt run; occasionally during adult run; susceptible to variable spring ice conditions and winter thaws; open water at causeway near river mouth; direct interactions.	red	yellow
Campbellton	Commonly observed during smolt run; occasionally during adult run; susceptible to variable spring ice conditions; changing capelin and herring abundances/delayed spawning times; direct and indirect interactions.	red	yellow
Exploits	Never observed during smolt or adult run; river is inland; no observed interactions.	green	green
St. Lewis	Occasionally observed during smolt run; commonly during adult run; changing capelin distributions/delayed spawning times; indirect interactions.	yellow	red
St. Mary's	Occasionally observed during smolt run; commonly during adult run; changing capelin distributions/delayed spawning time; constricted river mouth; indirect interactions.	yellow	red
St. Charles	Occasionally observed during smolt run; commonly during adult run; changing capelin distributions and delayed spawning time; indirect interactions.	yellow	red
Paradise	Rarely observed during smolt run; commonly during adult run; changing capelin distributions; indirect interactions.	green	red
White Bear, Eagle	Rarely observed during smolt run; commonly during adult run; changing capelin distributions; waterfall at river mouth restricts seals' access to the main stem but also impedes salmon migrating into river; indirect interactions.	green	red
North River	Rarely observed during smolt run; occasionally during adult; changing capelin distributions; indirect interactions; little resource user activity on/near river.	green	yellow
Sandhill	Rarely observed during smolt or adult run; changing capelin distributions; river is inland; obstruction near river mouth restricts seals' access to the river; no interactions.	green	green
Pinware, Forteau	Rarely observed during smolt or adult run; river mouth exposed to coastline; no interactions.	green	green
Torrent	Rarely observed during smolt or adult run; river susceptible to low water levels; no interactions.	green	green
Lomand	Rarely observed during smolt or adult run; river is inland; no interactions reported.	green	green
Humber	Rarely observed during smolt or adult run; no interactions reported.	green	green

Table 2.5 Evaluation of potential harbour seal predation on smolt and adult salmon in Newfoundland and Labrador rivers based on observations from resource users. Low potential (green); moderate (yellow); high (red).

Location	Key Observations	Evaluation	
		Smolt	Adult
St. Lewis, St. Mary's, St. Charles	Rarely observed during smolt or adult run; no interactions.		
Paradise	Commonly observed during smolt and adult run; haul-out and pupping areas up river; direct and indirect interactions.		
White Bear, Eagle	Commonly observed during smolt and adult run; waterfall at river mouth restricts seals' access to river but also impedes salmon migrating into the river; direct and indirect interactions.		
North	Rarely observed during smolt or adult run; unknown if seals migrate up river; no interactions; limited resource user activity near river.		
Sandhill	Occasionally observed during smolt and adult run; obstruction near river mouth restricts seals access to river; no interactions; limited resource user activity in area.		
Torrent, Lomand	Rarely observed during smolt or adult run; no known haul-out or pupping locations near the river; no interactions.		
Harry's	Rarely observed during smolt or adult run; bridge at entrance to estuary constricts area for salmon passing through; no interactions.		
SW Brook	Rarely observed during smolt or adult run but have been observed up river; bridge at entrance to estuary constricts area for salmon passing through; no interaction.		
Flat Bay Brook	Commonly observed in estuary and occasionally up river during smolt and adult run; constricted river mouth; haul-out site in close proximity to river; direct and indirect interactions.		
Fishchells, Robinson's, M. Barachois, Crabbes, Highlands	Commonly observed during smolt and adult run; constricted river mouth exposed to coastline; haul-out site in close proximity; indirect interactions.		
Conne	Rarely observed during smolt or adult run; river is inland; no interactions.		
Rocky, Collinet	Rarely observed at river mouth during adult run but occasionally in estuary; waterfall at river mouth restricts seals' access to river; haul-out site in bay during adult run; indirect interactions.		
Northeast Brook	Occasionally observed near river mouth and in estuary; waterfall at river mouth restricts seals' access to main stem of river; indirect interactions.		
Northwest Brook	Occasionally observed near river mouth and in estuary; indirect interactions		

Table 2.6 Evaluation of potential grey seal predation on smolt and adult salmon in Newfoundland and Labrador rivers. Low potential (green); moderate (yellow); high (red).

Location	**Key Observations**	**Evaluation**	
		Smolt	Adult
St. Lewis, St. Mary's, St. Charles	Rarely observed during smolt run; occasionally during adult run; indirect interactions.		
Paradise	Rarely observed during smolt run; commonly during adult run; haul-out site near river; indirect interactions.		
White Bear, Eagle	Rarely observed during smolt run; commonly during adult run; haul-out site near river; waterfall at river mouth limits seals access to river but impedes migrating salmon; indirect interactions.		
North	Rarely observed during smolt run; occasionally during adult run; haul-out site near river; no interactions; limited resource user activity near river.		
Sandhill	Rarely observed; obstruction at river mouth limits seal access to river; no interactions; limited resource user activity near river mouth.		
Torrent	Occasionally observed along headlands during adult run; no observations of seals at river mouth; susceptible to low water levels; indirect interactions.		
Rocky	Rarely observed but have been seen hauled out with harbour seals in estuary; waterfall at river mouth restricts seals access to main stem of river; no interactions.		
Collinet	Rarely observed but have been seen hauled out with harbour seals in estuary; bridge at river mouth restricts access to main part of river; no interactions.		

CHAPTER THREE: DIET OF HARP SEALS (*PAGOPHILUS GROENLANDICUS*) IN RIVERS AND ESTUARIES DURING ATLANTIC SALMON (*SALMO SALAR*) MIGRATIONS

3.1 Introduction

The diet of harp seals (*Pagophilus groenlandicus*) is the most comprehensively documented for all pinnipeds inhabiting the Atlantic Ocean (Sergeant 1965, 1991; Haug et al. 1991; Wallace and Lavigne 1992; Beck et al. 1993; Nilssen 1995; Nilssen et al. 1998; Lawson and Stenson 1997; Stenson et al. 1997). Stomach samples have been examined throughout the species' range, including nearshore and offshore waters in the Northwest Atlantic from the southern Arctic to the Gulf of St. Lawrence (Sergeant 1965, 1973, 1991; Finley et al. 1990; Murie and Lavigne 1991; Lawson and Stenson 1997). Harp seals feed on a wide range of prey species, but the majority of their diet is composed of relatively few key species. The importance of prey varies geographically, seasonally, and with age. Early studies dating from the 1960s to early 1990s found that harp seals fed primarily on Arctic cod (*Boreogadus saida*) in the Canadian Arctic and off northwestern Greenland (Sergeant 1973; Kapel and Geisler 1979; Finley et al. 1990). Capelin (*Mallotus villosus*), Arctic cod and invertebrates were the main prey species of seals off Newfoundland and the Labrador coast (Sergeant 1973, 1991), while harp seals examined from the St. Lawrence estuary (Murie and Lavigne 1991) and Gulf of St. Lawrence (Sergeant 1973) fed primarily on capelin and herring. Despite this relatively broad knowledge base, some of these early studies on the harp seals' diet relied on small sample sizes collected in different seasons, years and locations (Sergeant 1991; Wallace and Lavigne 1992).

More recent studies on the diet of harp seals in Newfoundland and Labrador waters have attempted to collect samples in nearshore (<30km from land) and offshore (>30km from land) waters throughout the year, and in multiple geographic locations to examine variability in their diet (e.g. Lawson et al. 1995; Lawson and Stenson 1997; Stenson and Perry 2001). From the late 1980s to the mid 1990s, stomach content analyses indicated that Arctic cod made up the largest component of harp seals diet in nearshore waters off northeastern Newfoundland, whereas capelin was the preferred prey item in offshore waters (Lawson et al. 1995; Lawson and Stenson 1997). These findings were in contrast to early studies that indicated capelin was the dominant nearshore prey item. However, these samples were taken when significant ecosystem and oceanographic changes were occurring in the Northwest Atlantic (Colbourne et al. 1994; Drinkwater 1996; Parsons and Lear 2001). Changes in the distribution and migration patterns of harp seals and some of their major prey, including capelin and Arctic cod, were observed (Frank et al. 1996; McAlpine et al. 1999; Lacoste and Stenson 2000; Carscadden et al. 2001; Parsons and Lear 2001). Since the late 1990s, capelin has returned as the main component of harp seal diets in both nearshore and offshore waters, but Arctic cod is still found in reduced amounts in their diet (D. Mckinnon, personal communication, 2007).

In addition to these changes, some Atlantic salmon (*Salmo salar*) stocks in Newfoundland and Labrador declined during this period (ICES 1999). Presently there is no clear evidence that any one factor has been responsible for their decline (see Dempson et al. 1998 for a review). However, since the mid 1990s, resource users have expressed concern about the potential impact of harp seal predation. Local ecological knowledge of resource users suggested that increased numbers of harp seals were spending more time in river and estuarine habitats during peak salmon run times beginning in the late 1990s and early 2000, resulting in increased potential for harp seal predation (Chapter 2).

The Department of Fisheries and Oceans has examined 8,000 food-containing harp seal stomachs since 1990, and found little evidence of salmon in their diet: only two salmon otoliths have been recovered, one from the northeast coast of Newfoundland and the other from the St. Lawrence estuary. However, the biological sampling program used to obtain stomach samples is not well designed to document predation on salmon (e.g. Sergeant 1991, Lawson et al. 1995, Lawson and Stenson 1997). Samples are primarily collected during the late fall and winter, with few samples from rivers or estuaries when salmon is most likely to be preyed. Despite the lack of scientific evidence of salmon in the diet of harp seals, observations of resource users indicate that harp seals consume the species. In order to fully quantify these observations and determine if seal predation is significant enough to contribute to the decline of certain salmon stocks, a more directed research approach is needed.

The objectives of this study were to document the diet of harp seals during smolt and adult salmon runs on three rivers and estuaries in Newfoundland and Labrador, and to evaluate the possible impact of harp seal predation on those salmon populations. Diet information on other seal species frequenting these salmon rivers and estuaries was also documented.

3.2 Materials and Methods

3.2.1 Stomach Samples

Study areas and sample collection

Seals were collected by experienced hunters during smolt and adult salmon runs from the Campbellton River in Indian Arm Bay on the northeast coast of Newfoundland, the English River in Kaipokok Bay in northern Labrador, and the Paradise River in Sandwich Bay in southern Labrador (Figures 3.1-3.3). Campbellton River was the main study site for a focused harp seal diet study because it was considered to have high potential for predation during the smolt salmon run (Chapter 2), and a counting fence monitored the daily downstream migration of smolt and kelt. Samples from the other two rivers were obtained on an opportunistic basis during adult migrations. Harp seals were collected from May to June 2005 (n=55) and 2006 (n=67) at Campbellton River. Adults were difficult to collect, so young harp seals (aged <1 yr old) accounted for most of the sample. Harp seals (n=3) and ringed seals (*Pusa hispida,* n=14) were collected from May to August 2003 and 2004 at English River. At Paradise River, no harp seals were collected, however a total of 13 grey (*Halichoerus grypus*) and harbour (*Phoca vitulina*) seals were collected from July to August 1999, 2000 and 2006 (Table 3.1).

Stomachs were removed from seals in the field, and ligated at the esophageal and pyloric sphincters within an hour of death. The lower jaw and reproductive tract (ovaries and uterus or testes) were also taken and placed in a cotton bag along with the stomach, then kept frozen at -20°C until analyzed. Sex, location, date, and the hunters' initials were noted. Standard body measurements were taken when possible.

Laboratory analysis

Stomachs were thawed and weighed to the nearest 0.1 g using an electronic balance. The contents were washed through a series of mesh sieves, decreasing from 4.75 mm to 1.0 mm (Murie and Lavigne 1985a; Lawson et al. 1995). When present, whole prey items were removed and rinsed separately. Whole fish (fork length) and invertebrates (dorsal carapace length) were measured to the nearest 0.1 cm and 0.1 mm respectively, and weighed to the nearest 0.1 g. Sagittal otoliths were collected as isolated elements (loose), or removed from intact fish skulls. The empty stomach was then weighed to determine wet content weight by subtraction. Otoliths were dried, stored in glass vials, and labeled as loose or skull.

Individual food items were identified by examining whole specimens, bones, scales, or recovered sagittal otoliths. Otoliths were identified to the species level or lowest possible taxonomic level using reference material on local fishes collected by DFO (Campana 2004), or with a published identification key (Harkonen 1986). When left and right side otoliths could be distinguished, the side with the greater number was used to calculate the minimal number of prey eaten. If otoliths were partially eroded, or it was difficult to distinguish left and right side (e.g. sand lance *Ammodytes dubius*), the total number of otoliths was divided by two to determine the minimal number of prey consumed.

Prey sizes were estimated using otoliths with minimal or no erosion. Degree of erosion was estimated by comparing the edge of recovered otoliths with those in the reference collection. Otolith lengths were measured to the nearest 0.01 mm using vernier calipers (> 5 mm) or Image-Pro Plus software (< 5 mm). A random sub-sample of 40 otoliths was measured from stomachs that contained large numbers of individual prey species. The presence of non-food items, such as rocks, was also recorded.

Regression equations relating otolith measurements to prey length were used for estimating the length and mass of fish prey (Table 3.2). Eroded otoliths from a single, uniformly sized prey species were assumed to be originally the same size as the average of uneroded otoliths for each species. To estimate total biomass of fish prey from eroded otoliths in each stomach, the number of eroded otoliths was multiplied by the average mass of uneroded otoliths from that species. Estimated energy density (kcal/g) for each prey type was taken from the literature (Lawson et al. 1995).

3.2.2 Distribution and abundance of seals

Campbellton River

To determine whether the relative abundance and distribution of harp seals varied with changes in the numbers of smolt and kelt exiting the Campbellton River, shore-based observations and boat-based strip transect surveys were conducted throughout the smolt run from May to June 2005 and 2006. Observation periods were planned to cover periods corresponding to pre, peak and post smolt run times based on data collected from the counting fence in previous years.

Shore-based observations of seals were made from four lookouts situated around the lower portion of the estuary. Binoculars (8 x 42) and a spotting scope (20 x 60) were used to locate seals in four quadrants delineated by landmarks and navigation buoys (Figure 3.1). The quadrants were designed to cover the river mouth area and lower portion of the estuary. Seals in each quadrant were counted three times a day (at approximately 0900, 1300 and 1800 h, depending on weather), using scan sampling techniques (Altmann 1974). Counts took approximately 20 min to complete, with approximately 5 min travel time between each lookout position. Care was taken to ensure that sculls of seals traveling near quadrant boundaries were not double counted. Shore observations were not conducted on days when boat surveys took place.

Boat-based surveys were conducted on May 22 and 26 and June 4 and 9 2005 and May 19 and 28 and June 4 and 9 2006. A 20-ft-long fiberglass speedboat was used for surveys in both years. Surveys were not conducted in adverse weather (fog or rain, Beaufort sea state >2), and most surveys took place between 0800 and 1300 h because winds increased in the afternoon. Transect lines spaced 1 km apart ran perpendicular to the shore. Lines were 1-7 km in length (Figure 3.1).

The boat moved at an average speed of 12 km-hr^{-1} along each transect line. Two observers, one starboard and one port (boat driver), were seated with their eye level approximately 2 m above sea level. They counted seals in a strip ~300 m wide on each side of the boat. All surveys were conducted by the same two observers in

2005 and 2006. Before each survey, the observer and driver conducted a series of distance exercises by placing buoys at fixed distances from the boat. This was to ensure that estimated distances to seals were consistent and accurate.

Environmental conditions, and the start and finish locations (latitude, longitude) of each transect were recorded. When a seal or group of seals was sighted, the location was recorded on a hand held Garmin Global Positioning System (GPS). Seals were identified to species and age class if possible.

Kaipokok Bay – English River

Observations on seal abundance and distribution within Kaipokak Bay and at the English River were made opportunistically during a 12 km boat ride between the community of Postville and the English River adult salmon counting fence (approximately 20-min each way, Figure 3.2). Community members who worked on the fence noted observations of seals from late June to October from 1999 to 2006. The start and end times of the observation periods, the seal species, number and location, and general comments on behaviour were recorded.

3.2.3 Statistical Analysis

Indices of seal abundance for a shore-observation day were calculated using the total number of seal sightings in all quadrants during each observation period because of the low frequency of seal sightings. Other seal species are rarely observed in the Campbellton area during the summer (Chapter 2), so uncertain identifications were assumed to be harp seals. Pearson's product-moment correlation was used to test the association between the number of seals observed in the estuary and the number of smolt exiting the river. Diet analyses were conducted using Minitab 14 and data were examined using one-way ANOVAs with alpha=0.05.

The boat-based survey data were analyzed using the methods outlined in Stenson et al. (2002). Eight transect lines covering the lower portion of Indian Arm Bay were used when estimating seal abundance to standardize for the total area covered by all surveys in both years (Figure 3.1). The remaining transect lines (upper portion) were covered opportunistically on survey days when weather permitted. However, these lines were not used for analysis purposes.

The estimated number of seals for each survey was determined by:

$$N_i = K_i \sum_{j=1}^{J_i} x_i$$

where J_i = the number of transects in the ith survey; k_i = weighting factor for the ith survey determined by dividing the transect interval by the transect width; and x_i = the number of seals on the jth transect.

The estimates of error variance for each survey were calculated as:

$$V_i = \frac{k_i (k_i - 1) J_i}{2(J_i - 1)} \sum_{j=1}^{J_i - 1} (x_j - x_{j+1})^2$$

3.3 Results

3.3.1 Stomach samples

A total of 155 seal stomachs were collected from the three areas over the study period (Table 3.1). All stomachs from Campbellton River and 14/18 stomachs from the English River contained food; however, 8/13 stomachs from Paradise River were empty.

Eighteen taxa were identified from the 143 stomachs that contained prey (Table 3.3). Capelin, sand lance and mysids (Mysidae) were the most common taxa. No salmon otoliths were recovered. Relatively few prey species were found in individual harp seal stomachs from Campbellton River (mean = 1.18, SD = 0.48) and only four fish species were identified from stomachs over both years (Table 3.4). Capelin was the major prey component, occurring in 53/55 stomachs in 2005 and 66/67 in 2006. Herring was found in only one harp seal stomach and consisted of one partially digested individual. Five sand lance were recovered between both years, and 44 Atlantic cod (*Gadus morhua*) were identified from one stomach in 2006 (Table 3.4).

Capelin and sand lance were the most prevalent prey species for seals at English River (Table 3.5). Seals from this area also consumed a broader range of prey types than those collected from Campbellton River. Capelin and sand lance were recovered from the three harp seal stomachs, with capelin being the most prevalent prey item. No harp seals were collected from the Paradise River; and the majority of stomachs that were sampled from this location were empty. Two unidentified *Gadus* and a single capelin were recovered from the three harbour seal stomachs that contained food in 1999 (Table 3.6). In 2006, two grey and two harbour seals were collected from Sandwich Bay. The grey seal stomachs were empty but otoliths from five species were recovered from harbour seals, with sand lance being the prevalent prey item (Table 3.6).

Campbellton River

Young harp seals (beaters) fed upon capelin ranging from 5.3-19.9 cm in length; however, a few larger prey items (herring 28.3 cm; Atlantic cod 48.9 cm) were also taken. There was evidence of differences in the mean length of capelin consumed between the two years. Smaller capelin were consumed in 2006 (mean = 12.4 cm, SD = 3.1) than in 2005 (mean = 14.3 cm, SD = 3.1; $F_{1, 2143} = 134.0$, p = 0.0001, Figure 3.4) and capelin in 2006 had a lower overall wet mass (mean = 9.6 g, SD = 5.3) compared to 2005 (mean = 15.1 g, SD = 8.9, $F_{1,2143} = 141.15$, p = 0.0001). However, in 2006, harp seals consumed significantly higher numbers of capelin (mean = 34.1, SD = 24.1) than those in 2005 (mean = 13.9, SD = 10.99; $F_{1,120} =$ 32.58, p = 0.0001; Table 3.4).

A total of 31,452 salmonids (30,123 smolt, 1, 329 kelt) and 25,813 smelt passed through the counting fence in 2005 with the peak of both runs occurring from May 27 to June 5. An earlier smelt run also took place from May 11 to May 16. During the period that harp seals were collected, a total of 3,883 smolt and 13,786 smelt had entered the estuary, and the majority of harps seals were collected by May 26 (Figure 3.5). In comparison, the peak smolt run occurred one week earlier in 2006 from May 18 to 27 (33, 304 smolt, 1,883 kelt, 9,679 smelt) and the smelt run was also earlier with a marked decrease in the number of fish (Figure 3.5). The majority of seals were collected from May 30 to June 16 2006, and a total of 33,280 smolt and 9,679 smelt had entered the estuary (Figure 3.5).

3.3.2 Distribution and abundance of seals

Campbellton River

Relatively few seals were observed in the estuary over the study period. Harp seals were the only seal species sighted in both years during shore-based observations. The frequency of seal sighting within the estuary in 2005 did not show a seasonal pattern, and was not associated with the number of smolt entering the estuary ($r = -0.127$, $p = 0.604$). Data were not analyzed for 2006 due to the low number of sightings. There were, however, anecdotal reports of more seals seen 15 km from the river in 2006 than in 2005. These observations were supported by hunter's reports that they had to travel further out of the estuary to find and collect seals (Figure 3.6).

In both years, harp seals were most often observed during the boat surveys at the beginning of the smolt run (Table 3.7). Sightings were of single animals (usually young seals) or small sculls (2-3) of adult harp seals. Sculls of 5-10 adults were observed in the upper portion of the estuary when transects were completed outside the main study area. Seals were observed during all surveys in 2005, but only during the first two in 2006. The highest estimated number of seals was observed on May 22 in 2005 (0.92 seals/ km^{-2}) before the peak smolt run, and on May 28 in 2006 (1.40 seals/km^{-2}) just after the peak. Sightings in 2005 primarily occurred in the lower portion of the estuary compared to those in 2006; however, in both years seals were observed more often along the last four transects of the main study area. Only two harp seals were observed within 500 m from the river mouth (1 each in 2005 and 2006).

English River – Kaipokok Bay

A total of 605 observation hours were made by salmon research personnel enroute from Postville to the counting fence 1999 to 2006. The majority of sightings were of harp seals (67%), but ringed, harbour, hooded (*Cystophora cristata*) and bearded seals were also observed (Table 3.8). The overall number of seals observed declined throughout the study period. The highest numbers of seals were observed in 2001 (1.14 seals/hour^{-1}), with 90% being harp seals in small sculls. Several sculls were also seen in 2002 and 2003, but unfortunately, no estimate of numbers was provided. The peak run of adult salmon at the English River usually occurs from mid July to mid August. In the estuary, 77%, 73%, 89% and 89% of seal sightings were made before mid July in 1999, 2000, 2001 and 2005 respectively. In 2003 and 2004, sightings were mainly in August and September. Minke whales (*Balaenoptera acutorostrata*) were also observed in the estuary in 1999, 2000 and 2001. Observations of harp seals and minke whales in these three years were concurrent with the presence of capelin in the estuary.

3.4 Discussion

No salmon otoliths were found in any seal stomachs examined from the Campbellton, English or Paradise rivers, even though the sampling period covered portions of both the peak smolt and adult run. Relatively few prey species were consumed by harp seals at Campbellton River; capelin was the predominant item in both years. These findings agree with previous studies that indicate young harp seals have a less diverse diet than adult seals, and exhibit a greater reliance on capelin during the summer (Lawson et al. 1995). Capelin was the main prey item for seals at English River, although seals from this area consumed a broader range of prey. Most stomachs collected from Paradise River were empty; sand lance was the predominant prey item.

The fact that no evidence of salmon was found in seal stomachs collected at any of the rivers, particularly the Campbellton River, is interesting given that there has been an increase in the spatial and temporal overlap of harp seals and salmon in these rivers and estuaries since the late 1990s (Chapter 2). In the case of the Campbellton and Paradise rivers, direct observations of seals foraging on salmon by local residents and DFO personnel provided evidence that harp seals, and harbour seals, could be important predators on salmon. The lack of evidence of salmon in the diet of seals sampled from these rivers suggested that otoliths and other hard parts were degraded or destroyed; they had already passed through the digestive tract before the seals were sampled; only the soft tissue of a salmon was eaten; or seals simply did not consume any salmon.

Identifying prey hard parts from stomachs, intestines, and feaces are the most commonly used methods for determining pinniped diets despite their well-known biases (Murie and Lavigne 1985b; Harvey 1989; Pierce and Boyle 1991; Tollit et al. 1997; Bowen 2000; Orr and Harvey 2001). Although salmon otoliths are known to be quickly digested (Boyle et al. 1990), they have been identified in two harp seal stomachs in eastern Canada. In addition, salmon and their otoliths have also been identified in six grey seals sampled in the northern Gulf of St. Lawrence (Cairns and Reddin 2000). Otoliths from other fish such as mackerel (*Scomber scombrus*) and stickleback (*Gasterosteus aculeatus*), like salmon, are fragile and digested quickly, and yet are identified in the stomachs of harp seals (D. McKinnon, personal communication, 2007). In the case of partially digested otoliths, it is often possible to identify the prey even though morphometric data cannot be used to estimate the length or weight of the prey. All partially digested otoliths were carefully examined; most could be identified to genus with reasonable confidence.

Even if salmon otoliths were totally digested, it is quite likely other skeletal bones would still be present; however, none were observed. A number of researchers use skeletal structures, such as vertebrae, gill rakers and scales, in addition to otoliths for identifying salmon in fecal samples collected in the field and in captive feeding studies (Olesiuk et a. 1990; Cottrell et al. 1996; Tollit et al. 2003; Orr et al. 2003). However, these studies were carried out on harbour seals and Steller's's sea lions (*Eumetopias jubatus*) and one difficulty in using skeletal remains is that hard parts of different fish species erode at different rates, and also erode at different rates across pinniped species (Tollit et al. 1997; Bowen 2000). In the case of harp seals, fecal sample analyses are not an option since the seals rarely haul out on land. In previous harp seal diet studies when both the stomach and large intestine have been examined, no new information was obtained from the latter (D. McKinnon, personal communication, 2007).

Due to the short retention time of food remaining in the digestive system, diet information is limited on a short temporal scale. Murie and Lavigne (1985b) were only able to recover Atlantic herring otoliths from harp seal stomachs up to 12 hr after ingestion. A recent *in vitro* study by Christiansen et al. (2005) indicated whole capelin and sagittae could become completely digested within 7-10 hr. Although these studies indicate that otolith digestion occurs within a short period, recently digested meals can accurately represent the number of prey consumed in that time frame. All stomachs collected from Campbellton River contained prey, and some contained undigested, relatively fresh capelin suggesting that harp seals were actively feeding throughout the smolt run. Consequently, if significant predation on smolt was occurring at Campbellton River, some evidence of salmon should have been found in the stomachs.

Previous observations of salmon predation by harbour seals and sea lions indicate that seals will bring large, harder to handle prey items to the surface (Roffe and Mate 1984; Stanley and Shaffer 1995; Carter et al. 2001). These observations have led to the argument that seals are only consuming the soft tissue (e.g. stomach and liver) of larger fish and consequently, no evidence of salmon would be detected in their diet because hard parts are not consumed. There is little quantitative evidence that harp seals selectively consume only the soft tissue of their fish prey under natural foraging conditions. However, they do consume larger prey items (Lawson et al. 1995; Lawson and Stenson 1997), and Pemberton et al. (1994) observed harps seals eating Atlantic cod (average length 49 cm) by swallowing them head first and whole. Harp seals in this study at the Campbellton River fed on larger prey items such as herring and Atlantic cod, and there is previous evidence that they forage on salmon. In 2002, a young harp seal (the same age as seals collected in this study) was sampled from the estuary during the smolt run with a salmon in its mouth (P. Downton, personal communication, 2005). In other pinniped species, Carter et al. (2001) have observed grey and harbour seals in Scottish rivers consuming whole salmon at the surface; thus, it is unlikely that consumption of only soft tissue by seals at Campbellton River explain the lack of salmon hard parts in the stomach contents.

The relative abundance, distribution, and movement patterns of harp seals in the Campbellton River estuary did not appear to be related to the number of smolt or smelt leaving the river. Increased numbers of seals at rivers during salmon runs have been noted in other studies (Roffe and Mate 1984; Olesiuk et al. 1990; Middlemas et al. 2006). However, these studies have mainly involved harbour seals that are residents or use the rivers for haul-out areas. Based on the location of seal sightings, there were no aggregation areas in the lower reaches of the estuary. Most seals observed were traveling through the area and there was little to no seal activity at the mouth of the Campbellton River. Based on these data, there was little evidence of potential foraging activity on smolt, and considering the lack of hard parts in the stomach contents, it appeared harp seals did not feed on smolt at the Campbellton River during the study period.

There was a considerable number of smelt, in addition to smolt, leaving Campbellton River, so it was surprising that neither of these species were consumed. This is particularly notable in 2005 when the biomass of smolt and smelt were greater, and more seals were observed in the lower bay area. Pinnipeds are considered to be generalist predators because they are readily able to switch to alternative prey species in response to changes in the local abundance of their preferred prey (e.g. Harcourt et al. 2001, 2002; Middlemas et al. 2006). However some seal species, including harp seals, may actively choose a particular prey type regardless of local prey abundance (e.g. Thompson et al. 1991; Lawson et al. 1998a). Lawson et al. (1998a) found that when given the opportunity, harp seals preferentially selected capelin in both near and offshore waters off Newfoundland and Labrador, regardless of their local abundance. This preference for capelin is important from an energetic perspective because harp seals are known to digest capelin more efficiently than most other prey species (Lawson et al. 1997), and capelin is one of the most energy dense prey items consumed by harp seals (Lawson et al. 1998b).

The strong predominance of capelin in the diet of seals sampled at Campbellton River likely reflects harp seal preference for capelin. The length of the capelin consumed, and the dates of spawning activity in the vicinity of the estuary indicated that capelin were 2 and 3 yr old fish, approximately 4-6 weeks pre-spawning (B. Nakashima, personal communication, 2007). Although there are geographic, seasonal (and likely annual) variations in the estimates of energy density for pre-spawning capelin, they range between 6.0-11.0 kJ/g^{-1} (Lawson et al. 1998b). This is considerably higher than the energy density reported for salmon smolt from the Campbellton River (4.43 kJ/g, Dempson et al. 2004) and provides an energetic basis for prey selection. In addition, it is likely more efficient for young seals to forage on highly aggregated, schooling prey such as capelin, than to spend time and energy searching for smolt that are more dispersed and moving relatively quickly through the estuary and out to sea (Holm et al. 2000; Lacroix et al. 2004; Gudjonsson et al. 2005). It was not possible to estimate the abundance of capelin in the estuary, but the predominance of capelin in the diets of the seals sampled suggested that seals were likely selecting capelin even if it was not as readily abundant as smolt or smelt.

The majority of stomachs sampled from Paradise River were from harbour seals that have established pupping and haul-out areas along the river. Seals utilize these areas from June to November, and have been observed >30 km upriver (Chapter 2). The relative abundance of seals in the river and estuary is estimated to be approximately 100 animals, and has been increasing since the 1990s. However, little is known about their foraging behaviour. Local ecological knowledge suggested seals forage on salmon in the river and at salmon nets during the subsistence food fishery in the area (Chapter 2). No salmon otoliths were retrieved from these seals and most stomachs were empty. The three otoliths that were recovered from seal stomachs collected in Paradise River were capelin and two unidentified *Gadus*, so seals in the Paradise River may be feeding in the estuary. These preliminary results are similar to Orr et al. (2004) and Carter et al. (2001), who reported that even though harbour seals use river habitats, they foraged primarily at sea. Although it is likely that seals sampled from the English and Paradise rivers did not consume only soft tissue while foraging, additional behavioral observations and larger diet samples are needed to confirm this. It is possible that seals from both locations consumed some soft tissue from salmon caught in nets.

It is often assumed by resource users that when seals are observed in the vicinity of a river or in an estuary during salmon runs, they are foraging on salmon and having a negative effect on the population of that river. This assumption is understandable from their perspective considering that even with stringent management initiatives, some salmon stocks have continued to decline. At the same time, harp seals and other species of seals were becoming increasingly common in many estuarine areas. Calls and requests for bounties or culls of nuisance seals from areas where seals and salmon co-occur are also based on the assumption that seals are primarily consuming salmon. However, results from this study have indicated this is not necessarily true. This research is the first attempt to document the importance of salmon in the diets of harp seals in rivers and estuaries in Newfoundland and Labrador, and no evidence of salmon was found. In the case of the Campbellton River, this does not mean that harp seals no longer consume salmon, but rather, the occurrence of predation is variable and its impact on salmon is not biologically significant in some years. From a broader perspective, the results emphasize that assessing the biological impact of seal predation will likely have to be done on a river specific basis. It will be important to take into consideration the species of seals involved, and the ecological and physical factors of the habitat that may be attracting seals into the area and affecting the susceptibility of salmon to predation.

Salmon are highly valued for recreational and cultural purposes by many residents of Newfoundland and Labrador, and conservation of the resource is a priority. Therefore, it will be necessary to examine the diets of harp seals on other rivers considered to have high potential for predation in order to evaluate the broader significance of these findings. Rivers where harbour and grey seals are becoming increasingly common during salmon runs also require further investigation.

Recognizing that salmon otoliths are easily degraded, any future research should incorporate fatty acid and DNA biomarker analyses in addition to the identification of otoliths and other prey hard parts (Iverson et al.1997; Rosel and Kocher 2002; Symondson 2002; Budge et al. 2006). These analysis techniques can provide information on seal diets over various time scales, and would document the smolt and adult run more effectively (Budge et al. 2000). In addition, if salmon otoliths are destroyed in the seal's digestive tract, or if seals only consume soft tissue, then these analyses would still confirm the presence of salmon in the diet (Symondson 2002).

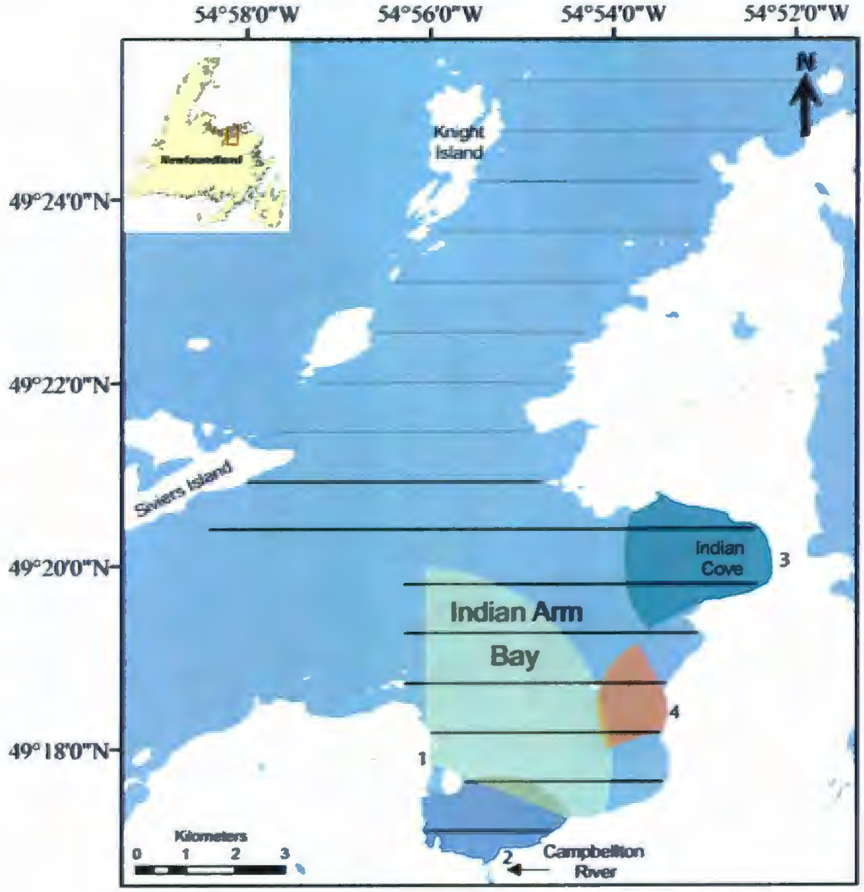

Figure 3.1 Location of shore-based observation quadrants (1-4) and boat-based line transects surveyed in 2005 and 2006 at Campbellton River. Darker lines indicate the main survey area for boat transects.

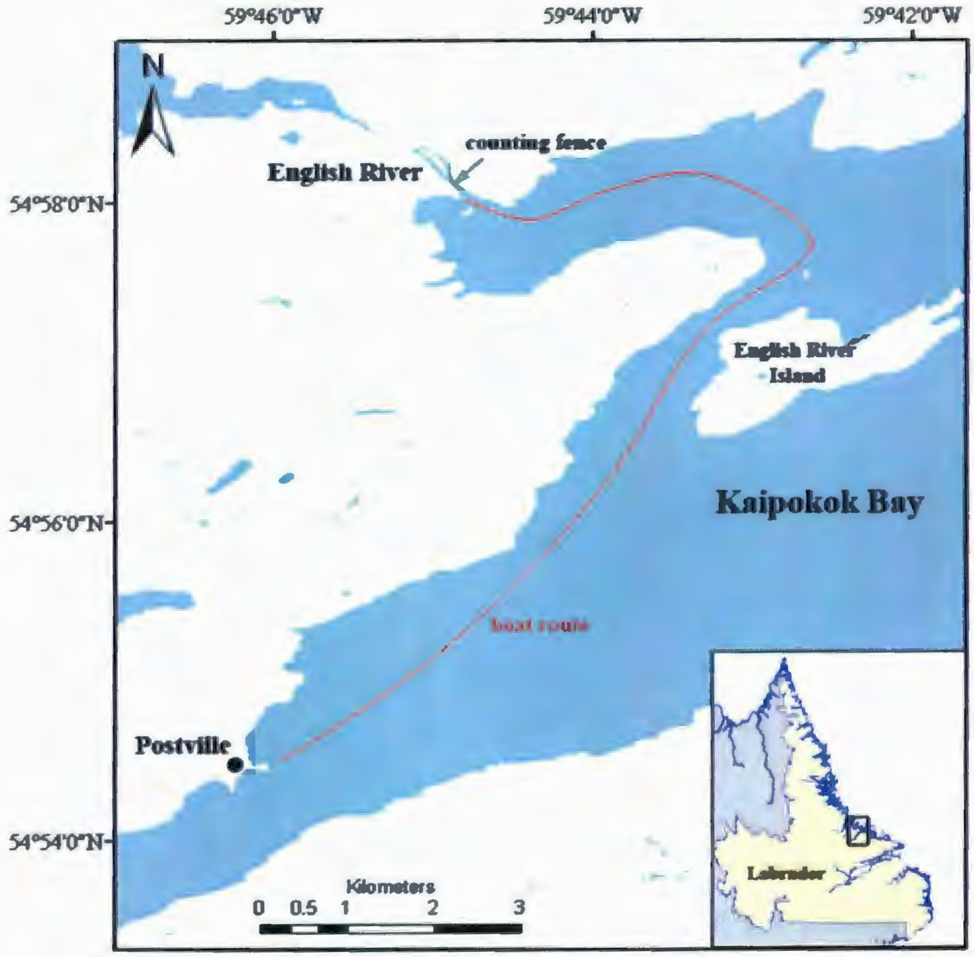

Figure 3.2 Location of opportunistic seal sightings in Kaipokok Bay and English River from 1999 to 2006. Observation data were recorded by salmon research personnel during a 20 min (12 km) boat ride to and from Postville to the English River counting fence.

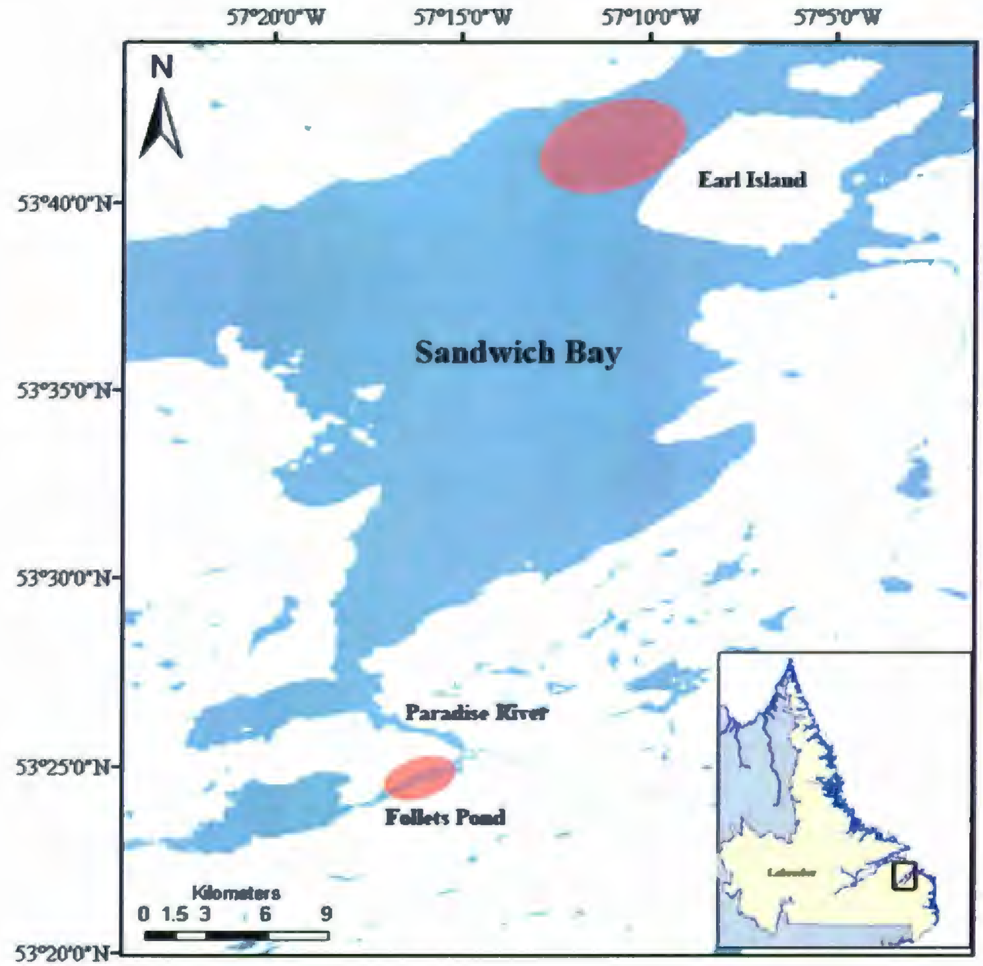

Figure 3.3 Shaded areas indicate primary seal hunting areas in 1999 and 2006 in Paradise River and Sandwich Bay, Labrador.

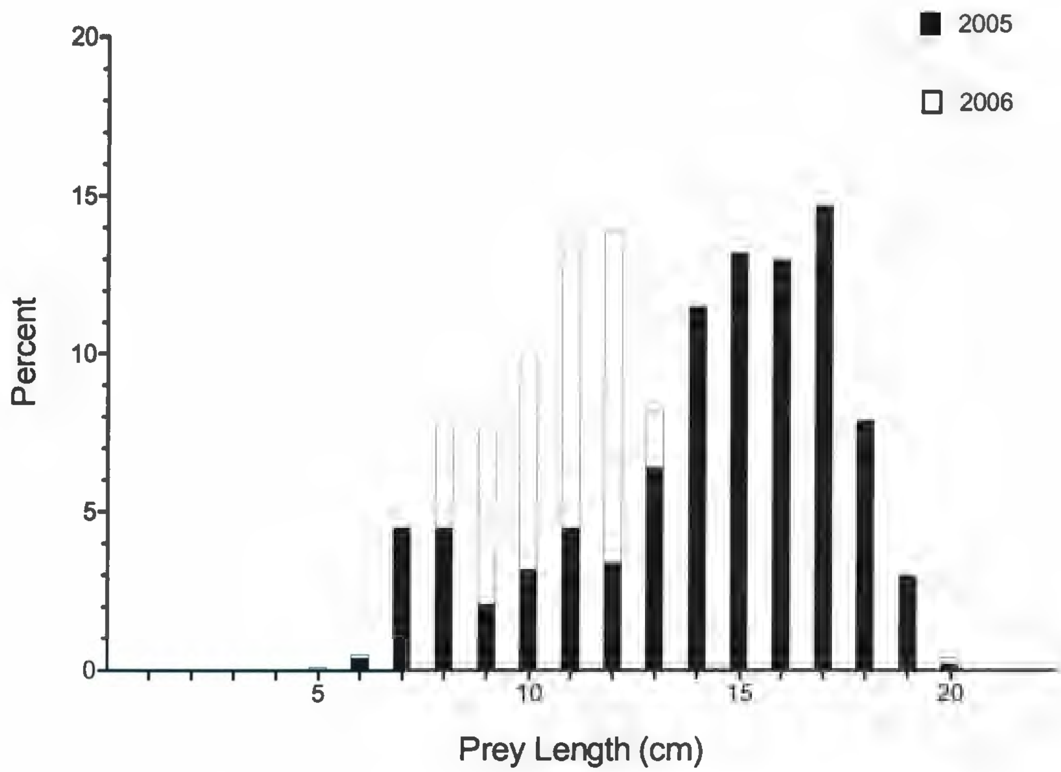

Figure 3.4 Frequency distributions of estimated capelin lengths eaten by harp seals in 2005 and 2006 at Campbellton River.

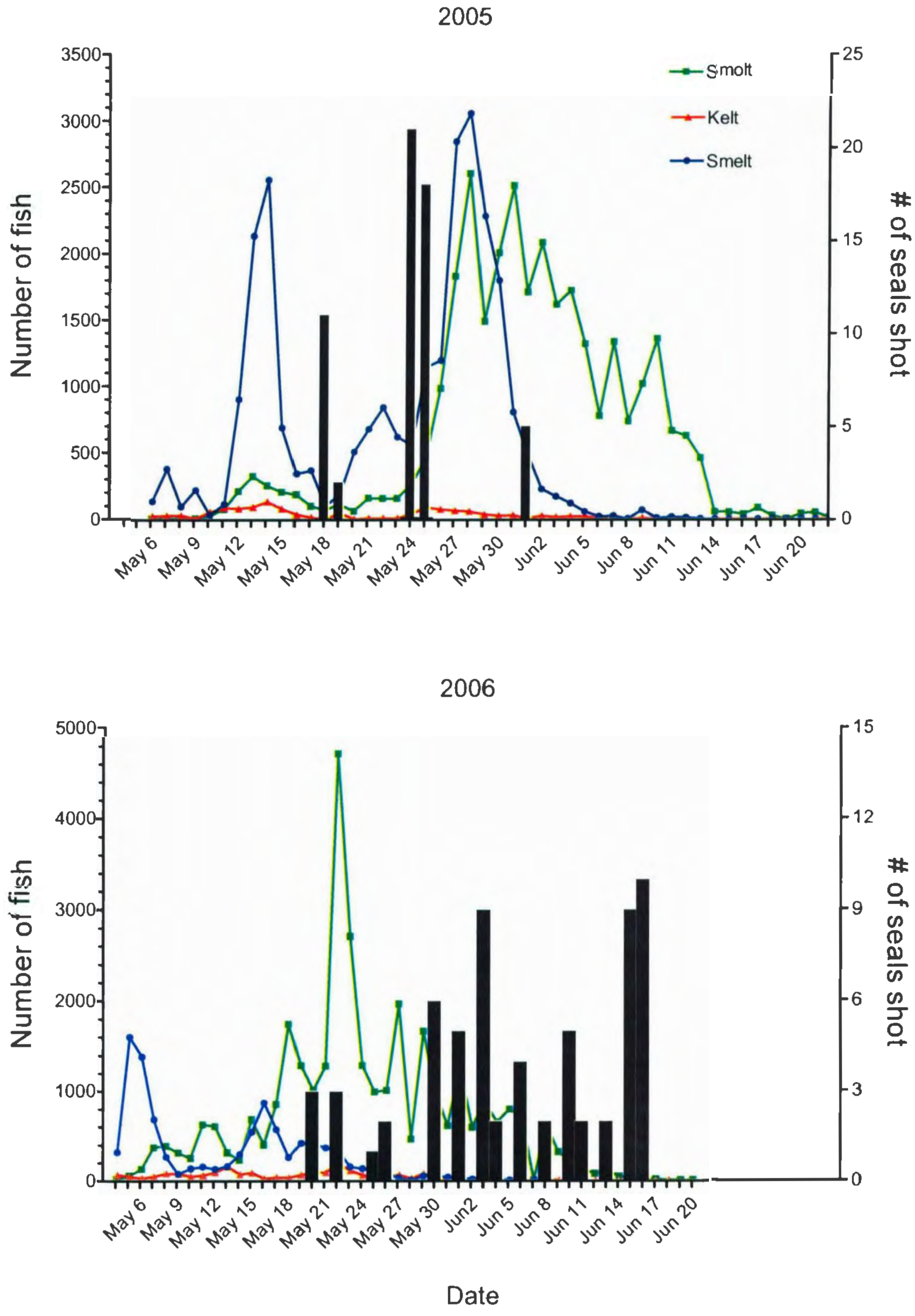

Figure 3.5 Total number of smolt, kelt and smelt counted at the Campbellton River counting fence in 2005 and 2006. Black bars show the date and number of seals collected throughout the duration of the smolt run.

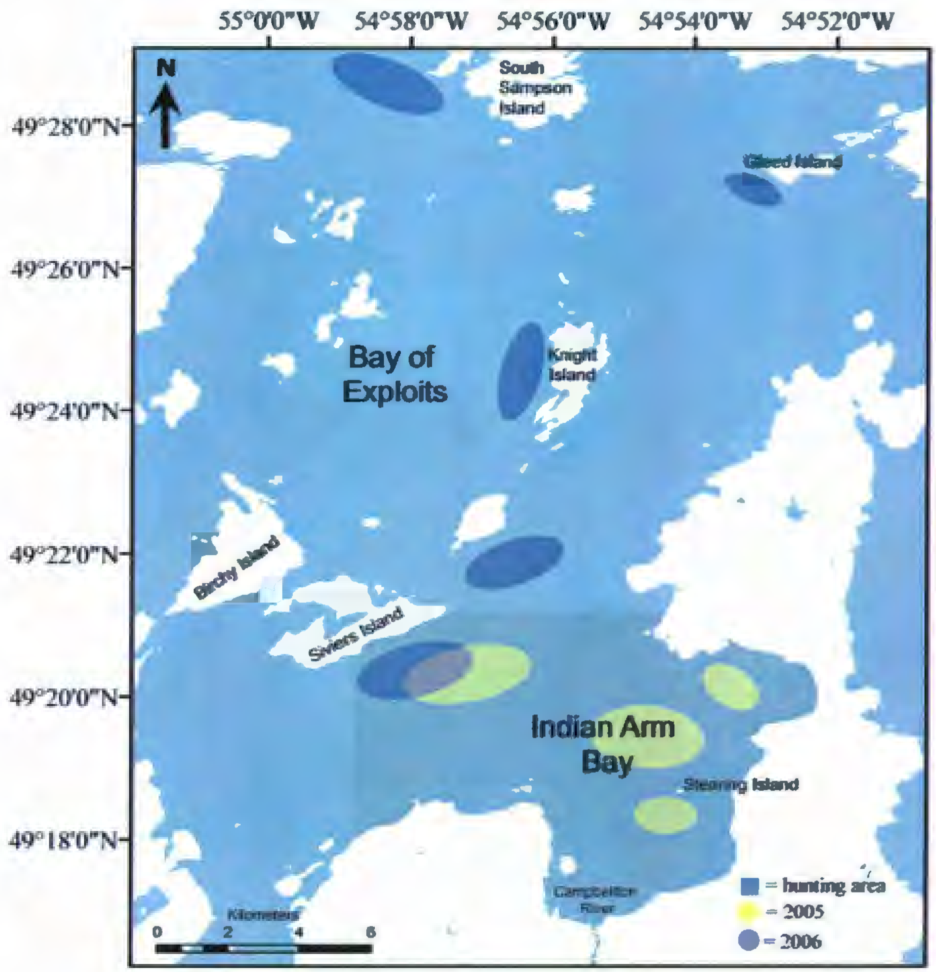

Figure 3.6 Primary harp seal hunting areas at Campbellton River in 2005 and 2006.

Table 3.1 Distribution of seal stomachs collected during smolt and adult salmon runs from three rivers and estuaries in Newfoundland and Labrador from 1999-2006.

		Species					
Location	Year	Harp	Harbour	Ringed	Grey	Bearded	Total
English River	2003	3		8			11
	2004			6		1	7
Paradise River	1999		5				5
	2000		1				1
	2006		5		2		7
Campbellton River	2005	55		1			56
	2006	67				1	68
Total		125	11	15	2	2	155

Table 3.2 Regression equations for calculating fish length (fork length, FL), weight (wet mass, W), and prey energy from otolith length (OL) measurements.

Prey Species[a]	Prey length (cm)	Prey weight (g)	Prey energy (kcal/g)
Capelin	FL = 216*OL - 177*OL^2 + 71.0*OL^3 - 9.4*OL^4 - 23.2/10	W = e^LNFL*3.8 - 3.808	2.01
Smelt	FL = 2.9*OL^1.1 R^2 = 0.8822	W = 0.0026*FL^3.3	1.65
Sand lance	FL = 76.5*OL - 13.5/10	W = 0.4*OL^3.89	1.06
Atlantic herring	FL = 5.6*OL + 0.04	W = 1.48*OL^3.08 R^2=0.98	2.24
Atlantic cod	FL = 4.5 + 0.1 * OL + 0.2 * OL^ 2 R^2=0.9613	W = 10^ -5.2 + 3.08 * LOG10FL * 1000	1.01
Arctic cod	FL = 19.4 + 18.6*OL + 0.5*OL^2/10	W = 0.2*OL^2.64 R^2 = 0.88	1.01
Daubed shanny	FL = 9.3*OL^0.6212 R^2 = 0.8652	W = 0.0009*FL^3.5 R^2 = 0.9314	1.14
Vahl's eelpout	FL = 2.9*OL^1.5 R^2 = 0.9197	W = 0.0047*FL^0.9 R^2 = 0.9385	1.51
Shorthorn sculpin	FL = 2.2*OL^1.2 R^2 = 0.8341	W = 0.077*OL^4.6	1.29
Sculpin spp.	FL = 27*OL/10	W = 1.6*OL	1.29

[a] Scientific names in Table 3.3

Table 3.3 Summary of prey covered from food containing seal stomachs (n=143) collected during smolt and adult salmon runs from three rivers and estuaries in Newfoundland and Labrador.

Prey Type	Estimated no. of individuals[a]	Prevalence[c]	Wet mass (kg)	Energy (MJ)
Capelin (*Mallotus villosus*)	3273 (84.0)	90.9	30.1	253.4
Smelt (*Osmerus mordax*)	14 (0.4)	0.7	0.6	4.2
Altantic herring (*Clupea harengus*)	1	0.7	0.2	2.1
Atlantic cod (*Gadus morhua*)	56 (0.1)	1.4	12.8	6.5
Arctic cod (*Boreogadus saida*)	55 (1.4)	2.1	1.0	4.4
Gadus spp. (unidentified)	5 (1.5)	3.5	1.6	54.2
Sand lance (*Ammodytes dubius*)	434 (11.1)	7.0	0.5	2.3
Sculpin (Cottidae)	1	0.7	trace	
Shorthorn sculpin (*Myoxocephalus scorpius*)	17 (0.4)	1.4	trace	0.5
Arctic staghorn sculpin (*Gymnocanthus tricuspis*)	2	0.7		
Vahl's eelpout (*Lycodes vahlii*)	1	0.7	N/A[b]	
Daubed shanny (*Lumpenus maculatus*)	36 (0.9)	2.1	0.2	0.8
Total	3898			328.4
Mysid (Mysidae)	5082	16.1		
Natantia (unidentified shrimp)	12	2.8		
Eualus macilentus (shrimp)	6	1.4		

[a] Estimated no. of individuals from recovered otoliths or whole prey
[b] One eroded otolith was recovered, not measurable
[c] Percent occurrence in prey-containing stomachs

Table 3.4 Estimated mean length, wet mass and energy density of fish prey recovered from harp seal stomachs (n = 122) collected at Campbellton River during the smolt salmon run from May to June in 2005 and 2006.

			Length (cm)		Wet mass (g)		
	Species	N[a]	Mean	SD	Mean	SD	Energy (MJ)
2005	Capelin	721	14.3	3.1	15.1	8.8	92.9
	Sand lance	3	17.7	3.2	14.3	7.6	
	Atlantic herring	1	28.3		233.6		
	Total	725					
2006	Capelin	2284	12.4	3.1	9.7	8.6	148.7
	Sand lance	2	15.5	3.8	9.2	7.3	
	Atlantic cod	44	24.4	9.9	188.2	242.6	
	Total	2330					

[a] estimated number of individuals from recovered otoliths

Table 3.5 Estimated mean length and wet mass of fish prey recovered from harp and harbour seal stomachs (n = 14) collected at English River during the adult salmon run from April to August 2003 and 2004.

			Length (cm)		Wet mass (g)	
	Species	N[a]	Mean	SD	Mean	SD
2003	Capelin	106	12.3	1.7	7.8	4.8
	Sand lance	129	10.9	2.6	2.9	2.0
	Atlantic cod	1	34.5		344.6	
	Arctic cod	52	12.7	3.1	16.1	9.0
	Daubed shanny	8	10.7	1.7	3.6	2.1
	Total	297				
2004	Capelin	132	12.4	2.3	8.4	6.5
	Sand lance	7	10.7	1.1	2.3	0.8
	Atlantic cod	4	28.6	13.6	299.9	342.5
	Arctic cod	3	14.5	5.0	23.6	21.5
	Duabed shanny	28	11.8	1.5	4.9	2.1
	Shorthorn sculpin	17	6.2	2.3	5.9	6.1
	Total	191				

[a] estimated number of individuals from recovered otoliths

Table 3.6 Estimated mean length and wet mass of fish prey recovered from harbour seal stomachs (n = 11) collected at Paradise River during the adult salmon run, July and August 1999 and 2006.

			Length (cm)		Wet mass (g)	
	Species	N[a]	Mean	SD	Mean	SD
1999	Capelin[b]	1			1.5	
	Gadus spp.	2	46.0	8.4	882.0	473.4
	Total	3				
2006	Smelt	14	18.8	3.2	86.5	16.7
	Sand lance	293	12.9	2.0	6.3	11.5
	Sculpin spp.	1	5.0		2.9	
	Gadus spp.	3	42.2	6.5	675.5	321.4
	Total	311				

[a] Estimated number of individuals from recovered otoliths
[b] Broken otolith, estimated mass based on stomach wet content weight

Table 3.7 Estimated harp seal abundance from boat-based surveys conducted during the smolt run at Campbellton River in 2005 and 2006 (Standard error in parentheses).

	2005			2006		
Survey	Date	Estimate	Density (seals/km^{-2})	Date	Estimate	Density (seals/km^{-2})
1	May 22	15.0 (4.4)	0.92	May 19	1.7 (1.9)	0.10
2	May 26	13.3 (6.1)	0.82	May 28	24.7 (4.4)	1.40
3	June 4[a]			June 4[b]	0.0	0.0
4	June 9	5.0 (3.1)	0.31	June 9[b]	0.0	0.0

[a] Survey was not included in analyses
[b] No seals were observed during these surveys

Table 3.8 Frequency of seal sightings during the adult salmon run at the English River, Labrador. Observations were recorded by salmon research personel from June to October 1999-2006.

Year	Observation hours	Harp	Ringed	Harbour	Hooded	Bearded	Unknown	Total	Sighting Effort	% of days with a sighting
1999	78.2	21	12	0	0	0	2	35	0.44/hr	19.1
2000	78.7	17	4	1	0	0	2	24	0.30/hr	12.6
2001	86.9	90	5	0	1	1	7	99	1.14/hr	24.0
2002	81.5	5[a]	1	0	0	0	12	18	0.22/hr	18.0
2003	82.8	4[b]	6	0	1	0	1	12	0.14/hr	15.4
2004	67.5	1	5	5	0	0	1	12	0.18/hr	10.8
2005	78.1	1	5	0	0	0	3	9	0.12/hr	7.9
2006	51.3	0	0	0	0	0	0	0	0	0
Total	605.0							209		

[a] Two separate sculls of harp seals were observed but no estimate on numbers was provided
[b] One scull of harp seals was observed but no estimate on numbers was provided

CHAPTER FOUR: SUMMARY AND RECOMMENDATIONS

Local ecological knowledge collected from interviews with resource users provided evidence of an increase in the spatial and temporal overlap of seals and salmon in some Newfoundland and Labrador rivers. This increase in overlap suggested that the potential for seal predation on salmon has increased since the mid to late 1990s. However, dietary data provided no evidence that harp seals, or any other seal species sampled, were feeding on salmon when seals and salmon co-occurred. In the case of the Campbellton River and estuary, this does not mean that harp seals never consume salmon, but rather, the occurrence of predation is variable and its impact on salmon is not biologically significant in some years. From a broader perspective, the results emphasize that assessing the biological impact of seal predation will likely have to be done on a river specific basis, taking into consideration the species of seals involved, and the ecological and physical factors of the habitat that may be attracting seals to the area and affecting the susceptibility of salmon to predation

Key Results from Local Ecological Knowledge Interviews:

- An increase in the occurrence and relative abundance of harp seals in rivers and estuaries during salmon runs started in the mid 1990s; 8/16 rivers in northeastern Newfoundland and southern Labrador were considered to have high potential for predation.

- Harbour seals have always been present on some rivers, but their populations have been steadily increasing since the 1990s; 10/24 rivers on the western and southern coasts of Newfoundland and in some parts of southern Labrador were considered to have high potential for predation.

- Historically, grey seals have been relatively rare summer migrants in most areas of Newfoundland and Labrador, but they have become more abundant during adult salmon migrations since 2000. Potential grey seal predation on salmon was considered to be high for 3/11 rivers in southern Labrador and moderate for the Torrent River on the western coast of Newfoundland.

- Most evidence of indirect interactions involving harp seals occurred when large sculls were observed foraging (usually for capelin) in the vicinity of salmon migration pathways or salmon feeding areas near the headlands of an estuary, or when individual seals were seen chasing salmon in a river. Harbour and grey seals were more often observed taking salmon from fishing nets or foraging at the river mouth.

- Several ecological and physical characteristics appeared to increase migrating salmon's susceptibility to seal predation including the following: 1) a river or estuary's proximity to habitats used by harps in the late spring for feeding and traveling; 2) a river's proximity to harbour and grey seal haul-out areas; 3) the presence of capelin beaches or spawning herring in the estuary; 4) variable, light spring ice conditions; and 5) low water levels and high water temperatures during salmon migrations.

Key Results from the Diet Study:

- A total of 155 seal stomachs were collected from the three study areas (Campbellton River, Paradise River and English River) over the study period. Eighteen taxa were identified from the 143 stomachs that contained prey. Capelin, sand lance, *Gadus* spp., and mysids were the most common taxa.

- No Atlantic salmon otoliths were found in seal stomachs regardless of the location, even though the sampling periods overlapped with portions of both the smolt and adult runs.

- Campbellton River was the main study area, and few prey species were consumed by young harp seals at this site. Capelin was the dominant prey in both 2005 and 2006. Capelin was also the main prey in seal stomachs from English River. Most stomachs from Paradise River were empty.

Recommendations:

This research included a comprehensive study of harp seal diet in one river and a more general diet survey in two others. To evaluate the broader significance of these findings, future research will require sampling harp seals at several other rivers with high potential for seal predation (e.g. rivers in southern Labrador). It would also be useful to determine if harp seal predation on smolt or kelt in the Campbellton River ever reaches levels that may be biologically significant for the salmon population, and if so, under what conditions. Rivers evaluated with a high potential for harbour and grey seal predation, including those in St. George's Bay, require more comprehensive studies. Any future diet research should include fatty acid and DNA biomarker analyses in addition to stomach reconstruction, because both techniques are able to provide information on a seal's diet over several months and over very short time frames without having to rely on prey hard parts. If salmon otoliths are destroyed in the seal's digestive tract, or if seals eat only soft tissue, both approaches would still reveal whether salmon occurs in the diet.

Local ecological knowledge has been collected on only 29 rivers; there are additional rivers that should be studied. Maintenance of this LEK database will allow researchers to monitor the occurrence of seal-salmon interactions in a changing coastal marine environment. Resource users can effectively monitor rivers, from both financial and human resource perspectives, for longer-term changes or extreme climate events that will provide research direction and contribute to salmon conservation initiatives. Rivers that have a moderate or high potential for seal predation, and are susceptible to low water levels and warm water temperatures should be considered for logbook-monitoring programs. When environmental conditions like these occur, salmon may be less able to cope with physiological stresses; increasing their accessibility to not only seals, but to avian predators and other mammalian predators, including humans. Monitoring programs should also be considered for rivers where potentially high seal predation and variable spring ice conditions allow increased access for harp seals and other seals into nearshore salmon habitats at critical times of their migration.

LITERATURE CITED

Altmann, J. 1974. Observational study of behavior: sampling methods. Behaviour. **49**: 227-267.

Anonymous. 2005. Stock assessment of northwest Atlantic harp seals (*Pagophilus groenlandicus*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/037. Available from www.dfo-mpo.gc.ca/csas

Ballance, L.T., Pitman, R.L., and Fiedler, P.C. 2006. Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: a review. Prog. Oceanog. **69**: 360-390.

Beck, G.G., Hammill, M.O., and Smith, T.G. 1993. Seasonal variation in the diet of harp seals (*Phoca groenlandica*) from the Gulf of St. Lawrence and western Hudson Strait. Can. J. Fish. Aquat. Sci. **50**: 1363-1371.

Benson, A.J., and Trites, A.W. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fish Fish. **3**: 95-113.

Boulva, J., and McLaren, I.A. 1979. Biology of the harbour seal, *Phoca vitulina*, in eastern Canada. J. Fish. Res. Board Can. Bull. No. 200.

Bowen, W.D. 2000. Reconstruction of pinniped diets: accounting for complete digestion of otoliths and cephalopod beaks. Can. J. Fish. Aquat. Sci. **57**: 898-905.

Bowen, W.D., and Siniff, D.B. 1999. Distribution, population biology, and feeding ecology of marine mammals. *In* Biology of Marine Mammals. *Edited* by J.E. Reynolds and S.A. Rommel. Smithsonian Institution Press, Washington, D.C. pp 423-484.

Bowen, W.D., McMillan, J. and Mohn, R. 2003. Sustained exponential population growth of grey seals at Sable Island, Nova Scotia. ICES J. Mar. Sci. **60**: 1265-1274.

Boyle, P.R., Pierce, G.J., and Diack, J.S.W. 1990. Sources of evidence for salmon in the diet of seals. Fish. Res. **10**: 137-150.

Brice-Bennet, C. 1977. Land use in the Nain and Hopedale regions. *In* Our footprints are everywhere: Inuit land use and occupancy in Labrador. *Edited by* C. Brice-Bennet. Labrador Inuit Association. pp. 97-203.

Brown, R.F., and Mate, B.R. 1983. Abundance, movements and feeding habits of harbor seals, *Phoca vitulina*, at Netarts and Tillamook bays, Oregon. Fish. Bull. **81**: 291-301.

Bryant, R., Jones, I.L., and Hipfner, J.M. 1999. Responses to changes in prey availability by common and thick-billed murres at the Gannets Islands, Labrador. Can. J. Zool. **77**: 1278-1287.

Budge, S.M., Iverson, S.J., and Koopman, H.N. 2006. Studying the trophic ecology in marine ecosystems using fatty acids: a primer on analysis and interpretation. Mar. Mammal Sci. **22**: 759-801.

Burns, J.J., Shapiro, L.H., and Fay, F.H. 1981. Ice as a marine mammal habitat in the Bering Sea. *In* The eastern Bering Sea shelf; oceanography and resources. *Edited by* D.W. Hood and J.A. Calder. University of Washington Press, Seattle. pp. 781-797.

Cairns, D.K. 2001. An evaluation of possible causes of the decline in pre-fishery abundance of North American Atlantic salmon. Can. Tech. Rep. Fish. Aquat. Sci. No. 2358.

Cairns, D.K. and Reddin, D.G. 2000. The potential impact of seal and seabird predation on North American Atlantic salmon. Can. Stock. Assess. Sec. Res. Doc. 2000/12. Available from www.dfo-mpo.gc.ca

Campana, S.E. 2004. Photographic atlas of fish otoliths of the northwest Atlantic Ocean. NRC Research Press. Ottawa, Ontario.

Carscadden, J.E., and Nakashima, B.S. 1997. Abundance and changes in distribution, biology and behaviour of capelin in response to cooler waters of the 1990s. *In* Forage fishes in marine ecosystems. Proceedings of the international symposium on the role of forage fishes in marine ecosystems. *Edited by* Alaska Sea Grant College Program Rep. No. 97-01, Fairbanks, Alaska. pp. 457-468.

Carscadden, J.E., Frank, K.T., and Leggett, W.C. 2001. Ecosystem changes and the effects on capelin (*Mallotus villosus*), a major forage species. Can. J. Fish. Aquat. Sci. **58**:73-85.

Carter, T.J., Pierce, G.J., Hislop, J.R.G., Houseman, J.A., and Boyle, P.R. 2001. Predation by seals on salmonids in two Scottish estuaries. Fish. Manage. Ecol. **8**: 207-225.

Christiansen, J.S., Gamst Moen, A., Hansen, T.H., and Nilssen, K.T. 2005. Digestion of capelin, *Mallotus villosus* (Mueller), herring, *Clupea harengus* L., and polar cod, *Boreogadus saida* (Lepechin), otoliths in a simulated seal stomach. ICES J. Mar. Sci. **62**: 86-92.

Colbourne, E., Narayanan, S., and Prinsenberg, S. 1994. Climate changes and environmental conditions in the northwest Atlantic, 1970-1993. ICES Mar. Sci. Symp. **198**: 311-322.

Colbourne, E.B. 2004. Decadal changes in the ocean climate in Newfoundland and Labrador waters from the 1950s to the 1990s. J. Northw. Atl. Fish. Sci. **34**: 43-61.

Cottrell, P.E., Trites, A.W., and Miller, E.H. 1996. Assessing the use of hard parts in faeces to identify harbour seal prey: Results of captive-feeding trials. Can. J. Zool. **74**: 875-880.

Crocker, D.E., Costa, D.P., Le Boeuf, B.J., Webb, P.M., and Houser, D.S. 2006. Impact of El Niño on the foraging behavior of female northern elephant seals. Mar. Ecol. Prog. Ser. **309**: 1-10.

Dempson, J.B., Myers, R.A., and Reddin, D.G. 1986. Age at first maturity of Atlantic salmon (*Salmo salar*) – influences of the marine environment. *In* Salmonid age at maturity. *Edited by* D.J. Meerburg. Can. Spec. Pub. Fish. Aquat. Sci. pp. 79-89.

Dempson, J., Reddin, D.G., O'Connell, M.F., Helbig, J., Bourgeois, C.E., Mullins, C., Porter, T.R., Lilly, G.R., Carscadden, J.E., Stenson, G.B., and Kulka, D.W. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. Can. Stock Assess. Sec. Res. Doc. 1998/114. Available from www.dfo-mpo.gc.ca

Dempson, J.B., O'Connell, M.F., and Cochrane, N.M. 2001. Potential impact of climate warming on recreational fishing opportunities for Atlantic salmon, *Salmo salar*, in Newfoundland, Canada. Fish. Manage. Ecol. **8**: 69-82.

Dempson, J.B., O'Connell, M.F., and Schwarz, C.J. 2004. Spatial and temporal trends in abundance of Atlantic salmon, *Salmo salar*, in Newfoundland with emphasis on impacts of the 1992 closure of the commercial fishery. Fish. Manage. Ecol. **11**: 387-402.

Dempson, J.B., Schwarz, C.J., Shears, M. and Furey, G. 2004. Comparative proximate body composition of Atlantic salmon with emphasis on parr from fluvial and lacustrine habitats. J. Fish. Biol. **64**: 1257-1271.

Dempson, J.B., O'Connell, M.F., Reddin, D.G., and Cochrane, N.M. 2006. Stock status summary for Atlantic salmon in Newfoundland and Labrador. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/028. Available from www.dfo-mpo.gc.ca/csas/

Derocher, A.E., Lunn, N.J., and Stirling, I. 2004. Polar bears in a warming climate. Integr. Comp. Biol. **44**: 163-176.

Drinkwater, K.F. 1996. Atmospheric and oceanic variability in the northwest Atlantic during the 1980s and early 1990s. J. Northw. Atl. Fish. Sci. **18**: 77-97.

Drinkwater, K.F. 2004. Atmospheric and sea-ice conditions in the northwest Atlantic during the decade, 1991-2000. J. Northw. Atl. Fish. Sci. **34**: 1-11.

Ferguson, M.A., and Messier, F. 1997. Collection and analysis of traditional ecological knowledge about a population of Arctic tundra caribou. Arctic. **50**: 17-28.

Ferguson, M.A., Williamson, R.G., and Messier, F. 1998. Inuit knowledge of long-term changes in a population of Arctic tundra caribou. Arctic. **51**: 201-219.

Finley, K.J., and Renaud, W.E. 1980. Marine mammals inhabiting the Baffin Bay north water in winter. Arctic. **33**: 724-738.

Finley, K.J., Bradstreet, M.S.W., and Miller, G.W. 1990. Summer feeding ecology of harp seals in relation to arctic cod in the Canadian high Arctic. Polar Biol. **10**: 609-618.

Fischer, J. 2000. Participatory research in ecological fieldwork: a Nicaraguan study. *In* Finding our sea legs: linking fishery people and their knowledge with science and management. *Edited by* B. Neis and L. Felt. ISER Books, Memorial University of Newfoundland, St. John's. pp. 41-54.

Fleming, I.A. 1996. Reproductive strategies of Altantic salmon: ecology and evoluation. Rev. Fish. Biol. Fish. **6**: 379-416.

Frank, K.T., Carscadden, J.E., and Simon, J.E. 1996. Recent excursions of capelin (*Mallotus villosus*) to the Scotian Shelf and Flemish cap during anomalous hydrographic conditions. Can. J. Fish. Aquat. Sci. **53**: 1473-1486.

Friedland, K., Reddin, D.G., and Kocik, J.F. 1993. Early marine life of Atlantic salmon, *Salmo salar*, post-smolts in the northern Gulf of St. Lawrence. ICES J. Mar. Sci. **50**: 481-492.

Friedland, K., Hansen, L.P., and Dunkley, D. 1998. Marine temperatures experienced by post-smolts and the survival of Atlantic salmon, *Salmo salar* L., in the North Sea area. Fish. Oceanogr. **7**: 22-34.

Furgal, C.M., Innes, S., and Kovacs, K.M. 2002. Inuit spring hunting techniques and local knowledge of the ringed seal in Arctic Bay (Ikpiarjuk), Nunavut. Polar Res. **21**: 1-16.

Gudjonsson, S., Jonsson, I.R., and Antonsson, T. 2005. Migration of Atlantic salmon, *Salmo salar*, smolt through the estuary areas of River Ellidaar in Iceland. Env. Biol. Fish. **74**: 291-296.

Hammill, M.O., Stenson, G.B., Myers, R.A. and Stobo, W.T. 1998. Pup production and population trends of the grey seal (*Halichoerus grypus*) in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. **55**: 423-430.

Hammill, M.O., and Stenson, G.B. 2000. Estimated prey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) in Atlantic Canada. J. Northw. Atl. Fish. Sci. **26**: 1-23.

Harcourt, R.G., Bradshaw, C.J.A. and Davis, L.S. 2001. Summer foraging behaviour of a generalist predator, the New Zealand fur seal (*Arctocephalus forsteri*). Wildl. Res. **28**: 599–606.

Harcourt, R.G., Bradshaw, C.J.A., Dickson, K. and Davis, L.S. 2002. Foraging ecology of a generalist predator, the female New Zealand fur seal. Mar. Ecol. Prog. Ser. **227:** 11–24.

Härkönen, T.J. 1986. Guide to the otoliths of the bony fishes of the northeast Atlantic. Danbiu Aps, Hellerup, Denmark.

Harris, D.E., Lelli, B., and Jakush, G. 2002. Harp seal records from the southern Gulf of Maine: 1997 - 2001. Northeast. Nat. **9**: 331-340.

Harvey, J.T. 1989. Assessment of errors associated with harbour seal (*Phoca vitulina*) feacal sampling. J. Zool. (Lond.). **219**: 101-111.

Haug, T., and Nilssen, K.T. 1995. Ecological implications of harp seal *Phoca groenlandica* invasions in northern Norway. *In* Seals, whales, fish and man: Proceedings of the International Symposium on the Biology of Marine Mammals in the Northeast Atlantic, 29 November-1 December 1994, Tromsø, Norway. *Edited by* A.S. Blix, Ø. Ulltang, and L. Walløe. Developments in Marine Biology IV. Elsevier Science, Amsterdam, pp. 545-556.

Haug, T., Kroyer, A.B., Nillsen, K.T., Ugland, K.I., and Aspholm, P.E. 1991. Harp seal (*Phoca groenlandica*) invasions in Norwegian coastal waters: age composition and feeding habits. ICES J. Mar. Sci. **48**: 363-371.

Holm, M., Holst, J.C., and Hansen, L.P. 2000. Spatial and temporal distribution of post-smolts of Atlantic salmon (*Salmo salar*) in the Norwegian Sea and adjacent areas. ICES J. Mar. Sci. **57**: 955-964.

Huntington, H.P. 1998. Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. Arctic. **51**: 237-242.

Huntington, H.P. 1999. Traditional knowledge of the ecology of beluga whales (*Delphinapterus leucas*) in the eastern Chukchi and northern Bering seas, Alaska. Arctic. **52**: 49-61.

Huntington, H.P. 2000a. Using traditional ecological knowledge in science: methods and applications. Ecol. Appl. **10**: 1270-1274.

Hungtington, H.P. 2000b. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. US National Marine Fisheries Service Marine Fish. Rev. **62**: 134-140.

Hurrell, J.W., Kushnir, Y., Ottersen, G. and Visbeck, M. 2003. An overview of the North Atlantic oscillation. *In* The North Atlantic oscillation: climatic significane and environment impact. *Edited by by* J.W. Hurrell, Y. Kushnir, G. Ottersen and M. Visbeck. Geophysical Monograph Series 134, Washington, DC. pp 1-36.

Hutchings, J.A. 1996. Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. Can. J. Fish. Aquat. Sci. **53**: 943-962.

International Council for the Exploration of the Sea (ICES). 1999. Report of the working group on North Atlantic salmon. C.M.1999/ACFM:14.

Iverson, S.J., Frost, K.J., and Lowry, L.F. 1997. Fatty acid signatures reveal fine scale structure of foraging distribution of harbour seals and their prey in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. **151**: 255-271.

Kapel, F.O., and Geisler, A. 1979. Progress report on research on harp and hooded seals in west Greenland waters, 1978-79. 79/XI/10 NO21. Rep. No. Northwest Atlantic Fisheries Organization.

Klmetsen, A., Amundsen, P.A., Dempson, J.B., Jonsson, N., O'Connell, M.F., and Mortensen, E. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus aplinus* (L.): a review of aspects of their life histories. Ecol. Freshw. Fish **12**: 1-59.

Lacoste, K.N., and Stenson, G.B. 2000. Winter distribution of harp seals (*Phoca groenlandica*) off eastern Newfoundland and southern Labrador. Polar Biol. **23**: 805-811.

Lacroix, G.L., McCurdy, P., and Know, D. 2004. Migration of Atlantic salmon postsmolts in relation to habitat use in a coastal system. Trans. Amer. Fish. Soc. **133**: 1455-1471.

Lavigne, D.M., and Kovacs, K.M. 1988. Harps & hoods; ice-breeding seals of the northwest Atlantic. University of Waterloo Press, Canada.

Lawson, J.W., and Stenson, G.B. 1995. Historic variation in the diet of harp seals (*Phoca groenlandica*) in the northwest Atlantic. *In* Seals, whales, fish and man: Proceedings of the International Symposium on the Biology of Marine Mammals in the Northeast Atlantic, 29 November - 1 December 1994, Tromsø, Norway. *Edited by* A.S. Blix, Ø. Ulltang, and L. Walloe. Elsevier Science, Amsterdam, pp. 261-269.

Lawson, J.W., Stenson, G.B., and McKinnon, D.G. 1995. Diet of harp seals (*Phoca groenlandica*) in nearshore waters of the northwest Atlantic during 1990-1993. Can. J. Zool. **73**: 1805-1818.

Lawson, J.W., and Stenson, G.B. 1997. Diet of northwest Atlantic harp seals (*Phoca groenlandica*) in offshore areas. Can. J. Zool. **75**: 2095-2106.

Lawson, J.W., Anderson, J.T., Dalley, E.L., and Stenson, G.B. 1998a. Selective foraging by harp seals *Phoca groenlandica* in nearshore and offshore waters of Newfoundland, 1993 and 1994. Mar. Ecol. Prog. Ser. **163**:1-10.

Lawson, J.W., Magalhães, A.M. and Miller, E.H. 1998b. Important prey species of marine vertebrate predators in the northwest Atlantic: proximate composition and energy density. Mar. Ecol. Prog. Ser. **164**: 13-20.

Le Boeuf, B.J., and Crocker, D.E. 2005. Ocean climate and seal condition. BMC Biol. **3**:9.

Le Boeuf, B.J., and Reiter, J. 1991. Biological effects associated with El Niño Southern Oscillation, 1982-83, on northern elephant seals breeding at Ano Nuevo, California. *In* Pinnipeds and El Niño. *Edited by* F. Trillmich and K. A. Ono. Springer-Verlag, Berlin. pp. 206-281.

Lilly, G.R., Hop, H., Stansbury, D.E., and Bishop, C.A. 1994. Distribution and abundance of polar cod (*Boreogadus saida*) off southern Labrador and eastern Newfoundland. ICES C.M. 1994/O:6.

Lilly, G.R., and Simpson, M. 2000. Distribution and biomass of capelin, arctic cod and sandlance on the northeast Newfoundland shelf and grand bank as deduced from bottom-trawl surveys. Can. Stock Assess. Sec. Res. Doc. 2000/91.

Lilly, G.R., and Carscadden, J.E. 2002. Predicting the future of marine fish and fisheries off Labrador and eastern Newfoundland under scenarios of climate change; information and thoughts for the Arctic Climate Impact Assessment (ACIA). DFO Can. Sci. Advis. Sec. Res. Doc. 2002/111. Available from www.dfo-mpo.gc.ca/csas/

Lucas, Z., and Daoust, P. 2002. Large increases of harp seals (*Phoca groenlandica*) and hooded seals (*Cystophora cristata*) on Sable Island, Nova Scotia, since 1995. Polar Biol. **25**: 562-568.

Majluf, P. 1991. El Niño effects on pinnipeds in Peru. *In* Pinnipeds and El Niño: responses to environmental stress. Ecological Studies. *Edited by* F. Trillmich and K.A. Ono. Springer-Verlag, Berlin. pp 55-65.

Mallory, M.L., Gilchrist, H.G., Fontaine, A.J., and Akearok, J.A. 2003. Local ecological knowledge of ivory gull declines in arctic Canada. Arctic. **56**: 293-298.

Mansfield, A.W. 1967. Seals of Arctic and eastern Canada. Bull. Fish. Res. Board. Can. **137**: 1-35.

McAlpine, D.F., and Walker, R.H. 1990. Extralimital records of the harp seal *Phoca groenlandica*, from the western North Atlantic: A review. Mar. Mammal Sci. **6**: 248-252.

McAlpine, D.F., Stevick, P.T., and Murison, L.D. 1999. Increase in extralimital occurrences of ice-breeding seals in the northern Gulf of Maine region: More seals or fewer fish? Mar. Mammal Sci. **15**: 906-911.

Middlemas, S.J., Barton, T.R., Armstrong, J.D., and Thompson, P.M. 2005. Functional and aggregative responses of harbour seals to changes in salmonid abundance. Proc. R. Soc. B. **273**: 193-198.

Mills, D.H. 1989. Ecology and management of Atlantic salmon. Chapman and Hall, London.

Murie, D.J., and Lavigne, D.M. 1985a. A technique for the recovery of otoliths from stomach contents of piscivorous pinnipeds. J. Wildl. Manage. **49**: 910-912.

Murie, D.J., and Lavigne, D.M. 1985b. Digestion and retention of Atlantic herring otoliths in the stomachs of grey seals. *In* Marine mammals and fisheries. *Edited by* J.R. Beddington, R.J.H. Beverton and D.M. Lavigne. George Allen and Unwin, London, England. pp. 292-299.

Murie, D.J., and Lavigne, D.M. 1991. Food consumption of wintering harp seals, *Phoca groenlandica*, in the St. Lawrence Estuary, Canada. Can. J. Zool. **69**: 1289-1296.

Nakashima, D.J., and Murray, D.J. 1988. The common eider (*Somateria mollissima* sedentairs) of eastern Hudson Bay: a survey of nest colonies and Inuit ecological knowledge. Environmental Studies Revolving Fund Report No. 102, Ottawa.

Neis, B., Felt, L., Haedrich, R.L., and Schneider, D.C. 1999a. An interdisciplinary method for collecting and integrating fishers' ecological knowledge into resource management. *In* In fishing places, fishing people: issues and traditions in Canadian small-scale fisheries. *Edited by* D. Newell and R. Omer. University of Toronto Press, Toronto. pp. 217-238.

Neis, B., Schneider, D.C., Felt, L., Haedrich, R.L., Fischer, J., and Hutchings, J.A. 1999b. Fisheries assessment: What can be learned from interviewing resource users? Can. J. Fish. Aquat. Sci. **56**: 1949-1963.

Nichols, T., Berkes, F., Jolly, D., and Snow, N.B. 2004. Climate change and sea ice: local observations from the Canadian western Arctic. Arctic. **57**: 68-79.

Nilssen, K.T. 1995. Seasonal distribution, condition and feeding habits of Barents Sea harp seals (*Phoca groenlandica*). *In* Seals, whales, fish and man: Proceedings of the International Symposium on the Biology of Marine Mammals in the Northeast Atlantic, 29 November - 1 December 1994, Tromsø, Norway. *Edited by* A.S. Blix, Ø. Ulltang, and L. Walloe. Elsevier Science, Amsterdam, pp. 241-254.

Nilssen, K.T., Haug, T., Oritsland, L.L., and Kjellqwist, S.A. 1998. Invasions of harp seals *Phoca groenlandica* erxleben to coastal waters of Norway in 1995: ecological and demographic implications. Sarsia. **83**: 337-345.

Olesiuk, P.F., Bigg, M.A., Ellis, G.M., Crockford, S.J., and Wigen, R.J. 1990. An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia British Columbia based on scat analysis. Can. Tech. Rep. Fish. Aquat. Sci. No. 1730.

Orr, A.J., and Harvey, J.T. 2001. Quantifying errors associated with using fecal samples to determine the diet of the California sea lion (*Zalophus californianus*). Can. J. Zool. **79**: 1080-1087.

Orr, A.J., Banks, A.S., Mellman, S., Huber, H.R., DeLong, R.L., and Brown, R.F. 2004. Examination of the foraging habits of pacific harbor seal (*Phoca vitulina* richardsi) to describe their use of the Umpqua River, Oregon, and their predation on salmonids. Fish. Bull. **102**: 108-117.

Parsons, L.S., and Lear, W.H. 2001. Climate variability and marine ecosystem impacts: a North Atlantic perspective. Prog. Oceanog. **49**: 1167-1188.

Pemberton, D., Merdsoy, B., Gales, R., and Renouf, D. 1994. Interactions between offshore cod trawlers and harp *Phoca groenlandica* and hooded *Cystophora cristata* seals off Newfoundland, Canada. Biol. Conserv. **68**: 123-127.

Pierce, G.J., and Boyle, P.R. 1991. A review of methods for diet analysis in piscivorous marine mammals. Oceanogr. Mar. Biol. **29**: 409-486.

Reddin, D.G. 1988. Ocean life of Atlantic salmon (*Salmo salar*) in the northwest Atlantic. *In* Atlantic salmon: planning for the future. *Edited by* D.H. Mills and D.J. Piggins. Timber Press, Portland, Oregon. pp. 483-511.

Rosel, P.E., and Kocher, T.D. 2002. DNA-based identification of larval cod in stomach contents of predator fishes. J. Exp. Mar. Biol. Ecol. **267**: 75-88.

Roffe, T.J., and Mate, B.R. 1984. Abundances and feeding habits of pinnipeds in the Rogue River, Oregon. J. Wildl. Manage. **48**: 1262-1274.

Rose, G.A., Atkinson, D.B., Baird, J., Bishop, C.A., and Kulka, D.W. 1994. Changes in distribution of Atlantic cod and thermal variations in Newfoundland waters, 1980-1992. ICES Mar. Sci. Symp. **198**: 542-552.

Sergeant, D.E. 1965. Migration of harp seals, *Pagophilus groenlandicus* Erxleben, in the northwest Atlantic. J. Fish. Res. Board Can. **22**: 433-464.

Sergeant, D.E. 1973. Feeding, growth, and productivity of northwest-Atlantic harp seals (*Pagophilus groenlandicus*). J. Fish. Res. Board Can. **30**: 17-29.

Sergeant, D.E. 1991. Harp seals, man and ice. Can. Spec. Pub. Fish. Aquat. Sci. No. 153.

Sjare, B., Lebeuf, M., and Veinott, G. 2005. Harbour seals in Newfoundland and Labrador: a preliminary summary of new data on aspects of biology, ecology and contaminant profiles. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/030. Available from www.dfo-mpo.gc.ca/csas/

Smith, T.G. and Stirling, I. 1975. The breeding habitat of the ringed seal (*Phoca hispida*): the birth lairs and associated structures. Can. J. Zool. **53**: 1297-1305.

Springer, A.M. 1998. Is it all climate change? Why marine bird and mammal populations fluctuate in the North Pacific. *In* Biotic impacts of extratropical climate variability in the Pacific. *Edited by* G. Halloway, P. Muller and D. Henderson. National Oceanographic and Atmostpheric Association and the University of Hawaii, USA. pp. 109-120.

Stanley, W.T., and Shaffer, K.E. 1995. Harbor seal (*Phoca vitulina*) predation on seined salmonids in the lower Klamath River, California. Mar. Mammal Sci. **11**: 376-385.

Stenson, G.B., and Kavanagh, D.J. 1993. Distribution of harp and hooded seals in offshore waters of Newfoundland. NAFO Sci. Counc. Stud. **21**: 121-142.

Stenson, G.B., Hammill, M.O. and Lawson, J.W. 1997. Predation by harp seals in Atlantic Canada: preliminary consumption estimates for Arctic cod, capelin and Atlantic cod. J. Northw. Atl. Fish. Sci. **22**: 137-154.

Stenson, G.B. and Perry, E.A. 2001. Incorporating uncertainty into estimates of Atlantic cod (*Gadus morhua*), capelin (*Mallotus villosus*) and Arctic cod (*Boreogadus saida*) by harp seals (*Pagophilus groenlandicus*) in NAFO divisions 2J3KL. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/074. Available from www.dfo-mpo.gc.ca/csas

Stenson, G.B., Hammill, M.O., Kingsley, C.S., Sjare, B., Warren, W.G., and Myers, R.A. 2002. Is there evidence of increased pup production in northwest Atlantic harp seals, P*agophilus groenlandicus.* ICES J. Mar. Sci. **59**: 81-92.

Stevick, P.T., and Fernald, T.W. 1998. Increase in extralimital records of harp seals in Maine. Northeast. Nat. **5**: 75-82.

Stirling, I., and Derocher, A.E. 1993. Possible impacts of climatic warming on polar bears. Arctic. **46**: 240-245.

Stirling, I., and McEwan, E.H. 1975. The calorific value of whole ringed seals (*Phoca hispida*) in relation to polar bear (*Ursus maritimus*) ecology and hunting behaviour. Can. J. Zool. **53**: 1021-1027.

Stirling, I., Lunn, N., and Iacozza, J. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic. **52**: 294.

Symondson, W.O.C. 2002. Molecular identification of prey in predator diets. Mol. Ecol. **11**: 627-641.

Taylor, V.R. 1985. The early Atlantic salmon fishery in Newfoundland and Labrador. Can. Spec. Publ. Fish. Aquat. Sci. No. 76.

Thompson, P.M., Pierce, G.J., Hislop, J.R.G., Miller, D., and Diack, J.S.W. 1991. Winter foraging by common seals (*Phoca vitulina*) in relation to food availability in the Inner Moray Firth, N.E. Scotland. J. Anim. Ecol. **60**: 283-294.

Tollit, D.J., Steward, M.J., Thompson, P.M. Pierce, G.J., Santos, M.B., and Hughes, S. 1997. Species and size difference in the digestion of otoliths and beaks: implications for estimates of pinniped diet composition. Can. J. Fish. Aquat. Sci. **54**: 105-119.

Tollit, D.J., Wong, M., Winship, A.J., Rosen, D.A.S., and Trites, A.W. 2003. Quantifying errors associated with using prey skeletal structures from fecal samples to determine the diet of Steller's's sea lion (*Eumetopias jubatus*). Mar. Mammal Sci. **19**: 724-744.

Trillmich, F., and Ono, K.A. 1991. Pinnipeds and El Niño: responses to environmental stress. Ecological studies. Springer-Verlag, Berlin.

Trillmich, F., and Dellinger, T. 1991. The effects of El Niño on Galapagos pinnipeds. *In* Pinnipeds and El Niño: responses to environmental stress. Ecological studies. Springer-Verlag, Berlin. pp. 66-74.

Trites, A.W., Miller, A.J., Maschner, H.D.G., Alexander, M.A., Bograd, S.J., Calder, J.A., Capotondi, A., Coyle, K.O., Di Lorenzo, E., Finney, B.P., Gregr, E.J., Grosch, C.E., Hare, S.R., Hunt JR, G.L., Jahncke, J., Kachel, N.B., Kim, H.J., Ladd, C., Mantua, N.J., Marzban, C., Maslowskil, W., Mendelssohn, R., Neilson, D.J., Okkonen, S.R., Overland, J.E., Reedy-Maschner, K.L., Royer, T.C., Schwing, F.B., Wang, J.X.L, and Winship, A.J. 2007. Bottom-up forcing and the decline of Steller sea lions (*Eumetopias jubatus*) in Alaska: assessing the ocean climate hypothesis. Fish. Oceanogr. **16**: 46–67.

Tynan, C.T., and DeMaster, D.P. 1997. Observations and predictions of Arctic climatic change: potential effects on marine mammals. Arctic. **50:** 308-322.

Usher, P.J. 2000. Traditional ecological knowledge in environmental assessment and management. Arctic. **53**: 183-193.

Wallace, S.D., and Lavigne, D.M. 1992. A review of stomach contents of harp seals (*Phoca groenlandica*) from the northwest Atlantic. Rep. No. 92-03, International Marine Mammal Association, Guelph, Ontario.

Weimerskirch, H., Inchausti, P., Guinet, C., and Barbraud, C. 2003. Trends in bird and seal populations as indicators of a system shift in the southern ocean. Antarc. Sci. **15**: 249-256.

APPENDIX A: SUMMARY OF INTERVIEWS

Location	No. of interviews
Gander	6
Campbellton	4
Exploits	2
St. Lewis, St. Mary's, St. Charles	5
Paradise, White Bear, Eagle, North, Sandhill	7
Pinware, Forteau	5
Torrent	4
Lomand	4
Humber	2
Harry's, SW Brook, Flat Bay, Fischells, Robinson's, M. Barachois, Crabbes, Highlands	10
Conne	2
Rocky, Collinet	3
NE and NW Brook Trepassey	3
Total	57

APPENDIX B: LOCAL ECOLOGICAL KNOWLEDGE QUESTIONS

A. Marine Mammal Component

*mark information on maps

1. Can you identify the species of seals(s) in your area? Show identification guide

2. During what months do you observe them?

3. How often do you see them during this time? (each time period they observe them)

    a. never

    b. rare (< once per week)

    c. occasional (once or twice per week)

    d. common (observed every day during this time period)

4. When you observe them, are they single animals, groups of 3-5, groups of 5-15, more than 15?

5. When is the peak time of sighting (month, season)?

6. Do you get the impression their general abundance and distribution has changed in your area over the past

    a. 5 years? Present

    b. During the 1990's? recent past

    c. Prior to 1990? historic

7. Do you notice a particular migration route they take in and out of the estuary or river in your area? Has this route changed from the past?

8. Are they moving into the area earlier, or staying later? Ask for specific dates

    a. When did you first notice a change?

If harbour and grey seals are observed in the area:

9. Can you locate seal haul-out sites on the map?
10. Is this spot new or has it been used in the past?
11. How often do you observe them?
12. How many do you observe? Average number
13. Is there a peak time they are present?
14. Do you know when pups are born?
15. Can you locate on the map where you observed seals in the water on a seasonal basis?
16. Have they always been here?
17. Are they rare, occasional, or common?

B. Capelin and Herring

*mark information on map

18. Do you have knowledge of spawning beaches or offshore spawning sites in your area?
19. When does spawning take place at each site?
20. How long does spawning last?
    a. One day/ Few days/ 1 week/ Several weeks
21. How often are capelin/herring observed at these beaches?
    a. Rarely/ Every year/ Every other year/ Most years
22. Are there predators in the vicinity during spawning?
23. Have you seen these predators feeding on capelin/herring?
24. Have you noticed a change in spawning times over the last
    a. 5 years?
    b. during the 1990's?

c. prior to 1990?

25. Have you noticed a change in the seasonal abundance and/or distribution during this time frame?

26. When did you first notice an increase/decrease in abundance?

27. When did you first notice a change in migration patterns?

C. Salmon

*mark salmon migrations on map, areas where they have fished commercially (set nets or traps).

28. Are you familiar with salmon run times?

29. When are the current run times (range and peaks) of salmon in the river?

    a. Smolt

    b. Kelt

    c. Adult

30. Do you get the impression that salmon run times have changed during:

    a. last 5 years?

    b. the 1990's?

    c. prior to 1990?

31. Have you noticed a change in the abundance and/or distribution of salmon in the river or estuary?

    a. Smolt

    b. Kelt

    c. Adult

32. When did you first notice this change?

33. Are you familiar with the present status of the population?

34. Do you ever observed salmon with scars in the river or estuary?

35. Do you have observations of seals feeding on salmon in the estuary or river?

36. What seal species do you see?

37. Location- have you always observed seals during salmon runs? If not, when did they start frequenting the area?

    a. Do you think this is an important location for predation?

    b. Timing

    c. Frequency of occurrence

    d. Is this feeding involving a large group or a single animal?

    e. What is the nature of the interaction?

38. Have you observed other predators feeding on salmon in the river or estuary?

    a. Timing

    b. Frequency of occurrence

    c. Is this feeding involving a large group or a single animal?

D. Local Ice Conditions

*mark ice extent on map with yearly/decadal changes next to line.
*mark areas of open water.

39. Can you locate on the map areas of current extent of ice freeze up within the river and estuary?

40. What time of year does freeze-up occur?

41. When are the breakup times?

42. Is the ice freeze up, break up, and extent different each year or have you noticed a trend over the past:

    a. 5 years?

    b. During the 1990's?

    c. Prior to 1990?

43. Can you locate any areas that remain open all year-round?

44. What is the nature of the open water?

45. Have you noticed any changes in ice condition in:

    a. last 5 years?

    b. the 1990's?

    c. Prior to 1990?

46. Has land fast ice or pack ice stayed the same or is it more/less variable then in previous years?

47. Have you noticed a change in the relationship between land fast ice and pack ice during:

    a. last 5 years?

    b. 1900's?

    c. prior to 1990?

48. At what point are seals able to gain access to river mouth and/or estuary?

49. Do you believe that there are other climate related issues that are influencing salmon?
    a. Examples could include low water levels, warmer water, new construction on the river, pollution, etc.?

*ask questions relating to other fish that are seen in the area when seals are present during salmon runs and at other times of the year (Arctic cod, rock cod, smelt etc.).

*ask respondents if they wish to add anything that you haven't already touched on.

APPENDIX C: DEMOGRAPHIC QUESTIONS

Background

1. Age
2. Current location:
    a. Years at residence:
    b. Previous residence/Years:

3. Occupation:
4. Father's occupation:
5. Mother's occupation:
6. Did/does your spouse help with fishing?
7. No. of children:
8. Do any of your children fish for a living? Yes______ No______

    a. If yes, how many? _________

Fishing Experience

9. How many generations has your family been in the fishery? 1 2 3 >3

10. Always based in this community? Yes________ No_________ If no, explain:
    ____

11. Age when you started fishing ______________

12. What fishery were you employed with before the moratorium?
    Cod salmon capelin herring other

13. What fishery were you employed with after the moratorium, or did you stop fishing?

14. Sectors in which you have fished?
    Inshore/longliner/65-foot/large dragger

15. General areas where you have fished in your career?

16. Total years fishing? ___________________

17. If not a commercial fisherman, are you a recreational salmon anlger?

    a. What rivers do you fish on?

    b. How many years have you been fishing on these rivers?

c. How many days do you fish per angling season?

Sealing Experience

18. How many generations has your family been involved with the commercial seal hunt? ________________

19. Always based in this community? Yes______ No__________ If no, explain____

20. General areas where you hunt? ________________

21. Age when you started sealing _________________

22. Last season as licensed sealer _____________

23. Total years sealing ______________

DFO Researcher/Fisheries Officer/Counting fence worker

24. How man years have you been employed as a departmental researcher? ______________

    a. In which section? _____________________________________

    b. What rivers do you work on? ___________________________

    c. How many years have you worked on them? ___________________

25. How many years have you been a fisheries officer? _______________

26. What part of the Province? ____________ Always this part? Yes____ No______ Explain:

27. How many years have you worked the counting fence?_____________________________

28. Have you worked on other counting fences around the Province?