Seabirds as indicators of change in the eastern Canadian Arctic

by

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BSc, University of British Columbia, 2003
BEd, University of British Columbia, 2004

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Abstract

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Climate change has a wide range of effects with the potential to cause broad changes in marine ecosystems. The Arctic is predicted to be one of the most highly impacted areas, with average temperatures increasing by as much as 3-5°C. As temperatures rise, Arctic sea ice is disappearing earlier each year, leading to changes in the ocean environment. Thick-billed murres (*Uria lomvia*) (TBMU) and northern fulmars (*Fulmarus glacialis*) were collected at colonies in the eastern Canadian Arctic to examine potential changes in Arctic marine food webs over the past three decades.

Otoliths and invertebrates were examined in the murre stomachs, and the results compared to data collected from the same colonies in the 1970s and 1980s. Few changes were observed in the diets of the high Arctic thick-billed murres where the ice-associated Arctic cod continue to dominant the prey items found in the thick-billed murres. Significant changes were found in birds sampled from the low and mid-Arctic. In the low Arctic, Arctic cod has declined across all of the colonies sampled, while the capelin, which is a sub-Arctic species, has become dominant in the diets of the birds in the low Arctic and a common prey species mid-Arctic where it was not observed in the diet of

TBMUs previously, indicating a northward expansion of this species. The proportion of invertebrate species has changed in some zones and mysids now constitute a large proportion of the murre diet in the low and mid Arctic where hyperid and gammarid amphipods used to be the main invertebrate consumed.

The birds can be used as samplers of the marine environment, and as integrators of the environmental changes that are occurring, but prey were not the only items found in the stomachs on birds sampled. Marine plastic debris was also found in the stomach contents of both murres and fulmars from every colony sampled indicating plastic ingestion is becoming a widespread problem for Arctic seabirds. Plastics found in northern fulmars indicate that marine plastic debris is increasing in the Arctic Archipelago, and monitoring of this recognized indicator species of plastic debris will allow long term monitoring of man-made debris in Canada's north. Plastic debris was also found in thick-billed murres from all of the colonies sampled. Although murres are not useful indicators of general marine plastic debris the presence of plastics at all the colonies sampled indicate that plastics are not just a problem for surface feeding seabirds, but a threat to a number of species found in Canadian waters.

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Chapter 1 Introduction

Changing environmental conditions are altering marine systems in many areas of the globe. Monitoring these changes is of the utmost importance due to the economic and environmental value of marine ecosystems worldwide. Where limited resources are available to study large and remote areas the use of an indicator species is a useful tool, allowing researchers to focus their energy on specific concerns and questions. In general indicator species need to be conspicuous and accessible to facilitate study and monitoring, and their biology must be tightly connected to the study system in order to link changes in indicator biology to larger overall patterns (Cairns 1987). As top predators in the marine environment many seabirds meet these requirements, and have been suggested as useful indicators of change (Cairns 1987, Furness & Camphuysen 1997, Piatt et al. 2007).

In chapters 2 to 4 I present two areas of study where seabirds are useful as indicators of changes in marine systems in the eastern Canadian Arctic. Chapter 2 focuses on how the diet of the thick-billed murre (TBMU) (*Uria Lomvia*) can be used as an indicator of change in the marine fauna by comparing the prey items consumed by the birds at four colonies in the summers of 2007, 2008 and 2009 with previous studies completed in the same areas in the 1970s and 80s. Changes in prey items, both fish and invertebrates, utilized by the TBMU are observed in three Arctic zones where TBMU have been sampled repeatedly.

Chapters 3 and 4 focus on two seabird species as indicators of marine plastic debris in Canada's northern waters. Chapter 3 examines plastic ingestion by northern fulmars (*Fulmarus glacialis*), a procellariiform, in the Canadian Arctic Archipelago. This chapter was published in Marine Pollution Bulletin in 2009 as a collaboration with Tony

Gaston and Mark Mallory (Provencher et al. 2009). Northern fulmars are used in the North Sea as indicators of marine debris and can be used in the same way as an indicator of plastic debris in the Canadian Arctic where no other marine debris monitoring or assessment work is currently done.

Chapter 4 examines plastic ingestion by thick-billed murres in the eastern Canadian Arctic. Although this species is not commonly known to ingest plastic debris birds from all of the colonies sampled were found to have plastics in their gastro-intestinal tracts, indicating that plastic debris may not only affect surface eating birds but also diving seabirds. This chapter has been submitted to Marine Pollution Bulletin for consideration in collaboration with Tony Gaston, Mark Mallory, Patrick O'Hara and Grant Gilchrist and is under review as of March 2010.

The thesis concludes with a short discussion of the validity and use of seabirds as indicators of changing marine systems in the Hudson Bay and the Arctic Archipelago. All of the field work completed for this thesis was done in collaboration with Environment Canada, funded primarily by NSERC and the Canadian International Polar Year 2007-2009 office. Scientific studies and collections were conducted in accordance with guidelines from the Canadian Council on Animal Care, and under appropriate territorial and federal research permits.

Chapter 2 Dietary changes in thick-billed murres

2.1 Introduction

2.1.1 Changing conditions

Changing climatic conditions have been shown to greatly influence biological systems worldwide (Cao et al. 1998, Kitaysky & Golubova 2000, Edwards & Richardson 2004, Guinotte et al. 2006). The poles are predicted to be particularly affected by changing atmospheric and oceanographic conditions with widespread impacts in sea ice and snow cover (IPCC 2007). Long term monitoring programs in the Canadian Arctic have observed changing environmental conditions over the last several decades, with an overall warming trend in temperatures and a continuing reduction in summer sea ice cover observed each year (Lindsay & Zhang 2005, Barber et al. 2008). As these changes in sea ice occur, Arctic ecosystems will be fundamentally altered.

The Arctic is a large region with up to 14 million km^2 of sea ice each winter (Spindler 1990). This area is covered with ice and snow for much of the year with summer temperatures rising above freezing for only two months of the year. As sea ice dominates the marine environment in the Arctic a number of sympagic, or ice-associated, marine species have adapted to live in this icy environment (Horner et al. 1992). Sea ice creates a complex surface that includes micro-habitats within the ice, on the surface of the ice and a sub-ice area where a number of these organisms occur (Horner et al. 1992). Some of the more abundant and widespread sympagic Arctic species include the Arctic cod (*Boreogadus saida*), a schooling fish known to overwinter under the ice, and the amphipods *Themisto libellula* and *Onisimus* spp. (Horner et al. 1992), which are important prey items for seabirds and marine mammals (Finley et al. 1990, Gaston & Bradstreet 1993).

In the Arctic Archipelago, where ice and snow dominate the landscape for most of the year, changes in environmental conditions that affect sea ice have direct impacts on local species. Changes in these icy habitats can affect numerous organisms from the primary producers living on the ice, to the top level predators that feed in and around the ice (Gaston et al. 2005a,b, Stempniewicz et al. 2007). Tracking these changes in ecosystems over time can help us understand ecosystem dynamics, and predict how changing climatic conditions may affect organisms.

2.1.2 Seabirds as indicators

Seabirds have long been suggested as an ideal species for tracking changes in marine environments (Cairns 1987, Furness & Camphuysen 1997, Iverson et al. 2007). To be an effective indicator species in any environment an organism must satisfy several key requirements such as being highly visible, easy to enumerate and having a life history that is tightly coupled with the environment in question (Piatt et al. 2007). Seabirds generally fulfill all of these requirements and have been identified as useful indicators of ecosystems (Furness & Camphuysen 1997). During foraging bouts many seabirds cover large areas of the marine environment and, as a result, integrate information from a much larger area than the immediate vicinity of the colony (Elliott et al. 2009). Seabirds are top predators throughout the world's oceans, and utilize the marine environment for much of their lives, only returning to land to lay eggs and rear their chicks during the breeding season (Gaston 2004).

Consequently, seabirds are often used as indicators of shifts in the marine environment. Several species of seabirds have been used to study changes in fish populations such as capelin (*Mallotus villosus*) in the North Atlantic (Davoren & Montevecchi 2003) and sandlance in the North Sea (Wanless et al. 2007). Seabirds are also useful indicators of change in remote areas where extensive monitoring may be costly and logistically challenging. In the eastern Canadian Arctic the thick-billed murre (*Uria lomvia*) (TBMU) has been shown to be an ideal indicator species for tracking changes in the marine environment since long term monitoring programs were first established by Environment Canada in the 1970s and 80s (Gaston et al. 2005a, Mallory et al. 2006, Gaston et al. 2009).

2.1.3 Thick-billed murre dietary studies in the eastern Canadian Arctic

The TBMU is a pursuit-diving marine predator that feeds on fish and an assortment of invertebrates. Starting in the mid 1970s, a number of studies examined the diet of adult thick-billed murres throughout the Arctic Archipelago (Bradstreet 1980, Gaston & Nettleship 1981, Gaston & Noble 1985). Murres were collected in the low, mid and high Arctic oceanographic zones (Salomonsen 1965) during the breeding season while actively feeding, and their stomach contents were examined to investigate diets of these birds at a number of different colonies (Gaston & Bradstreet 1993).

The diets of TBMUs in the high Arctic colonies were dominated by Arctic Cod (*Boreogadus saida*), a cold water schooling fish which lay their eggs on the under-surface of ice (Craig et al. 1982, Graham & Hop 1995), and gammarid amphipods, while TBMUs at low Arctic colonies were found to prey upon a more diverse range of fish and invertebrates, with mysids and hyperid amphipods constituting the major components of the diet (Gaston & Bradstreet 1993). TBMUs from the Minarets, a colony in the mid Arctic, showed dietary patterns intermediate to the colonies in the low and high Arctic zones (Salomonsen 1965, Gaston & Bradstreet 1993). These pioneer dietary studies have served as the baseline for understanding adult murre diets in the Canadian Arctic.

In the years since these initial studies, several long-term monitoring programs have been established by Environment Canada to study TBMUs in the Canadian Arctic. The colony at Coats Island, Nunavut (62°57′N, 82°00'W) has been a major centre of research with a number of monitoring programs established in the 1980s, including feeding watches observing the prey items brought to the chicks by the parents. During the 1980s and into the 1990s the majority of the items delivered to the chicks was Arctic Cod, with other less common species making up the balance of the items (Gaston et al. 2003). However, beginning in the 1990s capelin (*M. villosus*), a sub-Arctic schooling fish species became a more common prey in the nestling diet, and by 1997 capelin was the most common prey item delivered to the Coats Island colony, a pattern which has persisted to date (Gaston et al. 2010, Fig 2.1). The TBMUs at Digges Sound, one of the largest TBMU colonies in Canada, where nestling diet has been intermittently monitored since the 1980s, also shows a similar switch in the nestling diet from one dominated by Arctic cod, to one consisting almost exclusively on capelin over the last 20 years (AJ Gaston pers.comm.). This switch in prey species is consistent at these two low Arctic TBMU colonies separated by more than 200 km suggests that changes in marine prey species in the low Arctic are not local phenomena but are occurring at a large scale across the northern Hudson Bay region. This decrease in Arctic cod in TBMU nestling

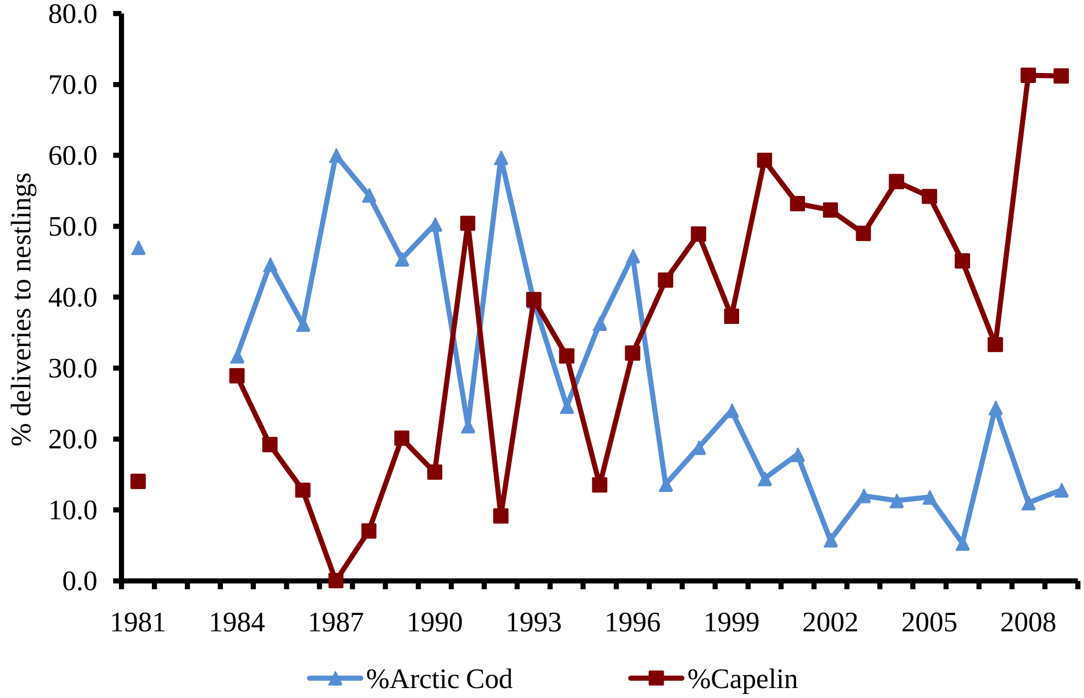


Figure 2.1. Nestling diet of TBMU at Coats Island from 1981 to 2009 (Gaston et al. 2010).

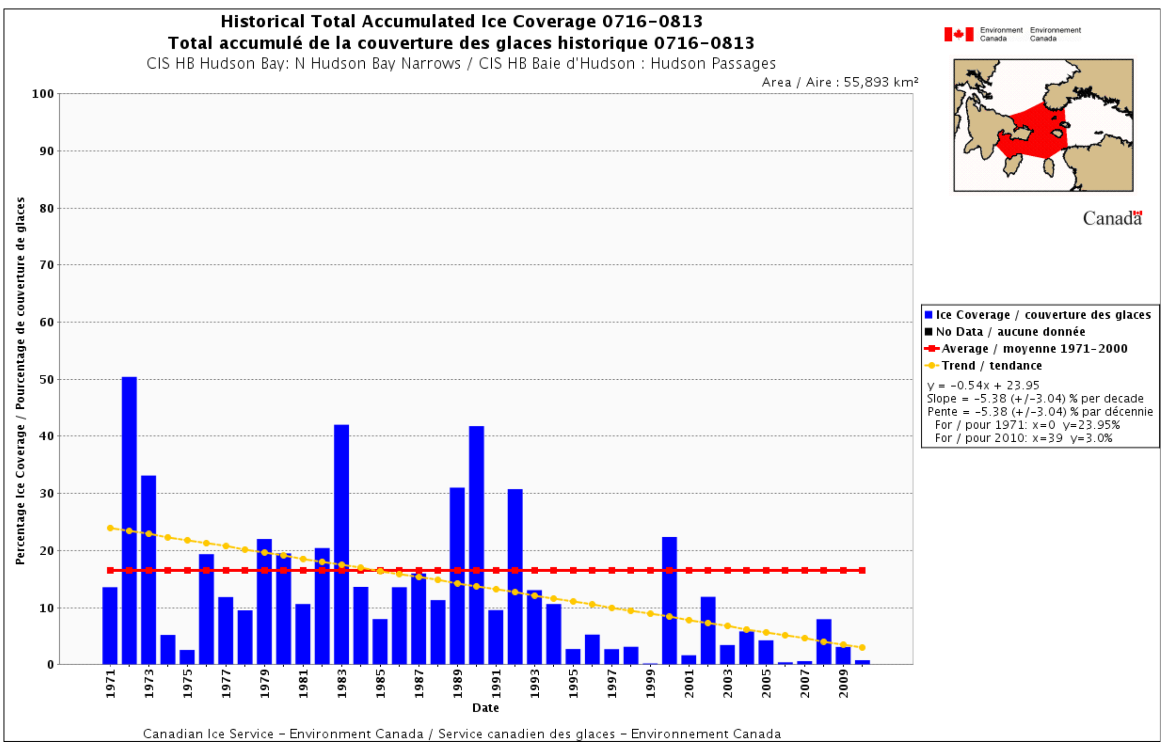


Figure 2.2. Total accumulated ice cover in Northern Hudson Bay, including the waters around Coats Island (Canadian Sea Ice Service, 2010).

diets corresponds directly with a decrease in summer sea ice in northern Hudson Bay (Barber et al. 2008) (See Fig 2.2).

Capelin, although common among seabird prey items in more sub-Arctic regions (Davoren & Montevecchi 2003), was not common in the diet of TBMUs in the Canadian Arctic until the late 1990s. The feeding watch data from Coats Island and Digges Sound is an important resource in examining changing prey species used by TBMU change over time, but this change has only been studied at two colonies, and documents changes only in nestling diet. As environmental conditions throughout most of the eastern Canadian Arctic have changed over the last several decades a re-assessment of the thick-billed murre diet throughout the area was needed to examine potential widespread changes in adult murre diets. To do this feeding thick-billed murres were collected for stomach content analysis in the same areas as collections from in the 1970s and 80s to compare current diets with the historical samples.

The recent stomach content results were compared with available historical collections (Table 2.1) at the same sites to assess changes in the diet of thick-billed murres as an indication of changes in Arctic marine ecosystems. All predators, including seabirds, make decisions regarding prey species as the assemblage of prey species available shift and change over time. In any given area seabirds will continue to select items from the available prey species, thus we can use seabirds to study how prey species in a given area potentially change over time. The assumption is made that the criteria that seabirds must eat remains unchanged, and the birds are forced to exploit new options in a changing environment. Using these criteria, changes in diet reflect changes in the surrounding ecosystems, and not simply changes in bird behaviour, especially when changes are observed consistently across colonies and geographic regions.

As sea ice conditions are a major factor structuring marine ecosystems in the Arctic, the diets of the birds are expected to change most in the low Arctic where dramatic changes have occurred in summer sea ice cover over the last few decades. In the high Arctic, where sea ice continues to be present for much of the summer, TBMU diets are expect to show little to no change. As previous studies have shown the Minarets in the mid-Arctic to be a colony with dietary patterns intermediate to the high and the low zones (Gaston & Bradstreet 1993) diets of the TBMUs are expected to change in some way, but not as much as observed in the low Arctic.

Stomach content analysis has limitations as a dietary study tool, as it is biased toward prey items with hard parts or which have been recently ingested (Piatt et al. 2007). The retention time of prey item will vary with species, and with stomach contents will most likely reflect species preyed upon in the last 6-24 hours (Brekke & Gabrielsen 1994, Hawkins et al. 1997). As a result, direct dietary comparisons are made between murres collected using the same methods in order to assess potential changes in the marine fauna available to birds feeding around the colonies where sampling took place between the 1970s and 80s, and the recent sampling in 2007-09.

Table 2.1. Historic and current collections of thick-billed murres for dietary studies in the eastern Canadian Arctic.

Colony	Oceanographic zone	Collection Date	Year	N
Akpatok Island	Low	early August	1983	19
Akpatok Island	Low	August 19	2008	31
Coats Island	Low	July 27	2007	25
Digges Sound	Low	June - August	1980/81/82	199
Digges Sound	Low	August 11	2008	30
Digges Sound	Low	July 28, August 1	2009	62
the Minarets	Mid	late July	1985	17
the Minarets	Mid	August 5	2007	30
the Minarets	Mid	August 3	2008	20
PLI	High	June - August	1976/77	96
PLI	High	June 5, August 9	2008	50

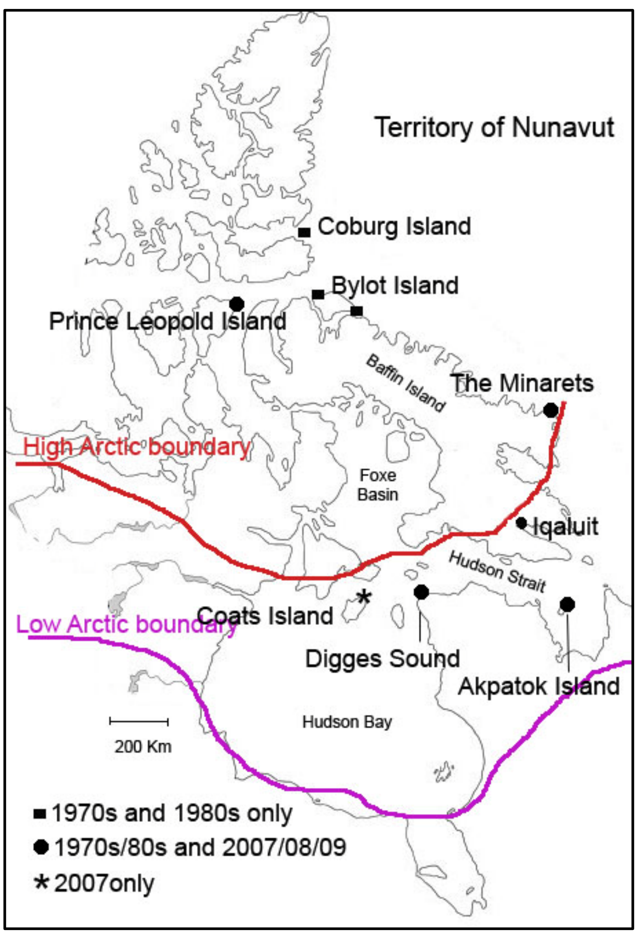


Figure 2.3. Location of thick-billed murre collections in the eastern Canadian Arctic in the 1970s and 80s, and in 2007/08/09.

2.2 Methods

2.2.1 Field collections

Adult TBMUs were collected throughout the Eastern Canadian Arctic to assess how the diet may have changed since Bradstreet (1980), and Gaston and Noble (1985) last assessed the diets of thick-billed murres in the 1970s and 80s. Birds were shot with a 12 gauge shotgun using steel shot from a small boat in areas where birds were seen to be actively feeding. During the 2007/08/09 breeding seasons murres were collected from Akpotak Island (60˚25′N, 68°08′W), Coats Island (62°57′N, 82°00'W), Digges Sound (62˚33′N, 77°35′W), the Minarets (66˚56’N, 61˚46’W) and Prince Leopold Island (PLI) (74°02′N, 90°00′W) (Fig 2.3). Table 2.1 summarizes the collection site details of the birds collected in 2007/08/09.

When possible, 70% isopropyl alcohol was inserted into the esophagus of each bird to aid in the immediate preservation of stomach contents. Each bird was bagged and labelled. After the collections were complete, carcasses were kept in a cool place for up to 24 hrs, and then frozen. Frozen carcasses were transported to Iqaluit, Nunavut for further processing.

2.2.2 Laboratory

Bird carcasses were kept frozen until dissections were completed by students from the Arctic College in Iqaluit under the supervision of an Environment Canada technician, as part of their wildlife training and education. The entire gastro-intestinal tract (GIT), from esophagus to cloaca was removed from each bird, labelled, and shipped to the University of Victoria for further examination. Other tissues were sampled and inventoried into the National Specimen Bank at the National Wildlife Research Centre for use in other studies.

At the University of Victoria each GIT was cut longitudinally with a scissors along the entire length of the tract. Once the GIT was opened, the stomach was flushed with ethanol to remove all the items, taking care to remove all items in the folds of the stomach. All items from the GIT were placed in 95% ethanol and labelled with the identification number of the bird from which it came.

Each stomach contents sample was sorted through with prey item remains divided into smaller vials and categorized as otoliths, zooplankton, fish pieces, miscellaneous hard parts and soft parts, using a MZ6 Leica binocular microscope. Any remaining fluid and contents from the original bottles were put back into the original bottles and retained for reference or future examination.

2.2.3 Prey identification and enumeration

Otoliths were viewed, measured and photographed using a MZ6 Leica microscope, a scope-mounted video camera and image analysis software. All otoliths were identified using Campana (2004) and voucher otoliths were sent to Otolith Technologies laboratory in Stillwater, Nova Scotia for confirmation of identification. Otoliths from a single stomach were examined together with partial and fragment pieces aligned to see if matches could be made. Where otolith pieces fitted together they were considered to be a whole otolith and measured. The length and width at its widest point were measured for all whole and partial otoliths. Fragments were mostly the tips of otoliths and were much less numerous and were not measured, but were considered in estimating the number of otoliths present in the sample. Many small unidentifiable otoliths were also found. The width of each was measured but no specific identifications were possible due to their small size and the relatively featureless shape. These small otoliths were considered as evidence of fish in the diet, but were not used in fish counts where other otoliths were present.

Otoliths were measured to the nearest 0.01mm. If two otoliths from a given stomach were within 0.2mm they were considered to originate from the same fish (Bradstreet 1980). The minimum number of fish in each stomach was calculated as the number of matched otolith pairs plus the number of unmatched individual otoliths. All data are presented as a function of paired otoliths in each stomach.

Body lengths of the consumed fish were estimated from the otoliths found in the stomachs. For a paired set of otoliths the average of their lengths was used to estimate body length and for single otoliths the one length was used to estimate fish body length. Body length conversion for Arctic cod *(Boreogadus saida)* from otoliths lengths followed Bradstreet (1980). Body length conversions from otoliths for capelin *(Mallotus villosus)* and sandlance *(Ammodytes* sp.*)* followed the formulae given by Lidster (1994).

All invertebrates, whole and partial, were sorted initially into general groups based on overall morphology: specific identification was done at a later date. A number of invertebrate guides were used to identify specific taxonomic groups (Holmquist 1959, Tencati & Leung 1970, Keast & Lawrence 1990, Squires 1990, Klekowski & Weslawski 1991, Vinogradov et al. 1996, Audzijonyte & Vainola 2007).

Intact zooplankton individuals, as well as heads and tails for each taxa were enumerated and identified to the lowest taxonomic level possible based on the condition of the specimen. Abundance estimates were based on the sum of whole zooplankton and the maximum number of heads or tails, giving a minimum number for each stomach.

Polycheate jaws and squid beaks were found among the prey remains in several stomachs. For polycheates jaws, all jaws were identified as left or right, and the number of individual polycheates present was determined from the maximum number of either right or left jaws. To estimate the number of squid in each stomach the maximum number of beak hoods or rostrums was used. Among squid beaks, only one set of jaws was intact surrounded by tissue. All the other jaws were found loose in the stomach, associated with numerous other prey items. Squid body mass was calculated following Clarke (1962) using the length of the ventral hood to estimate body mass in grams.

2.2.4 Analysis

For our analysis we grouped birds by colony and did not differentiate between sexes since Gaston and Bradstreet (1993) found no differences in diet between the sexes and the period of breeding cycle (incubation versus chick-rearing), when year and colony was controlled for.

In the colony-wide analysis of the prey items sampled by the murres, which examines potential changes in the diets over the two sampling periods and between zones, we included the colonies of Akpatok Island (low Arctic), Digges Sound (low Arctic), the Minarets (mid Arctic) and PLI (high Arctic). For this analysis the two low Arctic colonies of Akpatok Island and Digges Sound were grouped together, with the Minarets in the mid-Arctic zone and PLI in the high Arctic zone. Coats Island was not included in this analysis as there is no historical sample available from this colony.

To test for differences in the proportion of fish and invertebrates consumed by the birds as a function of the total prey items, all sites with historic and current stomachs were examined using a generalized linear mixed model (GLIMMIX) in SAS 9.2. A repeated design (within each bird) was used with time period (historic sampling versus recent sampling), zone (low, mid and high Arctic), prey category (fish versus invertebrate) as fixed effects, year of sampling nested within time period and colony nested within zones as random effects, and the invertebrate and fish counts as the response variables. The model was fit with a negative binomial distribution with a log-link function, which allows for the over-dispersion in the data. The effects of time period, zone and prey category, and their interactions were tested to examine how these factors contributed to any changes in the diet.

To further explore how fish and invertebrates varied between time periods among zones, orthogonal a priori tests were used by testing the differences between Least-Squares Means (LS-Means) to account for the unbalanced sampling of murres between years and colonies.   This sub-test explores how any significant variation found in the fish and invertebrates in the diet was partitioned out.

Differences between the time periods in specific fish and zooplankton assemblages was also explored using only birds that contained at least one fish or invertebrate, respectively. For this taxon-specific modeling only those colonies with robust historic and current collections were used, this includes Digges Sound, the Minarets and PLI. The identifiable items in the GIT of the murres collected at Akpatok Island collected in the 2008 were highly degraded making identification of fish and invertebrates difficult. As a result, this colony was not included in fish and invertebrate specific modeling.

The invertebrate diet data was highly zero-inflated and over-dispersed making the use of a GLIMMIX prohibitive, so a generalized linear model (GLM) was used to test for differences in between zones and time periods. As a result, the model results for the changes in fish and invertebrate contributions to the diet are slightly less robust results than produced in our GLIMMIX, but nevertheless the results are valid for the questions addressed. The random effects of year and colony, fixed effects of time period and zone and invertebrate counts as the response variables were used. These tests were not a repeated design as each subgroup of invertebrates was analyzed separately. All invertebrates were tested using the grouping of copepods, hyperid amphipods, gammarid amphipods, mysids, squid and other (annelids, cumaceans, euphasids, decapods). If a significant interaction was found between time period and zone in the proportion of invertebrate in the diet LS-Means were tested using orthogonal a priori tests.

A GLIMMIX with a negative binomial distribution and a log link function was used to test for differences in fish type (Arctic cod, capelin, sandlance and sculpin) among the years and colonies sampled with year nested within time period, and colony nested within zone as random effects, time period and zone as fixed effects and prey counts as the response variable. Similar to the invertebrate group analysis, these tests were not a repeated design as each fish subgroup was analyzed separately. Due to a non-convergence with the capelin data using a GLIMMIX when all the zones were included, which highly increased the degree of over dispersion and zero-inflatedness, a GLM was used to detect any change in the capelin in the diet of just the low and mid Arctic birds. The GLM used year and colony as random effects of, time period and zone as fixed effects and the capelin counts as the response variables. This allowed differences in capelin to be tested at colonies where it has been observed, without the zero data set from the high Arctic where we know there has been no change in this species in the diet.

Prey diversity at each site was examined using species richness accumulation curves, which allow for standardized comparison of diversity across collections that differ in size (Gotelli & Colwell 2001). This approach is normally used to describe species richness in a sample, but here it is used to examine prey species diversity in murre diets at three colonies with historic and current diet sampling: Digges Sound, the Minarets and PLI. All birds with at least one item identified in their GIT were grouped together by colony and sampling period, and all prey abundance data for each bird was put into a matrix in ECOSIM (Gotelli & Entsminger 2009). The prey item data were analyzed in ECOSIM using the birds as sampling units to create a sample-based curve, with a rarefaction curve as the randomization algorithm and species richness as the prey species diversity index. Prey diversity curves were then produced in EXCEL in order to compare the species richness with 95% confidence levels.

2.3 Results

A total of 248 GITs from 2007/08/09 were compared with 331 GIT sampled in the 1970s and 80s (Gaston & Nettleship 1981, Gaston & Noble 1985, Gaston & Bradstreet 1993). In the 2007/08/09 sample a total of 12,350 prey items were identified in the GIT collected (Table 2.2), with fish accounting for 21% of the prey items found in the stomach and a variety of invertebrates making up the rest. Most GITs contained multiple prey items with only a few stomachs containing no trace of any prey items (Akpatok Island – 1, Coats Island – 4, Digges Sounds – 5, the Minarets – 1 and PLI – 3) (Table 2.2).

Fish were detected in the diet primarily by the presence of otoliths, but a number of birds were found to have fish bones in their stomachs but no otoliths were found. The stomachs from Akpatok Island had the highest number with 33% identified with fish remains but containing no otoliths. Less than 5% of the birds identified to consume fish contained only bones at the other colonies with 0% at Coats Island to 4.2% at the Minarets.

Most stomachs contained intact or partial pieces of crustaceans that were identified to family or genus, but there were a number of stomachs that contained only unidentifiable crustacean pieces. 72% of stomachs from Akpatok Island contained only crustacean pieces that could not be identified to a lower taxonomic level, while the rest of the colonies had less than 5% of the stomachs with such degraded crustacea remains.

The prey item results are presented as percent totals, which describe the proportion of prey items as a function of the total amount of prey items found in the birds at a given colony. Percent occurrence is also given, which describes the proportion of birds which contained at least one of the prey items as a function of the total number of birds collected during the sampling.

Table 2.2. Percent occurrence of all prey items in thick-billed murre stomachs collected in the Canadian Arctic in the 1970s, 80s and in 2007/08/09.

	Akpatok Island		Coats Island	Digges Sound		the Minarets		PLI		Total number of all items in all stomachs
Year sampled	1983	2008	2007	1980/81/82	2008/09	1985	2007/08	1976/77	2008	
No. of GIT	19	31	25	199	92	17	50	96	50	579
All Prey items	1167	452	1604	8950	5557	768	4407	889	330	24124
All invertebrates	94.74	80.65	48.00	84.92	92.39	100.00	74.00	15.63	28.00	19343
Hyperid	94.74	12.90	16.00	59.30	54.35	0.00	14.00	7.29	20.00	4969
Gammarid	10.53	6.45	0.00	13.07	6.52	82.35	46.00	9.38	8.00	1397
Mysid	78.95	9.68	0.00	33.67	57.61	58.82	48.00	2.08	0.00	11346
Cumacea	0.00	0.00	12.00	0.00	0.00	47.06	10.00	0.00	0.00	150
Crustacea sp.	0.00	33.00	0.00	13.57	0.00	0.00	5.40	0.00	0.00	732
Copepod	36.84	3.23	4.00	15.58	35.87	5.88	2.00	0.00	0.00	59
Euphasiid	0.00	0.00	12.00	1.51	26.09	0.00	0.00	0.00	0.00	60
Nereis sp.	36.84	38.71	12.00	35.68	53.26	0.00	0.00	0.00	0.00	496
Gonatus fabricii	26.32	6.45	4.00	11.06	4.35	11.76	14.00	1.04	2.00	81
Decapod	26.32	0.00	0.00	2.51	3.26	11.76	8.00	0.00	0.00	29
All fish	94.74	54.84	68.00	78.39	67.39	58.82	92.00	62.50	88.00	4781
Boreogadus saida	10.53	0.00	12.00	27.14	3.26	17.65	62.00	59.38	78.00	949
Malleotus villosus	0.00	0.00	40.00	18.09	39.13	0.00	28.00	0.00	0.00	271
***Ammodytes* spp.**	0.00	3.23	4.00	36.68	30.43	0.00	8.00	0.00	0.00	1017
Cottidae sp.	0.00	9.68	0.00	16.08	5.43	23.53	20.00	0.00	2.00	169
Gymnocanthus tricuspis	0.00	0.00	0.00	2.01	2.08	0.00	2.00	0.00	0.00	18
***Triglops* spp.**	0.00	0.00	0.00	0.00	0.00	5.88	0.00	2.08	0.00	3
Leptoclinus maculatus	0.00	0.00	0.00	0.00	1.09	0.00	0.00	0.00	0.00	1
***Liparis* spp.**	0.00	0.00	0.00	26.63	4.35	0.00	0.00	0.00	0.00	347
Reinhardtius hippoglossoide	47.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25
All unknown fish species	73.68	61.29	24.00	48.74	33.70	35.29	40.00	2.08	38.00	1981
All taxon	100.00	96.77	84.00	93.47	94.57	100.00	98.00	66.67	94.00	24124

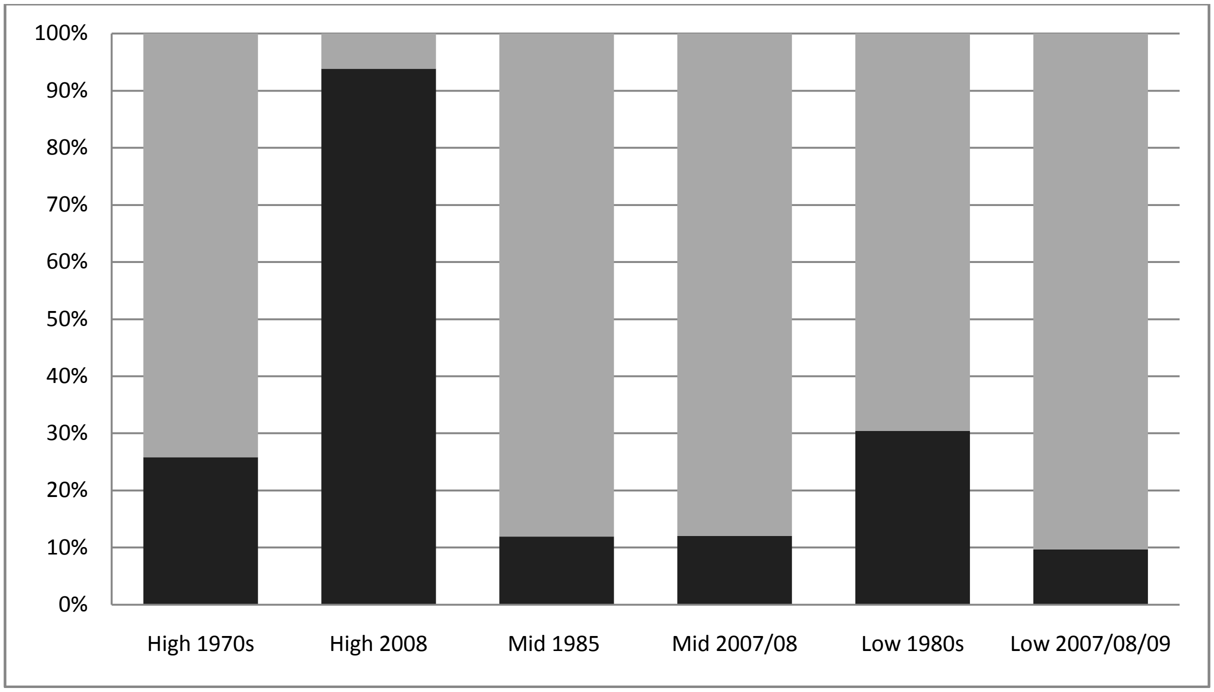


Figure 2.4. Percent total of fish and invertebrates in thick-billed murre diets sampled over two different time periods. The proportion of fish is represented by the dark bars and invertebrates are represented by the gray bars.

2.3.1 Proportion of fish and invertebrates in the diets

The proportion of fish and invertebrates in the diet of the murres appears to have changed in both the high and the low Arctic over the two time periods sampled, with very little change occurring in the mid-Arctic (Fig 2.4). When this change in diet was tested for examining how the interaction of prey category, time period and zone contributed to this change a significant interaction was found, ($F_{4,1032}$ = 3.88, p = 0.004) (Table 2.3 contains all model results) indicating that the amount of fish and invertebrates in the diet of the murres does differ between time periods and among zones tested.

When the proportion of fish and invertebrates in the diet was examined further in each zone, the high Arctic birds showed no change in the amount of fish in their diet (t=1.58, p=0.12), but did show a decrease in the amount of invertebrates in the diet (t=2.05, p=0.04). This indicates that the change in how fish and invertebrates contribute to the diet is due to an overall decrease in invertebrates, not an increase in fish. During the same time period the opposite trend was observed in the low Arctic, with a significant decrease in fish consumed as a percent of the total prey items (t=2.42, p=0.02), but no change was found in the invertebrates in the diet (t=0.70, p=0.48). This indicates that the apparent change in how invertebrates and fish contribute to the diet in the low Arctic is driven by a decrease in fish, not an increase in invertebrates. In the mid-Arctic no change in the proportion of fish or invertebrates was detected in the diet between the two time periods (t = 0.34, p=0.73 and t = 0.42 p=0.63).

Table 2.3. Modeling statistics for all prey items with sufficient data for model convergence. [1]Generalized linear mixed model results and [2]generalized linear model results are given. High, mid and low zones LS Mean values are given for those taxa that had significant time period and zone interactions.

Taxa	Time period - zone interaction		High			Mid			Low		
	Test value	p-value	Estimate	Test value	p-value	Estimate	Test value	p-value	Estimate	Test value	p-value
Prey category[1]	3.88	0.004									
Fish[1]			1.3	1.58	0.12	0.39	0.34	0.73	-1.22	-2.42	0.02
Invertebrate[1]			-2.4	-2.05	0.04	0.6	0.42	0.68	0.43	0.78	0.48
FISH											
Arctic cod[1]	6.90	0.00	0.96	1.11	0.27	2.71	1.95	0.05	-2.94	-2.90	0.004
Capelin[2]	3.35	0.07	/	/	/	24.52	6216.1	<0.0001	1.17	14.36	0.0002
Sculpins[1]	0.24	0.79	/	/	/	/	/	/	/	/	/
INVERTEBRATES											
Copepods[2]	0.97	0.62	/	/	/	/	/	/	/	/	/
Gammarids[2]	7.00	0.03	-5.30	20.16	<0.0001	-1.20	2.22	0.14	-2.86	20.64	<0.0001
Hyperids[2]	16.20	0.0003	-1.19	2.47	0.12	21.39	6748.30	<0.0001	-1.20	21.20	<0.0001
Mysids[2]	7.88	0.02	-18.48	0.00	1.00	2.18	5.94	0.01	0.95	2.25	0.02
Squid[2]	3.50	0.17	/	/	/	/	/	/	/	/	/
Other Invertebrates[2]	36.69	<0.0001	-21.20	0.00	1.00	-1.95	18.74	<0.0001	0.98	21.33	<0.0001

2.3.2 Diet composition

The composition of fish species in the diets of the murres also showed changes in the different oceanographic zones (Fig. 2.5). Sculpins did not show a significant change in the diet of the murres across all the zones examined between both time periods sampled (F = 0.24, p=0.79). Any changes in sandlance (*Ammodytes* spp.) could not be modeled due to limited data which prevented testing this change over the two sampling periods.

Arctic cod was found to differ significantly between time periods and zones (t = 6.9, p = 0.01). Arctic cod continued to be the main fish prey species in the high Arctic and showed no significant change in the diet (t = 1.1, p = 0.27). In the mid-Arctic Arctic cod significantly increased (t = 1.95, p = 0.05) in the diet of the birds sampled between the 1985 and the 2007/08 bird samples from l5% of the fish consumed to over 70%. While in the low Arctic the opposite trend was observed with the birds showing a significant decrease in Arctic cod in the diet from 30% of the fish species consumed down to less than 5% (t = -2.90, p = 0.004).

During the same time period capelin increased in the diet of the low and mid-Arctic birds diet from 0% to 12% of the indentified fish and from 8% to almost 30%, respectively. This change in capelin in the diets as an interaction between zone and time period was found to be slightly non-significant (χ-chi = 3.35, p= 0.07), but there was a significant change in capelin in the diet of the birds when just time was examined (χ-chi = 12.05, p= 0.0005) indicating that although change is occurring at the colonies in different ways, overall capelin is increasing in the diet of the murres in the low and mid Arctic

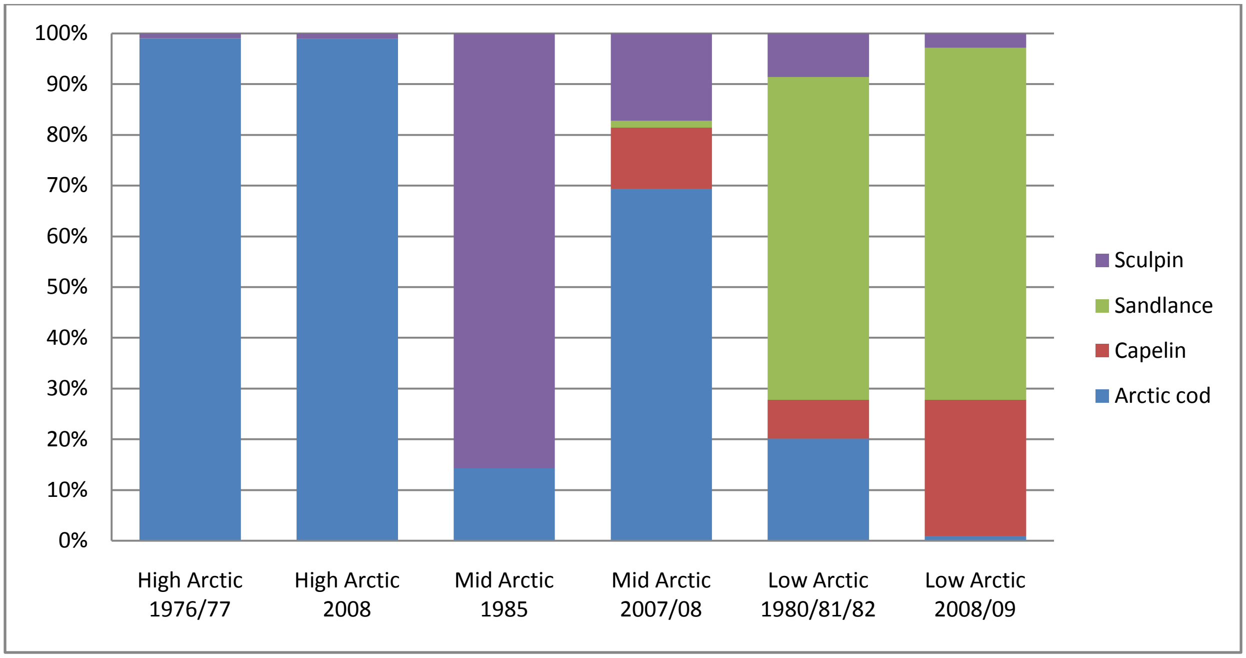


Figure 2.5. Percent total of identified fish species in adult thick-billed murre stomach contents collected in the low, mid and high Arctic in two different sampling periods.

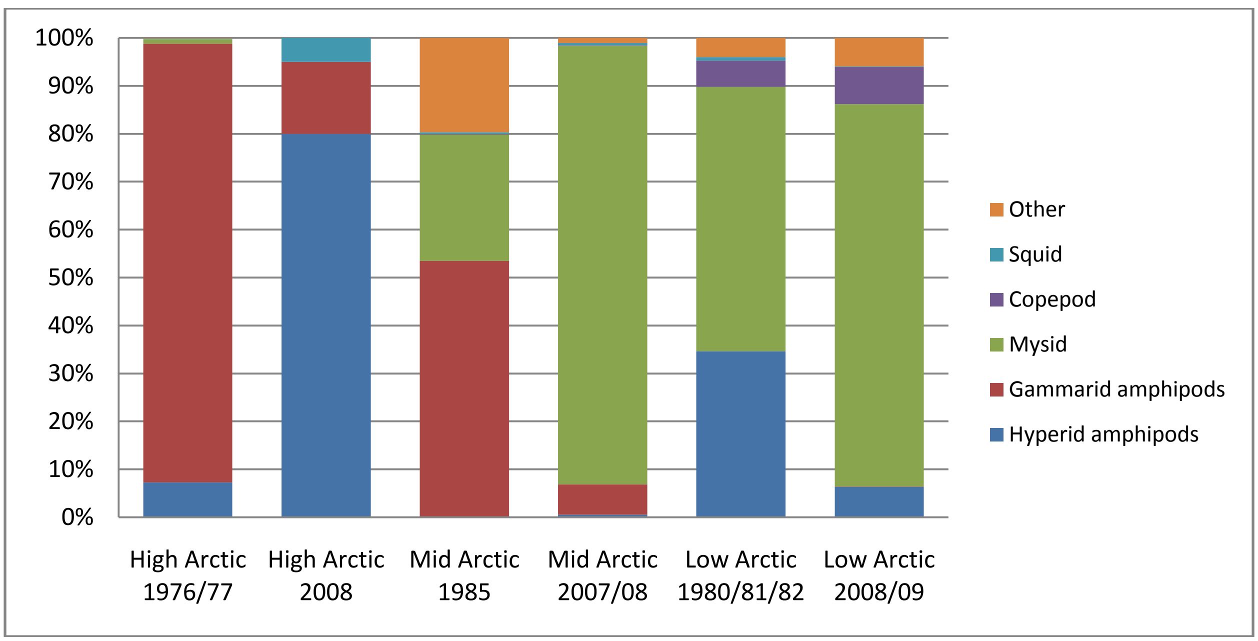


Figure 2.6. Percent total of invertebrate prey items in thick-billed murres stomach contents collected at the low, mid and high Arctic colonies in two sampling time periods.

Table 2.4. Summary of changes in prey items sampled in the 1970s/80s and in 2007/08/09 murre diets. ↑ denotes an increase, ↓ denotes a decrease, = denotes no change and na represents a prey species that is not applicable.

	High	Mid	Low
Fish	=	=	↓
Inverts	↓	=	=
Arctic cod	=	↑	↓
Capelin	=	↑	↑
Mysids	=	↑	↑
Hyperid amphipods	=	↑	↓
Gammarid amphipods	↓	=	↓
Other invertebrates	=	↓	↑

significantly between the two sampling periods. All trends in dietary changes are summarized in Table 2.4.

The composition of invertebrates in the diet also changes over time (Fig 2.6). No difference was found in the diets of the murres sampled over time in the three oceanographic zones for either copepods or squid. Gammarid amphipods in the TBMU diets did decrease at all zones significantly over time (χ-chi = 7.00, p= 0.03). In the high Arctic, where gammarid amphipods were a major invertebrate prey item previously, there was a large significant decrease in the recent samples (χ-chi = 20.16, p= < 0.0001). This decrease in gammarids is consistent in both our early and late season sampling at PLI. In the mid-Arctic, gammarid amphipods also formed a large part of the diet in the historic sample and have declined in the recent birds, but the decrease was found to be non-significant (χ-chi = 2.22, p= 0.13). In the low Arctic, gammarids continue to contribute a small portion of the invertebrates utilized by the birds, but a significant decrease in gammarids in the diets was also found (χ-chi = 20.16, p= < 0.0001).

The amount of hyperid amphipods in the diets of the murres also changes across time at all three colonies tested (χ = 12.05, p= 0.0003). In the high Arctic, hyperid amphipods continue to contribute to the diet of the birds in very small numbers, with only 14 hyperids found in 50 birds from PLI in 2008 (χ = 2.47, p= 0.12). In the mid-Arctic hyperids also contribute a very small amount to the birds diet but did show a significant increase (χ-chi = 6748.3, p= < 0.0001) (Fig 2.6). In contrast, in the low Arctic, where hyperid amphipods were a relatively large portion of the murres diet, there was a significantly large decrease in the diets (χ-chi = 21.20, p= < 0.0001), with hyperid amphipods representing over 30% of the invertebrates in the 1980s and in 2008/09 now accounting for less than 8% of the invertebrates consumed.

Mysids were also found to change differently by zone and time period. In the high Arctic, mysids showed no change in the diet (χ-chi = 0.00, p= 0.99). In both the mid-Arctic and the low Arctic zones mysids composed a large portion of the diet, more than 80% of the invertebrates consumed, and showed a significant increase between the older samples from the 1980s and the recent sampling (mid: χ-chi = 4.97, p= 0.01, low: χ-chi = 5.25, p= 0.02).

Other prey items found in small numbers include annelids, cumaceans, decapods and euphasiids. Grouped together these other prey items were found to account for less than 10% of all the invertebrate prey items, except at the Minarets in 1985 where more than 20% of the invertebrates were from these four groups. Independently, changes in these groups could not be modeled due to limited numbers in the samples so they were grouped together in order to test any changes that may have occurred. This other invertebrate group shows no change in the High Arctic (χ-chi = 0.00, p= 0.99). In the mid-Arctic, where these other prey items previously accounted for 20% of the invertebrate prey items found in the stomachs in 1985, there was a significant decrease in the 2007/08 sample to less than 3% (χ-chi = 18.74, p= <0.0001). In the low Arctic these four other prey species contribute less than 10% of the invertebrate prey items in both time periods sampled, but a significant increase was found in the recent sampling as compared to the 1980s sample (χ-chi = 21.33, p= <0.0001). A complete inventory of all the invertebrates found in the murre stomachs from both time periods identified to the lowest taxonomic level possible can be found in Appendix 1.

2.3.3 Prey Diversity

Combing all periods and colonies, 78 taxa were identified in the murres stomachs over the two sampling time periods; 62 in the earlier period and 39 in the recent period. The highest prey diversity in the historic sample occurred at Digges Sound (39 species) and the highest diversity in the 2007/08/09 sampling period was at the Minarets (29 species) in the mid-Arctic. The lowest prey item diversity for both time periods was found at PLI (Table 2.5).

At the three sites where robust stomach contents data were available (Digges Sound, the Minarets and PLI) the prey species diversity suggests TBMUs sampled recently are feeding on a less diverse selection of prey items than during the earlier sampling periods (Table 2.5, Fig 2.7). For birds sampled at the Minarets and PLI the prey diversity levels from the most recent sampling period fell outside of the 95% confidence intervals for the earlier prey diversity indicating this decrease is significant. The recent sample from Digges Sound also showed a decrease in prey diversity but the diversity level from the 2008/09 sample is just within the lower 95% confidence margin, indicating the diversity level between the sampling periods are not significantly different.

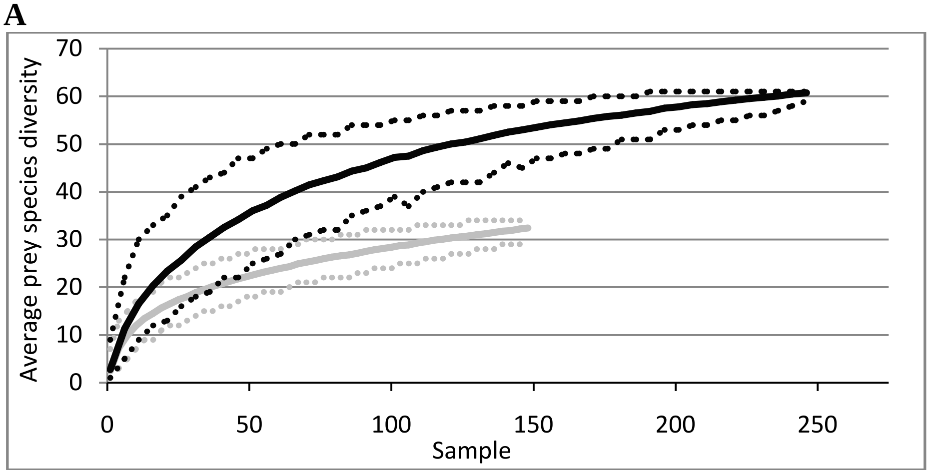
Overall, when the combined 1970s/80s stomach content prey is compared to the 2007/08/09 stomach content prey data the more recent murre diet shows a significant decrease in prey item diversity, with recent sampling showing a maximum diversity level of 34 taxa, a value outside of the 95% confidence interval of the historic sample of 61 (Fig 2.7A).

Prey diversity across of all the birds prey items between the two time periods was also examined excluding the gammarid amphipods. A significant decline in this

Table 2.5. Maximum prey species diversity found in the TBMU diets at colonies sampled in the eastern Canadian Arctic over two sampling periods.

Colony	Zone	Year	Maximum Average richness
Akpatok	Low	1983	15
Akpatok	Low	2008	14
Coats Island	Low	2007	16
Digges Sound	Low	1980s	39
Digges Sound	Low	2008/09	24
the Minarets	Mid	1985	29
the Minarets	Mid	2007/08	27
PLI	High	1976/77	17
PLI	High	2008	5

A



B

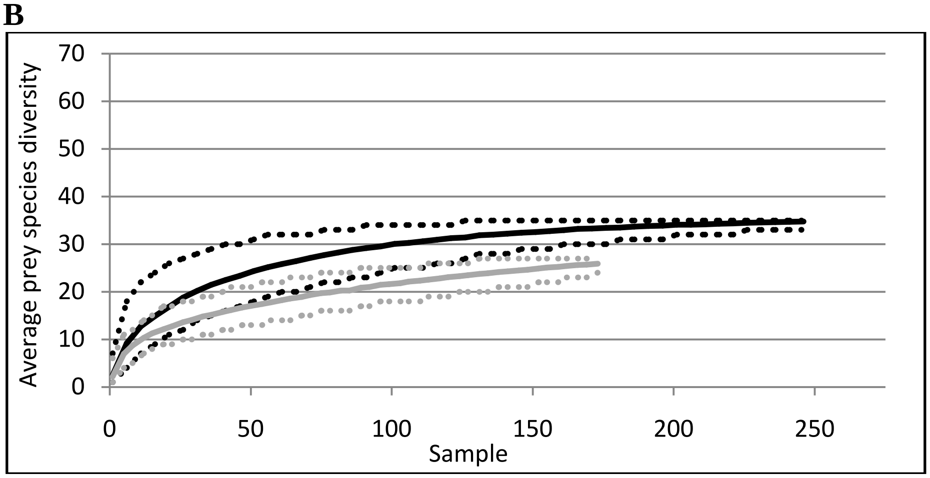


Figure 2.7. Prey diversity curve for prey items from thick-billed murres sampled in the 1970s and 1980s (black line) and 2007/08/09 (gray line) from Digges Sound, the Minarets and PLI. Dashed lines represent the upper and lower 95% confidence intervals. A – all prey species included, B – prey diversity with gammarid amphipods excluded.

diverse prey group was detected across the time periods and zones examined. Prey diversity was tested without the gammarid amphipods to examine if the significant decline in prey diversity was being driven by this overall decline in gammarids. Although the prey item diversity without gammarids amphipods was lower in both time periods and more similar in value, recent birds were still found to have significantly less diverse prey items overall. The historic birds had an average prey diversity of 35, while the recent sampling had an average of 26 species, with the end point of the recent curve falling outside of the 95% confidence intervals of the historic diversity curve. (Fig 2.7B).

2.4 Discussion

Changes in the diets of the murres is evident at all of the colony and zones sampled during the 1970s and 80s, and then again in 2007/08/09. In general, these changes are difficult to interpret as we have only two collection points separated by 30 years in some cases, with little information from the intervening time. Keeping this in mind the patterns and trends observed are examined and some general conclusions can be drawn from comparing the historic and current prey data as sampled by the murres in the eastern Canadian Arctic.

2.4.1 Changes in the High Arctic

Arctic cod still dominates the diet of the high Arctic TBMUs, where the main prey items show little change. This meets our predictions of little change in the diets of the high Arctic murres where sea ice conditions are variable but ice still dominates the seascape during the murres breeding season (Canadian Sea Ice Service, 2010).

More hyperid amphipods are present in the recent diet as compared with the historic diet, but this apparent 8-fold increase in hyperid amphipods should be taken cautiously as the number of invertebrates collected at PLI are few, and this large increase is attributed to a total of 18 hyperid individuals in only a few stomachs. The decrease of gammarid amphipods across all the colonies examined is most apparent in the high Arctic, where gammarid amphipods used to be found in large numbers in many stomachs and now occur in only a very few stomachs sampled. The overall impact of this decrease in gammarid amphipods is that the high Arctic TBMU diet is now comprised of more fish than previously observed.

TBMU at the high Arctic colonies have always been known to consume large amounts of fish (Gaston & Bradstreet 1993), but this trend is becoming more extreme with the decrease in invertebrates in the diet. This may make the birds of PLI more sensitive to changes in Arctic cod populations in the area, as cod contributes the large majority of the biomass consumed by the birds. This high dependence of the murres on Arctic cod also has implications for studies concerned with trophic level. If the birds at PLI are consistently eating significantly less invertebrates, as our results suggest, this may lead to the TBMUs feeding at a higher trophic level. This potentially increasing trend in trophic level has implications on how studies examining changes in contaminants are interpreted (Braune et al. 2001) and will need to be taken into consideration in future TBMU contaminant studies.

The TBMUs of PLI live at the northern end of the species range where harsh environmental conditions can lead to complete reproductive failure when ice and snow cover the birds (Gaston & Nettleship 1981). In the future, as summer conditions continue to warm, less sea ice and earlier breakup may mean more ice edge, and hence more Arctic cod to feed on for the murres of PLI. Although we do not see an increase in Arctic cod in our current assessment of high Arctic murre diet, this may be a dietary pattern signalling changes in the marine environment in the future. Further monitoring the of diets of TBMU will allow potential changes in Arctic cod availability in the high Arctic to be tracked as sea ice patterns continue to change.

2.4.2 Changes in the Mid-Arctic

No change was detected in the proportion of fish and invertebrates in the diets of the TBMU at the Minarets indicating TBMU are currently feeding at a similar trophic level in 2007/08 as they were in 1985. Although there are no changes observed in the proportion of fish and invertebrates in the diet there were several changes in the composition of the prey items.

The appearance of capelin in the diet of the murres sampled in 2007/08 suggests this sub-Arctic fish species is becoming an important prey item in Arctic waters. Capelin is an abundant seabird prey item in the North Atlantic coast of Canada, but before the mid 1990s was only observed as a secondary prey item for murres in the low Arctic (Gaston & Bradstreet 1993, Gaston et al. 2007). The appearance of capelin in the diet at the Minarets in both 2007 and 2008 suggest this fish is now consistently available to TBMU at this northern location during the breeding season, and are in great enough numbers to be a common prey item for mid-Arctic seabirds.

With the occurrence of capelin as a common prey item at the Minarets a northward shift in the range of this fish over the last several decades can be illustrated using seabird diet. Tuck and Squires (1955) observed capelin at Canada's most southern

TBMU colony, Akpatok Island, as a relatively common prey item in the 1950s. Throughout the 1980s and the 1990s capelin increased as a prey item in northern Hudson Bay (Gaston et al. 2007), an area within the range of this species (Liem and Scott 1966, Hart 1973, Scott & Scott 1988). While capelin was present in low Arctic prior to the 1980s no range maps for capelin extended north to the Arctic Archipelago, and no records existed for capelin on Baffin Island (Tee-van 1948, Liem and Scott 1966, Hart 1973, Scott & Scott 1988). Now, in 2007/08, capelin has become a common prey item in the mid-Arctic, which lies outside of the range described previously (Liem & Scott 1966), but within more recent range descriptions (Muss et al. 1999). The increasing use of capelin by seabirds in the low Arctic, and the appearance of this prey species in the mid Arctic over the last 50 years reflects a range expansion for this capelin, but also indicates a northward expansion of an important prey item in northern waters throughout the breeding season. This expansion may have positive impacts on seabird populations in some areas as capelin is a known keystone seabird prey item in other areas (Davoren & Montevecchi 2003).

Sandlance is another species that appears in the diets of the murres in the 2007/2008 collections that was not present previously. Sandlance is a schooling pelagic species that is an important prey item for seabirds in sub-Arctic areas in both eastern and western Canada, but is not recognized as an Arctic species (Sorensen et al.). This species has also increased in the diets of the birds in the low Arctic, but not to the same degree as capelin has (Gaston et al. 2010). Since the late 1990s sandlance has been observed in large numbers in some years, but is mostly a secondary prey item for the TBMUs. The appearance of sandlance in the diet of the murres at the Minarets in the mid-Arctic is potentially another example of a species expanding its range north as the open water period each summer increases and may potentially have influence other seabirds species beyond the TBMU(Gaston & Woo 2008).

Arctic cod also increased in the diets of the mid-Arctic birds in the recent sampling, indicating that this ice-associated species is still present in large numbers within the foraging range of the adult murres throughout the summer months. Although atmospheric and oceanographic changes may be taking place in this area, the presence of Arctic cod in the TMBUs diet suggest that sea ice is still an important feature in the mid-Arctic, as was seen in during the murre collections in both 1985 and in 2007.

The sea ice conditions in the mid-Arctic also show a decline over the last few decades, similar to those observed in the low Arctic (Fig 2.8). The occurrence of capelin in addition to the mainstay of Arctic cod in the diet of the seabirds in the mid-Arctic is similar to dietary patterns in the low Arctic in the 1980s and 90s. This recent change in the mid-Arctic marine environment while changes similar changes have been occurring in low Arctic areas for more than a decade and a half may represent a tipping point scenario in the marine ecosystem. The idea that systems may be able to undergo shifting conditions without significant change until a threshold is reached is a common idea among climate change biology (Winton 2006, Hoegh-Guldberg et al. 2007, Russill 2008). The marine ecosystem of the mid-Arctic may now be at its sea ice decline tipping point, with sympagic species still present but with sub-Arctic species such as capelin and sandlance now also becoming regular components of those species used by seabirds.

2.4.3 Changes in the Low Arctic

The most amount of change was found in the birds collected at the Arctic colonies. Unfortunately, the samples collected at Akpatok Island were not useful in our analysis due to severe degradation of the prey items in the stomachs. The number of identifiable items in the GIT of the murres collected at Akpatok Island was lower in the 2008 sample as compared with the 1985 sample. This may indicate that Akpatok TBMUs are consuming fewer items than in the past, but since many otoliths were degraded beyond recognition, and no difference in the masses of the birds was found (Provencher unpubl. data) it is more likely that the birds sampled in 2008 may not have been actively feeding, leading to less prey items that were more degraded in their GIT. Although the Akpatok Island birds provide useful general diet information, the stomach contents are have limited use for specific prey comparison. In order to get a better idea of the prey items now being sampled at Akpatok further sampling must be done on actively feeding birds.

At Digges Sound, in the low Arctic, a decrease in the proportion of fish in the diet of the birds was found, with no change in the proportion of invertebrates. The large decrease in Arctic cod in the diet of these TBMU is likely a main cause of this overall decline in fish prey items. Although the low Arctic birds appear to have switched to a diet dominated by capelin, the diet of the birds at Digges Sound suggest that although capelin and sandlance are abundant the overall consumption of fish has decreased. Although gram for gram cod and capelin have similar energy content a single averaged sized Arctic cod provides more energy (as measured in kJ) than either capelin or sandlance (Elliott & Gaston 2008). As a result, as cod decreases and capelin increase in the diet, one would predict the consumption of fish to increase in order to make up the

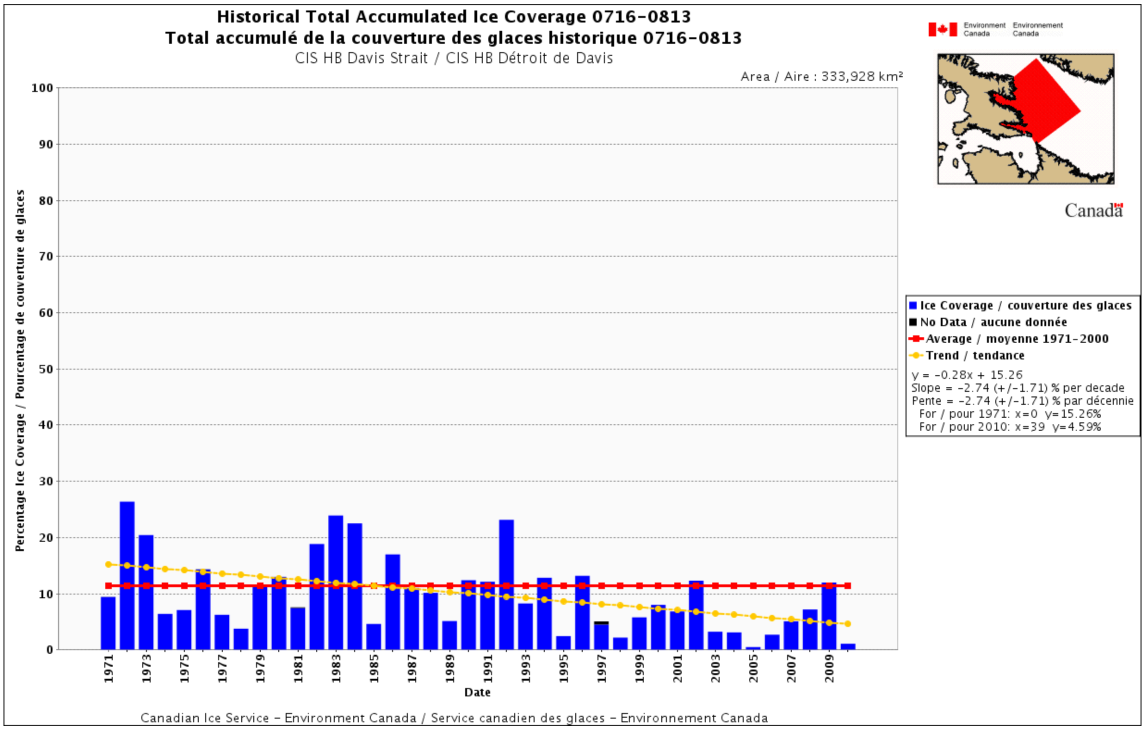


Figure 2.8. Total accumulated sea ice coverage in Davis Strait, around the mid-Arctic TBMU colony at the Minarets since 1971.

shortfall in calories, not decrease as we observe in the low Arctic TBMU. Unfortunately, we do not have the historic body masses of the birds sampled for dietary analysis in order to compare bird mass between the sampling periods, but there is no evidence that the birds at Digges Sound have declined in body condition or productivity (Gaston, pers. comm.). This suggests that although the amount of fish consumed is less, the murres are not adversely affected by this change in diet. As the increase in fish at PLI has trophic level implications for the birds, as does a decrease in fish in the low Arctic. Less fish in the diet suggests that TBMU are at a lower trophic level than those sampled in the 1980s.

Overall, the decrease in fish in the low zone murre diets is due in part to less Arctic cod being consumed, which corresponds to the increase in the open water season in northern Hudson Bay (Canadian Sea Ice Service, 2010). This supports the findings of the ongoing nestling diet data collected at Coats Island dating back to 1981 showing the decline of Arctic cod consumed by TBMU (Gaston et al. 2010). While Arctic cod was seen to decrease at Digges Sound, Arctic cod as a prey item has undergone the most change at the southern colony of Akpatok Island. Initially, Tuck and Squires (1955) found Arctic cod to be a major food item in 1954. It was later found in a small number of birds in 1983 (Gaston & Bradstreet 1993) and in 2008 Arctic cod was absent from the diet, illustrating a complete absence of this species from the current diet of TBMUs at this colony. The absence of Arctic cod from the diet represents a large change in the Akpatok TBMUs diet over the last 50 years. Akpatok Island is the most southern TBMU colony sampled in this study and demonstrates how prey species of these birds has changed over the last half century along with changing sea ice conditions of which the Arctic cod are dependent. Although little study has occurred at the Akpatok colony to detect changes in TBMU productivity, the body condition of the birds has not changed between the 1983 and 2008 sampling periods (Provencher, unpubl. data) suggesting TBMUs are capable of exploiting a number of prey species in order to meet their energetic demands. TBMUs seem capable of adapting to variation in prey availability, even with the complete disappearance of a major prey species such as Arctic cod.

While fish have decreased in the diet of the low Arctic birds, invertebrates have remained the same, with a decrease in hyperid amphipods and a large increase in mysids. As most of the hyperid amphipods are *Themisto libellula*, a species known to inhabit cold-water masses (Horner et al. 1992) this decline suggests a decrease in a second cold-water species from the waters around Digges Sound. The decline in both Arctic cod and *T. libellula* in the low Arctic illustrates a shift from cold-water fauna in the area to a suite of organisms found in warmer waters. This change in prey species indicates changing oceanographic conditions as summer sea ice declines the in the low Arctic (Barber et al. 2008).

The decline in both Arctic cod and *T. libellula* not only signals changes in the fauna in low Arctic waters, it may also have energetic ramifications for local seabirds. Since the average sized mysid represents less kilojoules gained from average sized individuals of the two cold-water species that have declined abundance in the low Arctic (Kaiser et al. 1992, Elliott & Gaston 2008), a switch to a diet based more on mysids may have implications for foraging patterns and energy trade-offs during foraging bouts.

The mysid species now found in abundance in the low Arctic is primarily *Mysis oculata*, a species found in the Arctic but also common in the North Atlantic, and usually found in the upper 15 meters of the water column. This species appears abundant in the low Arctic as demonstrated by several TBMU having hundreds of mysids in their stomachs.

The increase of mysids in both the low and mid-Arctic TBMU may also represent a shift in important prey species used by the birds in these regions. In the mid-Arctic the large increase in mysids and decrease in gammarid amphipods, and the simultaneous appearance of capelin suggests the prey items available at this site may be changing in a fundamental way. The Minarets, sitting on the oceanographic boundary of the low and high Arctic zones (Salomonsen 1965) still represents an intermediate in the dietary patterns observed in the low and high Arctic, but our sampling suggests that as climatic conditions change the prey items available to the Minarets TBMUs may be becoming more and more like those found in the low Arctic, and less similar to those prey found in the high Arctic.

2.4.4 Changes in prey species

A number of species predated upon by TBMU in the Arctic are known to be associated with icy conditions (Horner et al. 1992, Gaston & Bradstreet 1993). The most abundant ice-associated species in the diet of the TBMUs is the Arctic cod, which is declining in the diets of low Arctic birds across all the colonies sampled over the last three decades. This decline has been observed as a gradual change in the feeding watches at Coats Island since the mid 1980s, but this trend is now confirmed in adult TBMU diets across a number of low Arctic colonies. As in the feeding watch data from

Coats Island, the TBMUs sampled are indicating that major changes in the abundance of Arctic cod are occurring in the low Arctic.

The decrease in Arctic cod in the diet with the simultaneous increase in capelin could also be interpreted as a switch in prey choice by the TBMU to capelin, rather than a decrease in cod numbers. Arctic cod are known to depend on sea ice, but little is known about specific details relating to their life history and no information is available regarding Arctic cod abundance in Hudson Bay over during the length of our study. Arctic cod could still be present in the waters of Hudson Bay, but the murres might have chosen to exploit capelin instead. This is unlikely to be the case as long term monitoring from Coats Island suggests that during the period when the parents switched from feeding their young Arctic cod to capelin the nestlings had reduced growth rates indicating this change in prey was not beneficial to the young (Gaston et al. 2005a). It was only after several years of foraging on capelin did the birds appear to adjust to this new dominate prey item, and since the early 2000s nestling growth has returned to previous levels observed when they were fed a diet of mostly Arctic cod (Gaston pers. comm.).

The range of capelin includes northern Hudson Bay, but this fish was not the main prey item of TBMU until relatively recently. This relatively rapid change in TBMU diet from cod to capelin suggests that capelin were already present in the waters around the colonies but were not utilized by the birds. The nestling growth monitoring from Coats Island suggests that capelin were available to the birds, but may have required different foraging strategies to access this prey item. It is also follows that as Arctic cod decrease in the area capelin will increase as the predation pressure from cod decreases, which may have also contributed to the success of the birds of finding this schooling species in easily in years where cod is present in only low numbers.

Onisimus spp. is also a known ice-associated species (Horner et al. 1992) consumed by the TBMU in the eastern Canadian Arctic (Gaston & Bradstreet 1993). Several species of *Onisimus* were present in the diet of the birds from the Minarets in both time periods sampled, suggesting that this summer sea ice continues to influence the organisms found in this area during the murre breeding season.

At PLI the birds sampled in the 1976/77 had a large number of *Onisimus* gammarid amphipods, but more recently the birds sampled contained no *Onisimus* amphipods. Sea ice is still present at PLI during the breeding season so the lack of *Onisimus* amphipods in the recent PLI diet is probably not due to a lack of suitable ice habitat but to some other factor. Since a number of the birds were collected while feeding among the ice flow a decline in icy habitat is not likely the cause of this gammarid use decline. In order to assess whether a decline in gammarid amphipods is occurring in Arctic waters oceanographic sampling following historic methods is needed. The diet of the TBMU indicates that gammarid amphipods are in decline but no other evidence has been found to support this.

Based on the increase of capelin at low Arctic sites over the last decade, an increase in novel North Atlantic invertebrates was expected to be observed in the diet of the low Arctic birds. On the contrary, the birds sampled contained no invertebrate species that are known to be more southern in their distribution, indicating that a general northward movement of invertebrate species has not occurred as was observed in fish species. As invertebrates are often zooplankton and depend on the currents for movement, while fish being nekton can move of their own accord, a northward movement of zooplankton is likely to take more time than needed for fish species. Continued monitoring of seabird diet in the low Arctic is necessary to test this hypothesis. Introduction of southern zooplankton species may be more likely at the Minarets than in the low Arctic due to the direction of prevailing currents (Rekacewicz & Bournay 1998).

Overall, the prediction that most dietary change would occur in the low Arctic birds was confirmed, with observed changes in how hyperid amphipods, mysids, gammarid amphipods, capelin and Arctic cod all contribute to the TBMU diet. The diet of the TBMU in the high Arctic also met our prediction with little change in the species consumed and only gammarid amphipods significantly changing in the TBMUs diet. The Minarets, located at the boundary between the high and low Arctic, continues to be a site with dietary patterns intermediate to the low and high Arctic, but shows significant changes in prey items used by the TBMU signalling that major shifts in the marine fauna in this area are occurring as changing climatic conditions continue to affect this area.

2.4.5 Changes in prey diversity

When prey diversity at all the colonies sampled in the 1970s and 80s was compared with the 2007/08/09 samples an overall decrease in prey diversity was found. A total of 78 prey species were found in the TBMU from the two time periods, with fish species contributing a total of 10 species, with a maximum of six species out of a total 39 taxa found at Digges Sound in 1980/81/82. Thus, more than 80% of the prey species diversity measure is contributed by invertebrate species. Therefore, large differences in prey species diversity are mostly due to differences in invertebrate species diversity.

When gammarid amphipods were excluded from the prey species diversity a significant difference in the prey diversity between the two sampling periods was still detected. This indicates that although gammarid amphipods contribute greatly to the prey species diversity, changes in this group of invertebrates is not the only factor in the decrease in prey species diversity over time.

Several factors could be contributing to lower prey species diversity in the stomach contents of the murres sampled in 2008/09. First, lack of species specific identification for the 2007/08/09 GIT could have contributed to a decrease in species richness at all of the sites. This is unlikely to be the cause for a decrease in prey diversity at all the colonies examined, however, as the numbers of the invertebrates at the colonies have also decreased, not just the identifiable specimens. Second, the diversity of prey items in the stomachs could have decreased due to differences in the storage of the birds between the time of death and freezing. This is also unlikely the cause for the decreased prey diversity in the stomachs, as birds were collected in the same way as they were previously and similar time lapses would have occurred at similar sampling locations due to local conditions and amenities.

Third, the birds may be feeding on a less diverse marine biota. If the birds are sampling the current marine fauna in a similar way to which they were sampling the marine system during the previous collections, then the prey diversity in the waters surrounding the colonies appears to be decreasing across all of our sites. A decrease in prey diversity could be the result of limited food resources resulting in a decreased diversity, or by an increase in variable environmental conditions limiting the overall diversity of prey species, or a number of other factors that influence invertebrate populations in northern waters.

The highest prey diversity previously was found at Digges Sound in the early 1980s whereas it is now found at the Minarets. The Minarets, located on the east coast of Baffin Island, may be more vulnerable to a large number of species moving northward on the currents as North Atlantic species may follow the currents north up the east coast of Baffin Island (Rekacewicz & Bournay 1998), past the colony allowing the birds to sample a large variety of marine fauna. As oceanographic conditions change, coastlines and micro-habitats around TBMU colonies may play an important role in which prey species that can continue to take advantage of an area.

In the high Arctic at PLI sea ice may exclude many species for most of the year, but it is the high Arctic where we may expect to see the most change in the next few decades as summer sea ice declines and oceanographic patterns change (Barber et al. 2008). Cheung et al. (2009) argue that high latitude marine areas are likely to be sensitive to changes in biodiversity as climate change alters environmental conditions and suggest that “marine communities at the extreme ends of the environmental spectrum are especially at risk” (Cheung et al. 2009). The information about prey species diversity gained from comparing murre diets over decades across the Arctic support this hypothesis, as species diversity has decreased across all the sites sampled in the eastern Canadian Arctic, though local geographic and oceanographic conditions need to be taken into consideration in order to make regional predictions about changes in biodiversity.

2.5 Conclusions

With only two sampling periods to compare, changes in prey species need to considered carefully, and more detailed sampling is needed to fully understand potential biodiversity changes in Arctic waters. The decrease in Arctic cod and *T. libellula* across the low Arctic, along with the increase in capelin in the low and mid-Arctic illustrates that the biota of these regions is undergoing dramatic changes. Continuing monitoring of these regions will allow for the tracking of changes in the marine environment caused by changing climatic conditions in Canada's north.

The diets of the TBMU in the low Arctic suggest that as changing environmental conditions occur, ice-dependant cold water species are in decline. In the mid-Arctic where the change in the length of the open water season has not been as dramatic as in the low Arctic, changes in prey species are already occurring with capelin and sandlance now found at more northern latitudes than previously reported, and being consumed by the birds in similar levels as observed in the low Arctic 25 years ago. Along with razorbills (Gaston & Woo 2008) and great black-backed gulls (Smith et al. 2009), the movement of capelin to more northern latitudes adds to our knowledge of sub-Arctic are now becoming more common in low and mid-Arctic areas.

As changes in climatic conditions continue to alter northern ecosystems we may see further changes in the TBMU in the low Arctic. Ice break-up in Hudson Bay is now three weeks earlier than it was 30 years ago but the timing of peak TBMU hatch has moved by only a week earlier (Gaston et al 2009). This difference in ice breakup and TBMU breeding may lead to a mismatch between Arctic cod timing and the chick-rearing season in the low Arctic as has been observed in other seabird species (Hipfner 2009). For now Canadian TBMU appear to be able to adapt and take advantage of other fish within their foraging ranges. Capelin have long been the primary prey item for other seabirds and a number of marine mammals so as long as these species continue to be available for the birds Hudson Bay (Ferguson et al. 2010).

TBMU in the Canadian Arctic provide significant and relevant information on a number of fish and invertebrate species where little to no other fisheries assessment work is currently being done. Over the next few decades it is imperative to continue monitor low Arctic TBMU populations for changes in diet, breeding success and population trends as these areas have already undergone significant changes in the available prey, which may have long term affects on these TBMU populations. The mid-Arctic colony of TBMU at the Minarets may also prove as an important study site of progressing climatic changes as we are now seeing the beginnings of dietary patterns similar to those observed in the low Arctic over the last 30 years. The high Arctic colony of PLI, where little change in prey species has occurred, is also a strategic monitoring location where further studies will allow us to track potential changes in seabird populations and their prey species as changing climatic conditions continue to be observed.

Chapter 3 Plastics ingestion by northern fulmars

3.1 Introduction

Marine plastic debris floating in the oceans is a worldwide problem. When ingested by seabirds it may cause starvation and reduced growth, as well as more subtle effects that can be difficult to detect, including reduced dietary efficiency and increased levels of PCBs and other organochlorine assimilation (van Franeker 1985, Dickerman & Goelet 1987, Ryan 1988, Ryan et al. 1988). Globally, the incidence of plastics in seabirds has increased since it was first reported in 1960 (Harper & Fowler 1987, Moser & Lee 1992, Petry et al. 2007). By 2008, ingested plastic debris has been reported in more than 200 seabird species (Moore 2008), and is a problem even in isolated and remote colonies (van Franeker & Bell 1988).

The northern fulmar, *Fulmarus glacialis*, a medium-sized petrel with a circumpolar distribution, is particularly vulnerable to ingesting marine plastic debris and was one of the first species in which a high incidence of plastic ingestion was reported among North Atlantic seabirds (Baltz & Morejohn 1976, Moser & Lee 1992). Because they ingest and retain a wide variety of plastic debris (van Franeker & Meijboom 2006), fulmars are useful indicators of trends in marine debris in offshore areas. The incidence of plastics in their stomachs has been used as an indicator of marine debris in the North Sea since the 1980s (van Franeker et al. 2005). Unlike Europe's North Sea, the Canadian Arctic is remote from industrial centres and major shipping lanes. In the 1970s, Bradstreet (1976) collected Arctic fulmars for dietary analysis and reported no ingested plastic, despite the contemporary occurrence of debris in seabirds elsewhere

(Baltz & Morejohn 1976, Harper & Fowler 1987, Moser & Lee 1992). The first evidence of ingested plastic in breeding fulmars in the Canadian Arctic was recorded in 2003 by Mallory (2008) who sampled northern fulmars from Cape Vera, a breeding colony in the High Arctic.

In this study, we collected fulmars for dietary analysis and contaminant studies at two different colonies in the Canadian Arctic (Fig. 3.1). Our collections were made at colonies > 250 km south of Cape Vera, where Mallory (2008) first reported ingested plastics in breeding fulmars, and thus our collections were closer to shipping traffic and with a longer open water season. Previous studies have shown that incidence of plastic pieces in fulmars is lower at higher latitudes (van Franeker 1985, Mallory 2008), however, the sites we sampled were still in Arctic environments constrained by sea ice, and thereby with limited sea traffic and with no industrial activity nearby. We use these results to establish plastic ingestion by northern fulmars in a wider portion of their Canadian range then previously studied.

3.2 Methods

In August 2008 15 fulmars were shot at sea with a shotgun within 5 km of the fulmar colony at Cape Searle, Nunavut (67˚15'N, 62˚35'W). Farther north, 10 breeding adults with eggs or chicks were captured on their nest sites with a noose pole on the cliffs at

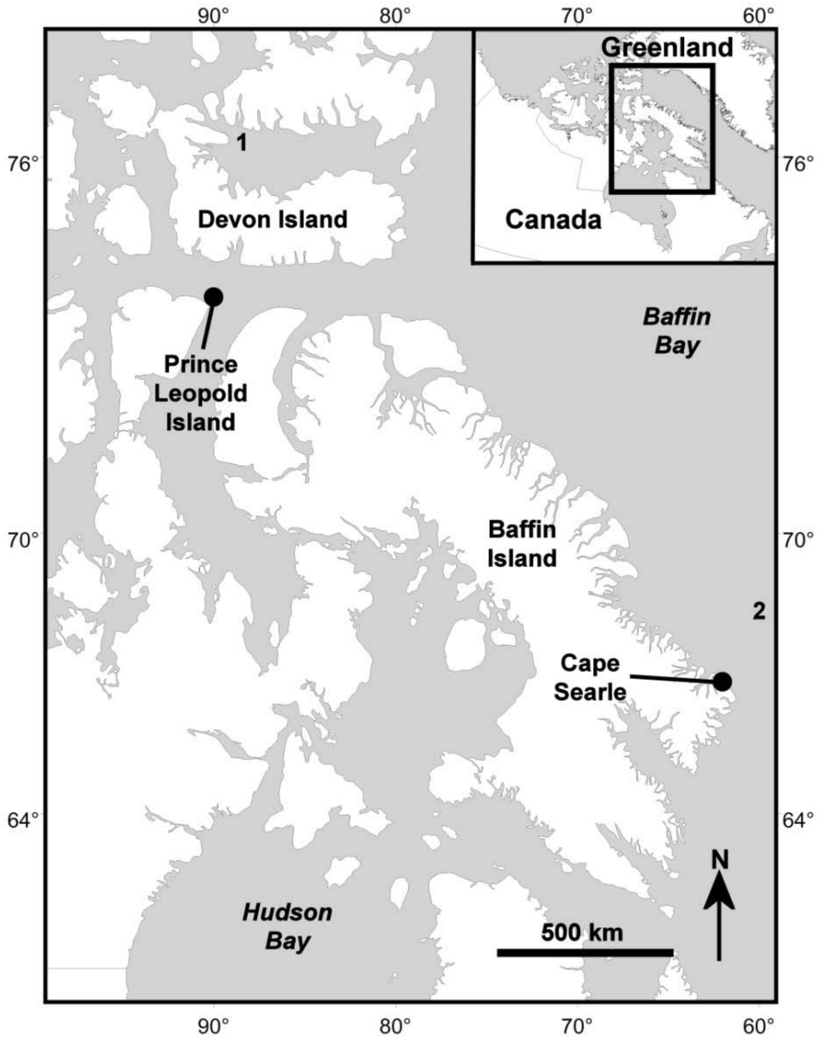


Figure 3.1. Northern fulmars were collected at two colonies in the Canadian Arctic: Prince Leopold Island, and Cape Searle. Sites where previous studies have documented plastic ingestion by fulmars are noted as "1" (Cape Vera; Mallory 2008) and "2" (Davis Strait; Mallory et al. 2006).

Prince Leopold Island, Nunavut (PLI) (74˚N, 90˚W), and were immediately euthanized. Each carcass was kept cool until it could be placed in a freezer (within 24 h) and shipped to the laboratory. In November 2008 the carcasses were thawed, measured (standard metrics including body mass), and dissected. The gastrointestinal tracts were removed intact, refrozen, and sent to the University of Victoria for processing and sorting, while the remains of the birds were processed and entered into the National Tissue Bank at the National Wildlife Research Centre in Ottawa for other analyses. Each gastrointestinal tract was later thawed, slit along their entire length, flushed with ethanol to remove all items present, and the contents were sorted into different prey types and plastics. All plastic debris was categorized as "user plastic" or "industrial plastic" (van Franeker et al. 2005). Total plastic debris from each stomach was dried and weighed using a Scaltec SCB22 analytical scale (± 0.00001 g).

3.3 Results

A variety of plastic types were found in the proventriculus and gizzards of the fulmars including plastic pieces from bottle caps, styrofoam (extruded polystyrene foam), industrial nurdles and plastic fragments from unidentified sources. Debris came in many colors: brown, black, grey, green, white, off-white, yellow and transparent colorless (Fig. 3.2). No plastic pieces were found lower in the digestive tract along the intestine. Plastics were sorted into the categories hard plastics and styrofoam, both user plastics, and industrial plastics which included all pellets and nurdles.

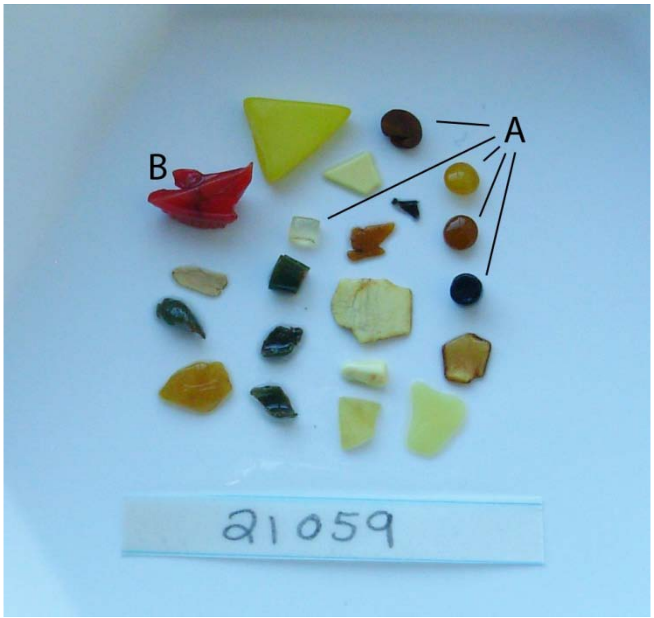


Figure 3.2. Plastic pieces found in a northern fulmar collected at Cape Searle in the 2008. A – industrial nurdles, B – bottle cap lid, remaining pieces are from unidentified sources.

The incidence of plastic ingestion was similar at both colonies (Table 3.1; Fisher Exact test, *P*=1.0), with 21 of 25 fulmars from both colonies (84%) containing plastic debris. The types of fragments ingested by fulmars at each colony were also similar, although styrofoam was not found in any birds from Prince Leopold Island. Fulmars at Cape Searle typically contained more pieces of plastic than those at Prince Leopold Island (Table 1; Wilcoxon rank-sum test, *P*=0.016). The mean total mass of ingested plastic was not significantly different (*P*=0.17), though the power of analysis of the Wilcoxon rank sum tested was very low (0.133).

Ingested plastic represented on average 0.000142% of fulmar body mass. At Prince Leopold Island, 10% of fulmars contained >0.1 g of total plastic (a threshold mass used in the North Sea plastic monitoring program; OSPAR 2008), which was less than the 40% of fulmars at Cape Searle that had ingested at least this much plastic (Fisher Exact test, *P*=0.18).

3.4 Discussion

Our results showed a markedly different pattern on the incidence of ingested plastics in fulmars of the Canadian Arctic compared to recent work in this region. More than 80% of the fulmars at Cape Searle and Prince Leopold Island had ingested plastic, nearly three times the levels recently reported from Cape Vera or Davis Strait (Mallory et al. 2006; Mallory 2008). Although we found no difference in incidence of ingested plastics between our two sites, we did find a significant difference between the two colonies in the number of pieces ingested, suggesting that individuals at the more southerly Cape Searle colony are exposed to greater amounts of plastic debris. These findings,

Table 3.1 Ingested plastic values for northern fulmars collected at a mid-Arctic colony and a High Arctic colony in the eastern Canadian Arctic during the 2008 breeding season.

Location (*n*)	% female	Total pieces	Industrial	User	Hard plastic	Styrofoam	Total plastic mass per fulmar (g)	% above EcoQO [1]
Overall (25)	52%							
Incidence		84%	28%	84%	84%	8%		
Mean (SD)		5.6 (6.0)	0.4(1.0)	5.1(5.5)	5.1(5.6)	0.1(0.3)	0.094 (0.143)	28
PLI (10)	50%							
Incidence		80%	20%	80%	80%	0%		
Mean (SD)		2.5 (3.5)	0.2 (0.4)	2.3 (3.5)	2.3 (3.5)	0.0 (0)	0.050 (0.099)	10
Cape Searle (15)	53%							
Incidence		87%	33%	87%	87%	13%		
Mean (SD)		7.6 (6.6)	0.6 (1.2)	7.0 (5.9)	6.9 (6.0)	0.1 (0.4)	0.124 (0.162)	40

[1] – OSPAR (2008)

along with those of Mallory (2008) support the pattern of decreasing incidence of plastics with increasing latitude proposed by van Franeker et al. (1985).

Compared to Cape Searle, the waters surrounding the Prince Leopold Island colony are ice-covered for a much greater amount of the breeding season (Mallory and Fontaine 2004), and this colony is considerably more remote from most shipping activity, major communities, and north-flowing ocean currents, all of which could bring plastic debris into the foraging range of a colony (below). Both Canadian sites were at or above the OSPAR Ecological Quality Objective (EcoQO) for marine plastic debris used in the Save the North Sea program (10% of fulmars with an average mass of ingested plastic ≥ 0.1 g; OSPAR 2008). Reanalyzing the data presented in Mallory (2008) and Mallory et al. (2006), 11% of those 144 fulmars were also above the EcoQO objective.

Although we did not find a statistically significant difference in the mass of the plastics ingested at our two sites, the low power of analysis, most likely due to our small sample size, suggests that we lack the ability to detect a difference in mass of plastics ingested between these two sites with our current data. In fact, the average fulmar at Cape Searle had three times as many pieces of plastic and carried nearly three times the mass of plastic, compared to birds at Prince Leopold Island (Table 1). We suspect that additional sampling from these sites will confirm that ingested plastic is a greater issue at the more southern colony. Despite our small sample size, the differences between our results (84% incidence) and those from the recent studies farther north in the Canadian Arctic (36% incidence, Mallory et al. 2006; 31% incidence, Mallory 2008) are striking, and highlight the importance of colony-specific information in environmental monitoring with seabirds (e.g., Braune et al. 2002).

The fulmars breeding in Arctic Canada are likely ingesting large amounts of plastic debris on their wintering grounds in the North Atlantic as shown by Mallory (2008) comparing plastic ingestion as the breeding season progressed. However, colony-specific differences suggest that debris is also being ingested during migration and/or the breeding season. Two mechanisms could explain the observed differences. First, fulmars at more northern colonies, such as Cape Vera, may have less plastic debris within their foraging range because sea ice excludes surface currents from bringing debris into some areas (Mallory 2008). At more southern colonies, foraging seabirds may be exposed to larger amounts of plastics as ocean and wind currents bring floating debris north from the more populated areas of eastern North America, and from refuse blown or washed into the marine environment from Arctic communities. Second, during the three to five year interval between these studies the amount of plastics floating in the ocean in this region could have increased. A growing human population, increases in ship traffic, and changing oceanographic processes (i.e., ice cover and currents; ACIA 2005) could all result in more refuse entering the eastern Canadian Arctic. Unfortunately, no data on debris occurrence in the sea, or temporal sampling of fulmars are available to discern between these possibilities.

Plastic ingestion has also been shown to differ with age of breeding status northern fulmars in the North Sea. Van Franeker and Meijboom (2006) have found that younger birds consistently ingest higher levels of plastics when sample sizes are large enough for the comparison. Due to our small sample size we were unable to compare plastic ingestion across age groups but age is also likely to be a factor in Canadian birds as has been observed in the North Sea.

The incidence of plastic in our study (84% of birds) approaches that found in the much more industrialized North Sea (95 - 100%, 1997 - 2003; van Franeker et al. 2005; van Franeker et al. 2008). Although the mean mass and number of ingested plastic fragments that we found in fulmars in Arctic Canada (0.09 g, 6 pieces) was lower than levels found in European birds (0.33 g, 40 pieces, 2002-2004; van Franeker et al. 2005; van Franeker et al. 2008), the mean mass of ingested plastics exceeded the EcoQO goal set for fulmars in the North Sea in 28% of the birds in our sample. Given that Bradstreet (1976) reported no plastic debris in 181 fulmars collected in the Canadian Arctic in the 1970s, but our study (2008) combined with that of other recent investigations (2003-2005; Mallory 2008; Mallory et al. 2006) found 40% of 169 fulmars in this same region containing ingested plastic (and 87% at the most southern colony) it seems clear that the amount of plastic debris entering Canadian Arctic waters is increasing, albeit still below levels seen in more industrial areas. This increase in incidence of plastics in Arctic seabirds, coupled with the much higher of number of plastic pieces and mass of plastics found at the more southern colony indicate plastic debris is now reaching Arctic marine systems with potentially negative effects on seabirds and other marine organisms.

Northern fulmars have been identified as an appropriate species to track the incidence of marine plastic debris and are used to monitor debris in Europe (van Franeker & Meijboom 2006), and may now be useful monitors of marine plastic debris in the eastern Canada. Van Franeker et al. (2005) proposed that the mass of plastics in seabirds stomachs be reported as this measurement is relatively easy to assess, report and compare across studies and geographic areas. Similar protocols and procedures could be modified to work along the coast of eastern Canada using seabirds (particularly fulmars), further enhancing their utility as indicators of the health of marine ecosystems (Schreiber and Burger 2002; Frederikson et al. 2006).

Chapter 4 Plastic ingestion by thick-billed murres

4.1 Introduction

Since plastic came into common use in the 1950s floating plastic debris has been recognized as a major pollutant in the world's oceans and has been found to be ingested by almost half of the world's 300 seabird species (Vlietstra and Parga, 2002; Moore, 2008). Plastic ingestion by seabirds was first observed in 1960 in New Zealand (Harper and Fowler, 1987), and in the North Atlantic in 1962 (Rothstein, 1973). Since then, marine plastic debris has become a global problem for the world's seabirds (Spear et al. 1995; Auman et al., 2004; Van Franeker et al., 2005; Mallory, 2008; Ryan, 2008). Plastic ingestion may have a wide range of deleterious effects on seabirds, including reduced appetite, growth and dietary efficiency, as well as increased levels of PCBs (Van Franeker, 1985; Dickerman and Goelet, 1987; Ryan, 1988a, Ryan et al., 1988b), all of which could have negative impacts on seabird populations already stressed by changing environmental conditions (Kitaysky and Golubova, 2000) and altered prey abundances (Mavor et al., 2008).

Seabirds have been found to ingest both user and industrial plastics (Van Franeker et al., 2009). Industrial plastics are the nurdles or pellets used by the plastics industry to transport raw plastic to factories for further processing. All other forms of plastics are considered user plastics, including hard sheet-like plastics, thread-like plastics, foamed polystyrene and polyurethane plastics, and fragmented hard plastics as used in most consumer products such as bottles and toys (Van Franeker et al., 2009). Despite their large populations and broad distribution (Gaston and Jones, 1998) there are no reports of plastic ingestion by auks (Alcidae) in the North Atlantic Ocean, although a low incidence of plastic ingestion has been reported for some auks in the North Pacific Ocean (Robards et al., 1995; Blight and Burger, 1997).

Approximately five million thick-billed murres (*Uria lomvia*), about one quarter of the world's population, breed in the eastern Canadian Arctic and overwinter in the Northwest Atlantic (Gaston and Jones, 1998) where they feed on fish and invertebrates at sea in Davis Strait, Labrador Sea and around Newfoundland (Gaston and Hipfner, 2000). Thick-billed murres in the Canadian Arctic Archipelago have been monitored since the 1970s to track population size, contaminant levels, and changes in diet (Braune et al., 2001; Gaston, 2002; Woo et al., 2008). In the 1970s and 1980s murres were collected from low, mid and high-Arctic colonies for dietary studies (Bradstreet, 1980; Gaston and Noble, 1985; Gaston and Bradstreet, 1993). During the 2007 and 2008 breeding seasons we collected thick-billed murres from several Canadian Arctic colonies for dietary analysis, and here we report on the incidence, type and size of plastics found in murres from this region. We use the murres as sentinels of floating plastic debris in the marine environment, and as samplers in the absence of direct work assessing plastic debris in the Canadian Arctic and North Atlantic marine ecosystems.

4.2 Methods

In June, July and August, 2007 and 2008, thick-billed murres were collected from five colonies in Nunavut, Canada, as follows (Fig. 4.1): Coats Island (62°98′N, 82°00'W), Digges Sound (62˚33′N, 77°35′W) and Akpatok Island (60˚58′N, 68°08′W) in the Low Arctic oceanographic zone (Salomonsen, 1965), Prince Leopold Island

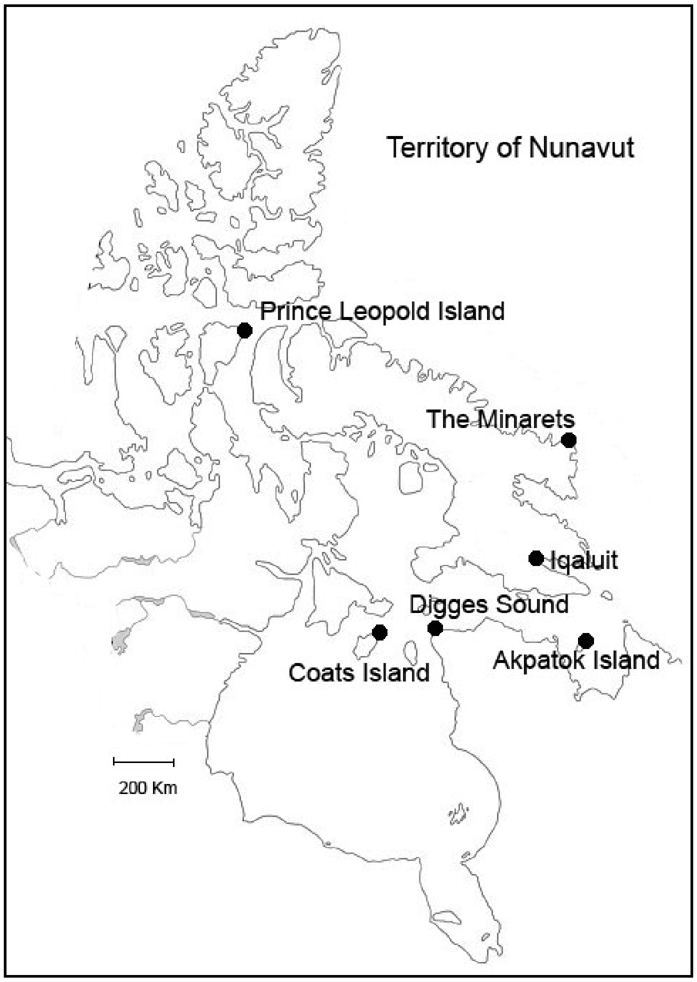


Figure 4.1. Thick-billed murre colonies sampled in Nunavut, Canada.

(74°02′N, 90°00′W) in the High Arctic oceanographic zone, and the Minarets (67˚00’N, 61˚80’W), located at the boundary of these two zones.

At Prince Leopold Island birds were sampled when they had first arrived from the wintering grounds (June 2008, n = 32), and during chick-rearing (August 2008, n = 18) allowing us to compare plastic ingestion at different periods in the breeding season. At the Minarets we were able to sample during chick-rearing in 2007 (August; n = 30) and 2008 (August; n = 20) allowing for an inter-year comparison for this one site. All other sites were sampled only once.

Murres were shot from small boats using 12 gauge shotguns and steel shot while the birds were feeding within 15 km of colonies. Immediately upon retrieving the carcass, 70% isopropanol was injected into the digestive tract to aid in the preservation of prey items in the stomach. Carcasses were kept in a cool place for up to 24 hrs, then frozen and transported to a laboratory for dissection. The entire digestive tract of each bird was removed and re-frozen for transport. All digestive tracts were later thawed, dissected and plastic items were set aside for examination. Plastics were sorted by type, dried and weighed (Van Franeker et al., 2005) using a Scaltec SCB22 analytical scale measuring to the nearest 0.00001 g (excluding plastic fibre pieces). Plastics were categorized as rigid plastics, soft plastic, fibres or industrial nurdles. All rigid and soft plastic pieces were measured ± 0.1 mm. Each piece of plastic was estimated to a standard geometrical shape (sphere, cylinder, triangular prism or a rectangular prism) and standard equations used to calculate the surface area and volume.

Two-tailed Fisher Exact tests to compare the incidence of plastic debris among the samples collected at the Minarets in 2007 and 2008, and to compare the birds collected early and late in the breeding season at Prince Leopold Island. The Mann-Whitney rank sum test was used to test for variation in number and mass of plastics found at the Minarets over the two years of sampling and between the seasons sampled at Prince Leopold Island. To test for variation among colonies in numbers of pieces per bird, proportion of birds found with ingested plastic per colony, and mass of ingested plastics per bird during the 2007-2008 sampling period, maximum-likelihood was used to fit generalized linear models with nonlinear link functions (“Proc Genmod”; SAS 2008). Number of plastic pieces per colony was modeled with a loglinear model (“Proc Genmod” with a log link function). Deviation from the Poisson distribution was estimated using an index of dispersion calculated by dividing the model deviance by degrees of freedom. Data on the number of plastic pieces per stomach were underdispersed (i.e., deviance/df = 84.8/149 = 0.57, which is less than 1.0), and a dispersion parameter was used to correct for underdispersion (“scale = d” in “Proc Genmod”; SAS, 2008). Proportion of birds found with plastic was modeled using a logistic regression model (“Proc Genmod” with a logit link function; SAS 2008). As well, we tested for variation in plastic mass load among colonies for birds that had consumed plastic using a General Linear Model (“Proc GLM”; SAS, 2008). Only data from birds detected with plastics were included in this analysis. Number of plastic pieces, proportions with plastic, and plastic mass loads were compared orthogonally (*a priori*) between colonies using least-squares mean statements in “Proc Genmod” and “Proc GLM” (SAS, 2008). Means are reported with standard deviation (± SD), and chi-square-values (χ) and F-values were reported with numerator and denominator degrees of freedom as subscripts. Significance was determined for all statistical tests with an alpha of 0.05.

4.3 Results

Of the 186 thick-billed murres collected, 11% contained ingested plastics in their digestive tracts with a mean of 0.2 ± 0.8 plastic pieces found ingested per bird (Table 4.1). All the plastic found in the murres was user plastic, including a soft airgun pellet found in a bird from Coats Island (Figure. 4.2), with no nurdles or industrial plastics found. Plastic was found in at least one murre at all colonies sampled.

Rigid plastics (black, brown, white, off-white, green) were found in 5% of murres, and were the most common type of plastic debris ingested at all colonies except Coats Island. A single piece of white soft plastic (incidence 0.5%) was found in a bird from Akpatok Island. Fibres (incidence 5%) were also found at every colony sampled except Coats Island and were either blue or red.

At Prince Leopold Island, 12% of the early season birds contained plastic, while none of the late season birds did so. However, this difference was not statistically significant ($P = 0.28$; Fisher's Exact). Although there was no significant difference in the birds containing plastics in the early and late season we discuss trends in plastic ingestion by the murres sampled early in the breeding season, but use only the birds collected during chick-rearing for our inter-colony comparison to control for any potential seasonal variations.

The colony at the Minarets was sampled during the 2007 and 2008 breeding season, making it the only colony we were able to sample in multiple years.

Table 4.1. The proportion of birds with ingested plastics, mean number of pieces per bird and mean mass of ingested plastics per bird found in thick-billed murre stomach contents collected from five Canadian Arctic sites in 2007 and 2008. SD = standard deviation.

Location	Date collected	% female	All user plastic debris	rigid plastic	soft plastic	fibres	Average mass of plastics
Overall (186)		45.57					0.0016 (0.0099)
Mean number of plastic(SD)			0.20 (0.83)	0.12 (0.75)	0.005 (0.07)	0.0 (0.33)	
Proportion of ingested plastic			11	5	1	5	
Akpatok Island (31)	19-Aug-08	32.26					0.0025 (0.0094)
Mean number of plastic(SD)			0.29 (0.64)	0.16 (0.45)	0.03 (0.18)	0.13 (0.34)	
Proportion of ingested plastic			23	13	3	13	
Coats Island (25)	27-Jul-07	96.00					0.0032 (0.0162)
Mean number of plastic(SD)			0.04 (0.20)	0.00	0.00	0.00	
Proportion of ingested plastic			4	0	0	0	
Digges Sound (30)	11-Aug-08	27.59					0.0015 (0.0084)
Mean number of plastic(SD)			0.27 (0.69)	0.30 (0.18)	0.00	0.23 (0.67)	
Proportion of ingested plastic			17	3	0	13	
Minarets (50)	overall	34.00					0.0003 (0.0014)
Mean number of plastic(SD)			0.06 (0.26)	0.04 (0.20)	0.00	0.02(0.14)	
Proportion of ingested plastic			6	4	0	2	
2007 (30)	5-Aug-07	46.67					0.0004 (0.0018)
Mean number of plastic(SD)			0.10 (1.40)	0.07 (0.25)	0.00	0.03 (0.18)	
Proportion of ingested plastic			10	7	0	3	
2008 (20)	3-Aug-08	15.00					0.00
Mean number of plastic(SD)			0.00	0.00	0.00	0.00	
Proportion of ingested plastic			0	0	0	0	
Prince Leopold Island (50)	overall	38.00					0.0017 (0.0119)
Mean number of plastic(SD)			0.30 (1.39)	0.28 (1.38)	0.00	0.02 (0.14)	
Proportion of ingested plastic			8	6	0	2	
early breeding season(32)	5-Jun-08	30.77					0.0026 (0.0146)
Mean number of plastic(SD)			0.47 (1.72)	0.44 (1.72)	0.00	0.03 (0.18)	
Proportion of ingested plastic			13	9	0	3	
late breeding season(18)	9-Aug-08	38.89					0.00
Mean number of plastic(SD)			0.00	0.00	0.00	0.00	
Proportion of ingested plastic			0	0	0	0	

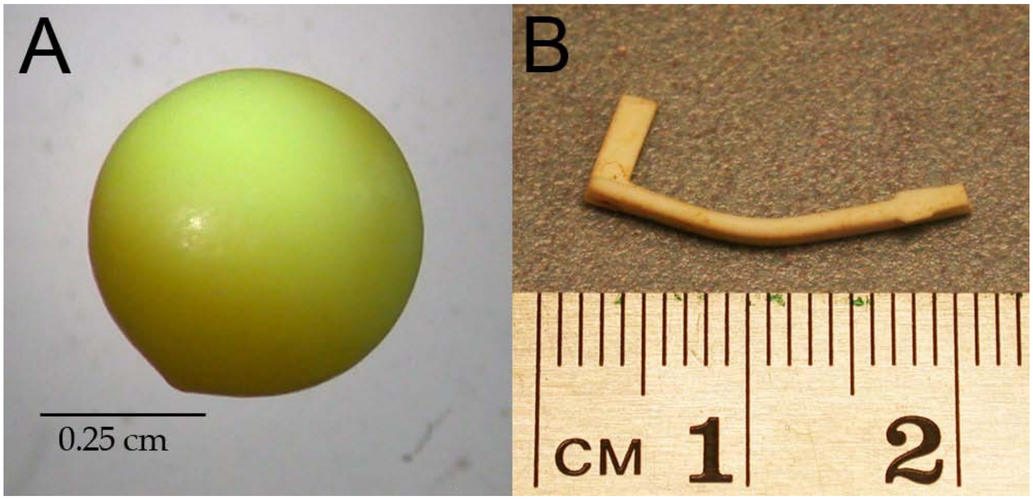


Figure 4.2. A: a soft airgun pellet, found in the digestive tract of a murre from Coats Island, B: a piece of consumer plastic found in a murre collected at Akpatok Island.

In 2007, 2/30 (7%) of the birds sampled contained ingested plastics, while none of the 20 birds collected in 2008 contained plastics (P = 0.52; Fisher's Exact). All birds collected at the Minarets were pooled for further analyses.

Among all the colonies sampled during the chick-rearing season both the number of ingested plastic pieces ($\chi_{4,149}$ = 32.6, P < 0.0001) and the proportion of birds containing them ($\chi_{4,149}$ = 11.5, P = 0.022) varied significantly. Akpatok Island samples had the highest mean number of plastics per individual (0.3 plastic pieces per bird, n = 31, Table 4.1) and contained the highest proportion of samples with plastic (23% contained plastic, Table 4.1). The Prince Leopold Island sample from the chick-rearing period contained no plastics. Pairwise comparisons revealed that numbers of plastic pieces per sample varied among all colonies (χ_1 > 5.6, P < 0.018), but not between Akpatok Island and Digges Sound (χ_1 = 0.28, P = 0.59), Coats Island and the Minarets (χ_1 = 0.22, P = 0.64), nor between the Minarets and Prince Leopold Island (χ_1 = 0). Pairwise comparisons for proportion of birds containing plastic indicated that only Akpatok Island and the Minarets (χ_1 = 4.28, P = 0.038), Akpatok Island and Prince Leopold Island (χ_1 = 1200, P < 0.0001), Coats Island and Prince Leopold Island (χ_1 = 380, P < 0.0001), and Digges Sound and Prince Leopold Island (χ_1 = 1020, P < 0.0001) differed significantly (other pairwise comparisons χ_1 < 3.1, P > 0.079).

For the 186 thick-billed murres sampled the average mass of plastic represented 0.0002% of body mass. This is approximately 80 times lower than amounts found in northern fulmars (*Fulmarus glacialis*) collected in the eastern Canadian Arctic during the same sampling period (0.0142%) (Mann-Whitney U test U = 448, P < 0.001 (Provencher et al., 2009). Two of the murres sampled carried plastic loads of 0.084 g (Prince Leopold

Island, June 2008) and 0.081 g (Coats 2007); otherwise all murres had ≤ 0.05 g of plastic. When only the birds containing plastics are considered the average plastics represented 0.003% of body mass.

Plastic pieces ($n = 22$) ingested by murres were small. Mean length (4.5 ± 3.8 mm), width (3.9 ± 3.1 mm) and thickness (0.6 ± 1.1 mm) of plastic debris ingested by murres were all smaller than pieces found in northern fulmars in Nunavut (respectively 10.6 ± 10.4 mm; 6.0 ± 4.1 mm; 0.7 ± 0.4 mm, Mallory, 2008; Mann Whitney U tests, all $U > 3187$, all $P \leq 0.03$). Several of the pieces in murres were very small and were only identified as plastic debris using a dissecting microscope. Based on visual inspection of the size of plastic and of prey items also in the gastrointestinal tracts, all of the colonies sampled had at least one murre with an ingested plastic piece that could have been potentially mistaken for a prey item by the seabird during a foraging bout.

Within birds containing plastic, the mean mass of plastic varied among the colonies (GLM $\chi_3 = 5.33$, $P = 0.014$). The murres sampled at Coats Island had the heaviest average mass of ingested plastics (Table 4.3.1), though only one bird contained plastic, pairwise comparisons between Coats Island and all other colonies were significant (all t-values >3.73 with $P < 0.0030$). No other pairwise comparisons were significant (all t-values < 0.53 with $P > 0.61$).

4.4 Discussion

Since the 1980s seabird researchers worldwide have found the incidence of ingested plastics on the rise in many species, with plastic debris most likely mistaken for prey items and ingested during foraging bouts (Cadee, 2002). Studies have reported high levels of ingested plastics in surface feeding procellariiforms from both hemispheres, including fulmars (Van Franeker et al., 2005; Mallory, 2008) and albatrosses (Auman et al., 1998; Petry et al., 2007). Other waterbirds may ingest high levels of plastics, including phalaropes, terns and gulls (Moser and Lee, 1992; Robards et al., 1995), but despite the large populations and wide distribution of auks in northern waters there have been few reports of ingested plastic debris for this group of birds (Robards et al., 1995; Blight and Burger, 1997).

Our results show thick-billed murres, which feed below the surface, also ingest marine plastics debris but at a lower incidence than most other species reported to date. The finding of ingested plastics at each of the colonies examined ranging across 11° of latitude (1300 km direct distance) suggests that this is a widespread occurrence among thick-billed murres in Canada, not just a local phenomenon. Overall, the incidence of plastic ingested by thick-billed murres approximately follows the pattern observed in northern fulmars with the incidence of ingested plastics decreasing with increasing latitude (van Franeker 1985) (during chick-rearing season low Arctic: 14%, mid-Arctic: 6%, high Arctic: 0%).

In the Canadian Arctic, Bradstreet (1980) and Gaston and Noble (1985) sampled thick-billed murres in the 1970s and 1980s and although no plastics were reported among the stomach contents examined some birds did contain irregular, plastic-like fragments (MSW Bradstreet pers. comm.). Plastics may have been present in thick-billed murre stomachs during the 1970s and 80s, but here we report the first quantitative assessment of plastics in this species as a baseline for future work in this area.

Only user plastics were found in thick-billed murre from the Canadian Arctic indicating that local garbage sources represent the main source of plastic debris around murre colonies. User plastics in the marine environment come from sites such as municipal landfills, urban centres and large vessels moving through the area (Moore et al., 2005). Industrial nurdles are present in other Arctic seabirds (Mallory 2008; Provencher et al., 2009) but the lack of nurdles in murres suggests that although plastics are being introduced to Arctic ecosystems far from their point sources due to an absence of major shipping routes and plastic factories in Canada's North, industrial plastics are not affecting all seabird species that are known to ingest plastics.

The retention time of plastics in murres is unknown but we can assume that smaller pieces would pass more easily than larger pieces. Small transmitters hidden inside fish fed to thick-billed murres were passed through the digestive tract in 6 to 24 hours (Hawkins et al., 1997) but larger pieces of plastic that cannot pass from the crop, through the pyloric sphincter into the intestine, may stay in the digestive tract for much longer. As a result, we are unable to determine when and where ingested plastics were picked up by the murres which could have happened in the North Atlantic during the wintering period, or in Arctic waters during the breeding season. Further study of the passage time of plastics is essential to understanding how seabirds may be transporting plastics in the marine environment.

The bio-transport of plastics into the Arctic by seabirds is supported by our finding of more plastics in the murres sampled at PLI early in the season as compared with those collected later in the season. We found 13% of birds had ingested plastic early in the season when the birds had just arrived at the breeding colony and none later in the season after the birds had been foraging in the area for several months, suggesting a seasonal effect on the incidence of plastic. Thick-billed murres may be ingesting plastics in the Northwest Atlantic during the winter months spent at sea, and bringing them north during migration, however, our sample sizes were relatively small which probably contributed to the non-significant statistical results.

Digestion through the breeding season may explain the absence of plastics in August (see also Mallory, 2008). The lack of plastic in murres from Prince Leopold Island collected during chick-rearing suggests that murres were not ingesting plastics within their foraging range in Lancaster Sound. Prince Leopold Island is the most northern site we sampled, has the most ice cover late into the season, and has east-flowing currents (i.e., towards sources of debris), which may exclude plastic debris from reaching this area. One of the impacts of less sea ice cover, which is associated with warming Arctic summers, may be an increase in plastics debris in the Arctic, leading to an increase in plastic ingestion in the marine environment (Mallory, 2008).

While the incidence of plastics found in the Prince Leopold Island sample may indicate a seasonal variation in the ingestion of plastics, it was also one of the early birds sampled at Prince Leopold Island that contained the highest number of plastics pieces (nine pieces in total). The large quantity of plastics found in a murre that had only recently arrived from the North Atlantic wintering grounds also supports the idea that most plastics are consumed in the southern regions of the range rather than in Arctic waters.

This high level of plastics from a bird sampled early in the year may indicate that we may be underestimating plastic ingestion in thick-billed murres in eastern Canadian waters by conducting most of our sampling in July and August. As many murres from the eastern Canadian Arctic breeding colonies overwinter off the coasts of Newfoundland

and Greenland (Gaston and Jones, 1998), they are likely to ingest plastics in these waters that experience year-round shipping traffic, and are closer to large industrial areas. By concentrating our sampling during the chick-rearing season when birds have been in the Arctic for several months we may be missing a large portion of plastics that have passed out of the birds by this time.

The site with the highest proportion of birds with ingested plastics was the low Arctic colony of Akpatok Island, and this site differed significantly from the Minarets (mid Arctic) and Prince Leopold Island in the high Arctic, but was similar to the other low Arctic colonies in proportion of birds with ingested plastics. The location of wintering areas differs among the colonies involved (Donaldson et al., 1997; AJG and P. Smith, unpubl. data) and the high incidence of plastic among Akpatok murres suggests that birds from this colony may winter in areas with higher levels of plastic debris. Unfortunately, the main wintering areas for this colony is unknown (Donaldson et al., 1997). As the murre colony on Akpatok Island is the largest in Canada this high level of ingested plastics indicates that a large portion of thick-billed murres may be ingesting plastic debris on a regular basis.

Although the mass of plastics is small in murres and on average represents only 0.0002% of the body mass, plastic ingestion by this species demonstrates that surface feeders are not the only seabirds that are susceptible to ingesting marine debris. However, the murres sampled had a significantly lower mass of plastics to body mass ratio compared to northern fulmars sampled at the same time indicating that although murres ingest marine debris, the plastic load carried by each bird on average is still much lower than those carried by breeding northern fulmars using the same areas.

Plastic ingestion in murres is still much lower than observed in northern fulmars sampled in the same area, but ingestion by this species has implications not associated with other seabirds that ingest plastic debris in Canada. Murres are among the most hunted migratory bird species in Canada, with several tens of thousands harvested each year in Newfoundland and Nunavut to be consumed by people. One of the negative effects of plastic ingestion, the absorption of hydrophobic chemicals, may then be passed on to humans by these birds. When streaked shearwaters chicks (*Calonectris leucomelas*) were feed plastic pellets it was found that levels of total PCBs and lower chlorinated congeners in their preen glands peaked after plastic ingestion, and then decreased a short time after plastic debris ingestion stopped (Teuten et al., 2010 in review). This suggests that seabirds ingesting plastics are absorbing contaminants from the plastics through their digestive tract and into their tissues and glands. The consumption of these birds may then pass these contaminants on to humans, though more work needs to be done to understand how this may or may not be happening in the Canadian murres.

We interpret the detection of plastic ingestion by thick-billed murres in the eastern Canadian Arctic reported here as evidence of an increase in plastics in the marine environment in general. This finding mirrors the recent results from northern fulmars (Mallory, 2008; Provencher et al., 2009), which also indicated increasing ingestion of plastic by Arctic seabirds. The plastic pieces ingested by the murres were significantly smaller than pieces found in northern fulmars in the same region, suggesting that murres may be selecting for smaller pieces of debris than fulmars.

The Canadian Arctic is considered a pristine, remote area of the world with a small population and little industrialization. Although the Arctic is remote from point sources of pollution, atmospheric and oceanographic processes, and bio-transport are bringing pollutants from the south into these northern landscapes (Braune and Scheuhammer, 2008; Mallory, 2008). As ship traffic increases in the area and the human population grows, more plastic debris is likely to enter the Arctic marine environment, and we predict that the incidence of plastic debris ingestion by Arctic seabirds will continue to increase. This study provides a necessary baseline for future comparative studies measuring potential impacts associated with these changes.

Chapter 5 General Conclusions

The main objective of this thesis was to assess potential changes in the diets of adult TBMU throughout the Arctic, since initial dietary assessments were carried out in the 1970s/80s. Changes in the diet of the chicks have been observed at Coats Island since the mid 1990s (Gaston et al. 2007), but little other dietary monitoring has occurred. Recent sampling shows several changes in the prey items consumed by TBMUs in the low, mid and high Arctic zones between historic sampling and recent sampling in 2007/08/09. The decrease in the ice-dependent Arctic cod in the diet across the low Arctic colonies sampled, and the appearance of capelin in the mid-Arctic murre diet confirms that as warming conditions persist during the Arctic summer, prey species used by the TBMU are changing.

A decrease of gammarid amphipods in the diets of the murres across all the zones sampled was also observed. This signals a large change in the prey used by the murres, specifically in the high Arctic where gammarids used to be found in large numbers in many murre stomachs. Since gammarid amphipods used to comprise a large portion of the diet this change may indicate the murres are feeding at a higher trophic level, which has implications for ongoing contaminant studies in the north. An overall decrease in gammarid amphipods in the diet of the murres also suggests that changes in gammarid abundance and distribution may be occurring. Since this invertebrate group is known to be a major prey item in northern waters changes in its abundance and distribution may have impacts on marine species that are not as capable of switching prey items as the TBMU. Along with the decrease in gammarid amphipods an overall decrease in prey diversity was also found in the diet of the TBMU across all the colonies examined. This finding also has implications that may affect marine top predators throughout the area. A decrease in marine prey species in polar latitudes has been modelled as a potential effect of changing climatic conditions (Cheung et al. 2009), which may already be happening in northern Canada, as observed through the diet of the TBMU.

An increase in mysids in both the low and mid-Arctic murre diets also indicates a large change in the main prey items utilized by the murres in the Canadian Arctic. Previously, mysids have not been recognized as a the main invertebrate species consumed by TBMU in these two areas, but in the 2007/08/09 sampling mysids accounted for more than 80% of the invertebrates found in the stomach contents of the murres. This represents a large portion of the prey consumed in both the low and mid-Arctic as invertebrates represent approximately 90% of the prey consumed. This large increase in mysids may be related to changing climatic conditions, but regardless of the reasons an increase in mysids in northern waters will change zooplankton dynamics in the area all the way up the food chain. Studying the diets of TBMUs in the Canadian Arctic continues to be of great use in tracking trends in prey species in Arctic waters, an area where little other fisheries assessment work is being done.

Changes in the Arctic are predicted to be extreme as changing climatic conditions affect ecosystems around the world (IPCC 2007). Thick-billed murres are an ideal indicator species in Canada’s north being abundant, relatively easy to observe and highly dependent on the marine environment immediately surrounding the breeding colonies (Gaston et al. 2005, Gaston et al. 2005). With continuation of the long-term monitoring the TBMU will continue to be useful as an indicator of the change that is likely to take place in the Arctic over the next several decades. Change may continue to occur in the low Arctic, but it will be the monitoring of change in the mid and high Arctic zones that will become more imperative as summer sea ice continues to decline.

The second, and unexpected, finding of this work was assessment of plastic ingestion by seabirds in the eastern Canadian Arctic. Plastic debris was found in both thick-billed murres and northern fulmars from all of the colonies sampled. Ingestion of plastics by these two species is useful in the assessment of plastic debris in the marine environment. The surface feeding northern fulmar is recognized as a useful indicator of marine debris in the North Sea (van Franeker & Meijboom 2006), but has not been widely utilized in Canadian waters. This assessment of plastics in fulmars along with work done by Mallory (2008) now establishes a baseline of plastic ingestion by fulmars in Canada’s north. This plastic ingestion assessment in fulmars can be used alongside future assessment to monitor marine debris in Arctic waters.

The ingestion of plastics by thick-billed murres is also a useful tool in assessing marine debris even though these seabirds are pursuit divers, not usually known for debris ingestion. Although the location of the debris ingestion is difficult to determine as murres over-winter in the North Atlantic and large pieces of plastic may persist in the gastro-intestinal tract for long periods, ingestion of plastics by this species signals that plastic debris is affecting not only surface eating procellariiforms, but alcid species as well. As TBMUs are an important hunt species in Canada the overall health of these populations is important to monitor, including the ingestion of plastics which has been shown to have a number of negative effects on seabirds (van Franeker 1985, Dickerman & Goelet 1987, Ryan 1988, Ryan et al. 1988).

Seabirds have been used as indicators of changing marine ecosystems for decades, mostly as an indicator of changing fish stocks (Cairns 1987, Davoren & Montevecchi 2003, Piatt et al. 2007), but with the increase of plastic debris in the marine environment seabirds are now useful not only as indicators of prey species, but also of other marine conditions as well (van Franeker et al. 2005). Continued monitoring and assessment of seabirds in the Arctic will allow us to detect numerous changes in the Canada's northern marine environment.

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Appendix 1

Percent total of all invertebrates identified to the lowest taxonomic level possible found in the stomach contents of thick-billed murres.

	Akpatok Island		**Coats Island**	**Digges Sound**		**the Minarets**		**PLI**	
	1983	**2008**	**2007**	**1980/81/82**	**2008/09**	**1985**	**2007/08**	**1976/77**	**2008**
Invertebrates									
Polycheates									
Nereis sp.	2.12	8.16	0.32	3.26	4.90	0.00	0.00	0.00	0.00
Cephalopoda									
Gonatus fabricii	0.64	0.58	0.19	0.70	0.14	0.30	0.42	0.15	5.00
Crustacea spp.	0.00	5.25	0.00	0.46	0.06	0.15	0.25	0.15	0.00
Mysids									
Mysis oculata	0.00	0.00	0.00	45.58	79.43	11.74	91.57	0.89	0.00
Mysis mixta	0.00	0.00	0.00	0.03	0.00	4.01	0.00	0.00	0.00
Mysis mixta	19.80	3.79	0.00	0.00	0.00	0.89	0.00	0.00	0.00
Mysis polaris	0.00	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00
Mysis spp.	0.55	0.00	0.00	5.16	0.00	8.77	0.00	0.00	0.00
Boreomysis nobilis	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00
Boreomysis sp.	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
Meterythrops sp.	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Mysid sp.	0.55	0.58	0.00	1.72	0.31	1.04	0.05	0.00	0.00
All mysids	20.90	4.37	0.00	53.82	79.74	26.45	91.62	0.89	0.00
Euphasids									
Thysanoessa longicaudata	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00
Thysanoessa rashii	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thysanoessa sp.	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00

	Akpatok Island		Coats Island	Digges Sound		the Minarets		PLI	
	1983	2008	2007	1980/81/82	2008/09	1985	2007/08	1976/77	2008
euphasid sp	0.09	0.29	0.06	0.00	0.69	0.00	0.07	0.00	0.00
All euphasids	0.09	0.58	0.06	0.09	0.93	0.00	0.07	0.00	0.00
Decapods									
Natantia sp	0.46	0.00	0.00	0.05	0.02	0.00	0.10	0.00	0.00
Hippolytidae sp.	0.00	0.00	0.06	0.00	0.00	0.00	0.07	0.00	0.00
Argis dentata	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Lebbeus polaris	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Lebbeus microceros	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Sclerocrangon boreas	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Spirontocaris phippsi	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Eualus fabricii	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
All decapods	0.46	0.00	0.06	0.10	0.06	0.30	0.30	0.00	0.00
Hyperiid amphipods									
Themisto libellula	67.77	77.84	98.26	14.80	5.53	0.00	0.15	4.46	30.00
Themisto abyssorum	0.09	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00
Themisto spp.	4.70	0.00	0.06	18.06	0.14	0.00	0.00	2.82	0.00
Hyperia galba	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
Hyperia medusarum	0.00	0.00	0.06	0.07	0.00	0.00	0.00	0.00	0.00
Hyperia spp.	1.01	0.29	0.58	0.41	0.16	0.00	0.39	0.00	50.00
Hyperoche medusarum	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
All hyperid amphipods	73.57	78.13	98.97	33.83	5.85	0.00	0.54	7.28	80.00
Copepods									
Pareuchaeta glacialis	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00
Pareucheata spp.	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
Pareuchaeta norvegica	0.00	0.00	0.00	3.84	0.00	0.00	0.00	0.00	0.00
Metridia longa	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00
Xanthocalanus spp.	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Calanus hyperboreus	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00

	Akpatok Island		Coats Island	Digges Sound		the Minarets		PLI	
	1983	2008	2007	1980/81/82	2008/09	1985	2007/08	1976/77	2008
Calanus spp.	0.00	0.00	0.00	0.00	2.09	0.00	0.00	0.00	0.00
Cyclopina sp.	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Calanoid sp	1.84	0.29	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Harpacticoida sp.	0.00	0.00	0.00	0.12	0.00	0.15	0.00	0.00	0.00
Copepod sp.	0.00	0.00	0.00	0.65	4.11	0.00	0.02	0.00	0.00
All copepods	1.84	0.29	0.06	5.34	7.78	0.15	0.02	0.00	0.00
Cumaceans									
Diastylis rathkei	0.00	0.00	0.00	0.00	0.00	19.02	0.44	0.00	0.00
Lamprops fuscata	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Cumacean sp.	0.00	0.00	0.06	0.00	0.00	0.15	0.02	0.00	0.00
All cumaceans	0.00	0.00	0.06	0.00	0.00	19.32	0.47	0.00	0.00
Gammarid amphipods									
Onisimus nanseni	0.00	0.00	0.00	0.05	0.02	0.15	0.00	0.00	0.00
Onisimus littoralis	0.00	0.00	0.00	0.00	0.00	12.93	3.45	0.15	0.00
Onisimus glacialis	0.00	0.00	0.00	0.00	0.00	2.53	0.00	0.00	0.00
Onisimus plateus	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Onisimus sp.	0.00	0.29	0.00	0.00	0.00	0.30	0.12	23.63	0.00
Anonyx sarsi	0.00	0.00	0.00	0.00	0.00	0.00	0.94	1.63	0.00
Anonyx nugax	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00
Boeckosimus edwardsii	0.09	0.00	0.00	0.03	0.00	0.15	0.00	0.00	0.00
Orchomenella sp.	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fam Lysianassidae	0.00	0.00	0.06	0.00	0.00	15.45	0.02	0.00	0.00
Byblis spp.	0.00	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ampelisca macrocephala	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Fam Ampeliscidae	0.00	0.29	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Apherusa glacialis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00
Apherusa spp.	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Weyprechtia pinguis	0.00	0.00	0.00	0.48	0.00	0.15	0.00	22.59	0.00

	Akpatok Island		Coats Island	Digges Sound		the Minarets		PLI	
	1983	**2008**	**2007**	**1980/81/82**	**2008/09**	**1985**	**2007/08**	**1976/77**	**2008**
Pontegenia inermis	0.00	0.00	0.00	0.02	0.00	0.15	0.00	19.47	0.00
Rhachotropis spp.	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Parapleustes bicuspis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00
Halegonis spp.	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Oediceros spp.	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Monoculodes spp.	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.15	0.00
Fam Stenothoidae	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
Ischyroceridae sp.	0.00	0.00	0.19	1.43	0.00	0.15	0.07	0.00	0.00
Ischyrocerus anguipes	0.00	0.00	0.00	0.00	0.00	20.36	0.00	0.00	0.00
Gammarellus homari	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.15	0.00
Gammarus oceanicus	0.00	0.00	0.00	0.00	0.00	0.00	0.64	0.00	0.00
Gammarus setosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.44	0.00
Gammarus wilkitzkii	0.00	0.00	0.00	0.24	0.00	0.00	0.00	3.27	0.00
Gammarus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.15	0.00
Gammaracanthus loricatus	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Gammarid amphipod species	0.09	0.00	0.00	0.03	0.04	0.30	0.27	8.32	15.00
All Gammarid amphipods	0.37	2.62	0.26	2.39	0.08	53.64	6.31	91.53	15.00
Total number of invertebrates	1086	343	1552	5858	5056	673	4056	673	20