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Merkel, Flemming Ravn; Linnebjerg, Jannie Fries; Andersen, Ole Gorm Norden; Huffeldt, Nicholas Per; Jansen, Teunis; Hedeholm, Rasmus; Frederiksen, Morten

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Changing winter diet of thick-billed murres *Uria lomvia* in Southwest Greenland, 1990s versus 2010s

Flemming Ravn Merkel[1,2], Jannie Fries Linnebjerg[1], Ole Gorm Norden Andersen[1], Nicholas Per Huffeldt[2], Teunis Jansen[2,3] Rasmus Hedeholm[2,4] and Morten Frederiksen[1]

[1]Department of Bioscience, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

[2]Greenland Institute of Natural Resources, Kivioq 2, PO Box 570, 3900 Nuuk, Greenland

[3]DTU AQUA – National Institute of Aquatic Resources, Kemitorvet, Building 202, 2800 Kgs. Lyngby, Denmark

[4] Sustainable Fisheries Greenland, Hellebarden 7, 9230 Svenstrup, Denmark

Corresponding author: *Flemming Ravn Merkel,* frm@bios.au.dk

Changing winter diet of thick-billed murres *Uria lomvia* in Southwest Greenland, 1990s versus 2010s

Abstract

Southwest Greenland constitutes an internationally important wintering area for seabirds, including thick-billed murres (*Uria lomvia* Linnaeus, 1758), but their prey may be affected by the general warming of this sub-Arctic region. We compare murre diet collected in winter in the 1990s and 2010s around Nuuk. Fish made up 36% of the diet (wet mass) and crustaceans 63% in the 1990s, changing to 22% and 78% in the 2010s, respectively. Capelin (*Mallotus villosus* Müller, 1776*)* was the dominant fish species, and the smaller contribution in the 2010s coincided with declining densities of capelin around Nuuk. The crustaceans were dominated by two krill species, *Meganyctiphanes norvegica* M. Sars, 1857*,* and *Thysanoessa inermis* Krøyer, 1846*.* However, *M. norvegica* was only important in the 2010s (51% wet mass), while *T. inermis* was dominating the 1990s with 62% wet mass and only 23% in 2010s. The dominance of *M. norvegica* in the 2010s confirmed our expectations of a gradual "borealization" of this region due to the generally warming sub-Arctic. The smaller contribution of fish in the diet may also support the hypothesis of deteriorating winter conditions for murres. Apart from the diet, plastic was found in 15% of the birds and 53% had parasitic nematods.

Keywords: seabird winter diet, thick-billed murre, *Uria lomvia*, Southwest Greenland, borealization, krill, capelin

Introduction

For migratory bird populations, the non-breeding season represents a very long and usually challenging period of their annual cycle, and their survival and subsequent breeding performance are highly dependent on a predictable and nutritious food base (Scott 1998; Newton 2008; Fort et al. 2009; Milner-Gulland et al. 2011). However, changing climatic conditions are currently affecting biological systems worldwide, especially in Arctic and sub-Arctic regions (Edwards and Richardson 2004; IPCC 2013; Fossheim et al. 2015), and birds may be forced into new feeding habits as regularly observed during the breeding season (e.g. Harris et al. 2007; Grémillet et al. 2012; Provencher et al. 2012). Climate induced ecosystem changes have also been observed in the coastal and offshore waters of Southwest Greenland, which constitute an internationally important wintering area for seabirds, with an estimated minimum number of 3.5–5.5 million birds, originating from the eastern and western North Atlantic (Lyngs 2003; Boertmann et al. 2004, see also http://seatrack.seapop.no). So far, a northerly shift has been documented for Atlantic copepods in this region (Møller and Nielsen 2019) and interdecadal variability of boreal fish abundance was highly influenced by local temperature variability and the dynamics of the subpolar gyre (Post et al. 2021).

One species potentially affected by changes in prey composition and distribution is the thick-billed murre (*Uria lomvia* Linnaeus, 1758), which is among the most numerous seabird species wintering in Southwest Greenland (Boertmann et al. 2004). This species is declining in most areas of Greenland, as well as in most regions of the Northeast Atlantic (Merkel et al. 2014; Kuletz et al. 2017). In a transoceanic analysis of migration patterns, Frederiksen et al. (2016) found a strong association among wintering area and breeding population status, in which stable populations were wintering mainly in Canadian waters, while declining populations wintered mainly in Southwest Greenland or around Iceland. This is in line with murre studies in Svalbard, where population decline and reduced adult survival were linked to an abrupt ecosystem shift in the North Atlantic (Descamps et al. 2013; Fluhr et al. 2017). According to a recent modelling study, winter mortality from oiling and harvest in Canada and Greenland also adds demographic stress to the population.

The impact, however, appears insufficient to explain the observed population decline, especially in Svalbard and Iceland (Frederiksen et al. 2019).

The possible role of the non-breeding season as a central driver for population change in thick-billed murres highlights the need for information about their winter diet. Only one study has previously reported on this and found that murres preyed almost exclusively on capelin (*Mallotus villosus* Müller, 1776) in the southern part of the Greenland wintering area, while crustaceans (mainly euphausiids) played a larger role in more northern wintering areas (Falk and Durinck 1993). Information from Newfoundland waters, the other major Northwest Atlantic wintering area for thick-billed murres, show that capelin was the dominant prey in the 1950s (Tuck 1961), while the diet was more diverse in the 1980s and 1990s, with several fish species, squids, euphausiids and amphipods contributing to the diet (Gaston et al. 1983; Elliot et al. 1990; Rowe et al. 2000).

Here, we report on the second study of the winter diet of thick-billed murres in Southwest Greenland, aimed at detecting any major change in the diet since the first study in the 1980s (Falk and Durinck 1993) Based on the indirect evidence that murres are facing deteriorating winter conditions in Southwest Greenland, we expected to find a larger contribution of low quality prey species in the murre diet, and we expected a larger dominance of boreal prey species based on the general larger influx of Atlantic species in sub-Arctic regions. As in the previous study, birds were shot by local hunters, and we analysed the stomach content of birds collected in mid and late winter in the 1990s and the 2010s in the central part of the wintering area west of Nuuk. We explore the influence of sampling decade, month and sex on prey selection, and we discuss the results in relation to previous knowledge about murre winter diet and possible links to ecosystem change.

Methods

Study area

The study area included the coastal area west of Nuuk, Southwest Greenland (Fig. 1). This is a key wintering area for thick-billed murre, common eider, *Somateria mollissima* Linnaeus, 1758, king eider, *S. spectabilis* Linnaeus, 1758, and long-tailed duck, *Clangula hyemalis* Linnaeus, 1758 (Merkel et al. 2019). The murres winter in the shelf region off Southwest Greenland, including the near-coastal archipelago (Boertmann et al. 2004). Seabird hunting is important to Greenlanders during winter in Southwest Greenland, and the thick-billed murre is one of the most important seabird species for hunters in this area (Merkel and Tremblay 2018). The coastal area and the inner shelf region west of Nuuk constitute the main hunting grounds for local hunters (Fig. 1).

Sample collections and measurements

This study was conducted in accordance with the ethical standards of the Greenland Institute of Natural Resources, and the murres used for diet analyses were shot by local hunters as part of their traditional winter harvest for the local market in Nuuk. Birds were shot by multiple hunters on 26 February 1996 (n = 36), 7 January 1997 (n = 13), 5 March 1997 (n = 41), 4 January 2012 (n = 20), 6 January 2012 (n = 14), 1 January 2017 (n = 1), 1 February 2017 (n = 9) and 6 February 2017 (n = 11), hereafter referred to as the 1990s (n = 90 murres) and the 2010s (n = 55 murres). All birds were shot west of Nuuk (Fig. 1). Birds were stored frozen at -18°C until dissected in 2017, when the stomach, i.e., the proventriculus including the lower part of the oesophagus and the gizzard, was removed and refrozen until diet analysis began in 2019.

Birds were aged and sexed during dissection. The sex was determined by the presence of oviduct or testicles. First-winter birds were distinguished from older birds by having an externally measured interorbital skull width of <12.5 mm (Gaston and Hipfner 2000). Where possible, this criterion was

combined with the presence or absence of bursa fabricii, the size of the testicles in males and the form of the oviduct (strait or convoluted) in females (Nevins and Carter 2003).

Upon opening the proventriculus and the gizzard (separated at the entrance to the gizzard), the content was washed into a tray to make sure that no small objects were missed. Contents from the proventriculus and from the gizzard were analysed separately due to the expectation that quickly digestible species would be under-represented in the gizzard. Food items were identified to species level whenever possible using standard identification literature (Muus 1959; Enckell 1980; Härkönen 1986; Kirkegaard 1992; Muus and Nielsen 1998). Fish were detected by the presence of otoliths, spines, bone fragments and eye lenses. The otoliths were measured to the nearest 0.1 mm on a millimetre paper placed in a petri dish. Crustaceans were measured from the anterior part of the head (tip of rostrum) to the tip of the telson. As they were often fragmented, they were counted by the number of eyes (in pairs). Pebbles and plastic particles were also recorded.

As the stomach content in most cases was partially digested, the wet mass composition was estimated from the number of individuals and their length, or the length of the otoliths for the fish. Both the overall percentages of wet mass and the aggregate percentages (the average of individual percentages) were calculated. For all prey species but capelin, it was not possible to assign a mean prey length to individual birds due to the fragmentation of most prey specimens. Instead, the overall mean prey length, measured across samples, was assigned to all birds. In the case of otoliths, we included length measurements from the gizzard content, as otoliths in the proventriculus usually are still inside the fish, while they are retained in the gizzard for some time. For the most frequent prey species, i.e., capelin, the krill (euphausiids) *Meganyctiphanes norvegica* M. Sars, 1857 and *Thysanoessa inermis* Krøyer, 1846 and the amphipod *Themisto libellula* Lichtenstein, 1822, we used the same length-mass regressions as in Falk and Durinck (1993).

Unidentified euphausiids were assigned the same length as the most common species in the same sampling period, e.g., *Thysanoessa inermis* in the 1990s and *Meganyctiphanes norvegica* in the 2010s. A single specimen of the amphipod *Anonyx lilljeborgi* Boeck, 1871 was assigned the same mass as an average sized *Themisto libellula*. The same applies for five specimens of unidentified gammarids and four (+1 from gizzard) unidentified amphipods. Two specimens of unidentified gadoids (+ 3 from gizzard) and one (+ 3 from gizzard) ragworm (*Nereis sp*.) were assigned a mass of 36 g and 0.5 g, respectively, based on information from Falk and Durinck (1993). Twenty-one specimens of glacier lanternfish (*Benthosema glaciale* Reinhardt, 1837) were each assigned a mass of 8 g, corresponding to a medium-sized capelin. Three specimens of unidentified decapods and one pasiphaeid shrimp *Pasiphaea tarda* Krøyer, 1845, were assigned a mass of 2 g (+ 1 penaeid shrimp from gizzard), corresponding to a small/medium sized *Pandalus borealis* Krøyer, 1838, the most common shrimp species in West Greenland (A. Burmeister 2020, personal communication). For 11 specimens of *Calanus* spp., one harpacticoid copepod and six unidentified squid/cuttlefish (cephalopods), we used direct mass measurements of the most complete individual found in the diet. Finally, 2.1 g of crustacean fragments (+ 4.1 g from gizzard) and another 2.3 g of unidentifiable diet fragments (+ 0.9 g unknown from gizzard), were not included when calculating the frequency and mass composition.

Information about the body condition of the murres, such as total body mass and abdominal fat pad mass, was also collected during dissection. However, these data were strongly influenced by the duration of storage in the freezer prior to dissection, which varied from a few months to 21 years. As we found no reliable method to correct for this bias, we did not use the data.

Data analyses

Previous studies of the murre harvest in Nuuk have shown that the proportion of first-winter birds is low after 1 January (Frich 1997; Frederiksen et al. 2019). This was also the case in this study. In total we had only 13 first-winter birds, which were all collected in the 2010s. In the diet analysis, these birds were

pooled with the older birds as the key prey species and their relative proportions appeared similar for both age-classes.

We applied zero-one-augmented beta regression for the observed proportion (by mass) of the three main prey types (capelin, *Meganyctiphanes norvegica*, *Thyssanoessa inermis*) separately. Beta regression, including the zero-one-augmented type that allows the presence of zeros and ones in the dataset (Ospina and Ferrari 2012), is a relatively recently developed alternative for analysing proportional data derived from continuous measurements (Ferrari and Cribari-Neto 2004). Such data do not follow standard statistical distributions, and cannot be analysed using binomial or multinomial methods (Douma and Weedon 2019). All models fitted had the same predictors for the beta component of the mixture and for the binomial proportions of zeros and ones. Models were fitted in the R package brms (Bürkner 2017), using four chains of 5000 samples from the posterior distribution with the first 2500 samples discarded as warmup. We used leave-one-out cross-validation in the R package loo (Vehtari et al. 2017) to select the most appropriate model to describe the data. Model convergence was assessed using trace plots and Rhat (Brooks and Gelman 1998). Models fitted included the effects of decade (1990s vs 2010s), month (January, February, March) or both (additive or interactive). An additive effect of sex was added to the model with the best structure for temporal variation, but did not improve the model for any of the prey types (results not shown).

Potential differences in the number of prey species per stomach between the two decades were tested using zero-truncated Poisson regression in the R package VGAM (Yee 2015), after removing three empty stomachs from February 1996. Differences in length distribution of capelin between the two study periods were examined using Kolmogorov-Smirnov and Wilcoxon tests in R (R Core Team 2018). Means are reported with standard error (mean ± SE), unless noted otherwise.

Results

Diet discrimination

The murre stomach content included a total of 29,478 prey items, of which 95% were found in the proventriculus and the remaining 5% in the gizzard (Tab. 1). Except for a few polychaetes (*Nereis* spp.) and squid (cephalopods), the murres were feeding exclusively on fish and crustaceans during winter (Fig. 2). When combining the contents from the proventriculus and the gizzard, a total of 19 species (or taxa) were identified (Tab. 1). In accordance with the expectation that the turn-around time in the stomach differs between prey species, the gizzards contained a larger proportion and higher diversity of fish (otoliths), but in contrast had a lower proportion and fewer species of crustaceans. Most birds (90%) had only one, two or three prey species in the proventriculus (Tab. 2). However, the mean number of prey species per stomach was significantly higher in the more recent sampling decade ($z = 2.829$, $p < 0.005$). In the 1990s, four prey species (6% of birds) was the highest number recorded, while 20% of the birds from the 2010s had between four and six prey species although sample size was smaller and no samples were collected in March (Tab. 2).

In terms of frequency of occurrence, four species were important in the proventriculus; capelin, the two krill species *M. norvegica* and *T. inermis,* and the amphipod species *Themisto libellula*, being present in 27% - 89% of the birds (Tab. 1). When expressed as estimated wet mass, the capelin and the krill *T. inermis* constituted the two most important species in the 1990s (36% - 62% of the total wet mass), while also the krill *M. norvegica* was important in the 2010s (Tab. 1). In both decades, the amphipod *T. libellula* was no longer important when calculated as estimated wet mass (Tab. 1).

Prey sizes

The length of the four most common prey species ranged from 11.0 mm to 143.7 mm: with a mean length of 110.1 ± 0.6 mm (n = 500) for capelin, 41.2 ± 0.7 mm (n = 100) for *M. norvegica*, 25.9 ± 0.4 mm (n = 23) for *T. inermis* and 17.6 ± 1.5 mm (n = 20) for *T. libellula*. The size distribution of the capelin differed between the 1990s and the 2010s (Kolmogorov-Smirnov test D = 0.145, p = 0.014, Wilcoxon test W = 34500, p = 0.0014), although the median length was identical in both periods (112.6 mm). It appears that in both decades the murres were feeding on capelin of sizes corresponding to ages of 2 and up, i.e. several age-groups of capelin except the smallest (hatched in the year before the sampling year) (Fig. 3).

Temporal variation

A shift occurred between the two sampling decades with respect to krill. *M. norvegica* was almost absent in the 1990s, but accounted for 51% of the wet mass in the 2010s (Tab.1). The opposite trend was observed for *T. inermis,* which by mass accounted for 62% in the 1990s, but only 23% in the 2010s. The overall diet contribution from capelin also changed between the two decades, from 36% in the 1990s to 19% in the 2010s. The direct comparison between the 1990s and the 2010s is biased by the fact that birds from March were only collected in the first decade. If comparing only birds collected in January and February, the 1990s was almost exclusively dominated by capelin. The beta regression showed that for the two main prey types where all models converged (capelin and *M. norvegica*), models including effects of both decade and month were strongly preferred (Tab. 3), whereas the need for including an interaction term between the two predictors was less clear. For consistency, we display results for all three prey types according to the month*decade model, i.e. separately for each combination of decade and month (Fig. 4). In the 2010s, capelin only contributed significantly to the diet in February. Instead, *M. norvegica* dominated the diet in January in the 2010s. The March samples from the 1990s were completely dominated by *T. inermis* (Fig. 4). The influence of decade and month may include an inherited effect of year; however, this potential effect

could not be quantified due to an unequal representation of samples between months and years. According to the beta regression analysis, sex did not influence the diet composition (see Methods).

Non-food items

Apart from the diet reported in Tab. 1, a number of non-food items were found in the stomachs. Plastic was found in 10 birds from the 1990s and in 11 birds from the 2010s, i.e., in 15% of the birds. All but one piece was found in the gizzard, with a maximum of three pieces per bird. A total of 32 pebbles were found in the gizzard in 14 and 4 birds from the 1990s and the 2010s, respectively. Parasitic nematods (*Nematoda*) were observed in 53% of the birds, usually both in the proventriculus and the gizzard. A total of 737 nematods were found in 55 and 19 of the birds from the 1990s and the 2010s, respectively. Up to 86 nematods were recorded in a single bird.

Discussion

General food base

The present study shows that capelin and krill (*M. norvegica* and *T. inermis*) form the main food base for thick-billed murres in the central part of their wintering area in Southwest Greenland. A similar narrow food base, with capelin as the main fish component, was also reported in Southwest Greenland in the 1980s (Falk and Durinck 1993) and in Newfoundland waters in the 1950s (Tuck 1961). Later studies from Newfoundland waters, the Barents Sea and northern Iceland reported only a small or no contribution from capelin (Elliot et al. 1990; Erikstad 1990; Rowe et al. 2000; Lilliendahl 2009).

Capelin availability

One of the marked changes found in the current diet study was the smaller contribution of capelin in the 2010s compared to the 1990s and the 1980s. This may be a result of fewer capelin being available for the

murres in the 2010s. Capelin catch data from two stratified random bottom-trawl offshore surveys (see survey data descriptions in Post et al. (2021)) are available for the Nuuk area (63 - 65°N). The surveys take place in the summer, and because adult capelin die after spawning in the spring, it is the catch rates in the summers preceding the bird collections that are relevant as proxies for capelin availability for the sampled murres. Surveys were not conducted in all years; however, the available pieces of information do suggest higher capelin abundance in the relevant years in the 1990s compared to the 2010s. Data from a German survey show that capelin were present in 47% of the trawls in 1996 (N=17), while only in 10% of the trawls in 2011 (N=10). Although catch efficiency is not comparable with the German survey due to differences in sampling gear, data from the Greenland Institute of Natural Resources can be used to add information about 2016 relative to 2011: 64% of the trawls in 2011 contained capelin (N=25) vs. only in 22% in 2016 (N=27).

Reasons for a possible decline in capelin density could be many: environmental changes, such as suggested for the decline in Iceland/East Greenland (Jansen et al. 2021), or a change in predation pressure from large populations of well-known capelin predators, such as Atlantic cod *Gadus morhua,* harp seal *Pagophilus groenlandicus* and humpback whale *Megaptera novaeangliae* (Heide-Jørgensen et al. 2012; ICES 2014, 2020). Unlike the stocks that spawn in Canada, Iceland and Norway, these West-Greenland capelin have not been targeted by large scale commercial fisheries, so fishing is not a direct cause for this decline (Vader et al. 1990; Rowe et al. 2000; Gudmundsdottir and Vilhjálmsson 2002; ICES 2020).

Capelin versus krill

Capelin is high in fatty acids and normally considered a superior prey species for murres compared to invertebrate prey species, including krill (Erikstad 1990; Falk and Durinck 1993, and references therein). This may, however, vary between regions and seasons. Measurements of the energy content of capelin and krill from local stocks in the Nuuk area show that the calorific value of capelin (4.3 kJ/g wet mass) was actually lower than for *M. norvegica* (6.0 kJ/g wet mass) and *Thysanoessa raschii* M. Sars, 1864 (6.4 kJ/g

wet mass) when measured in July[1]. No local measurements are available for *T. inermis* or for any of the species during mid-winter, when the diet samples were collected for this study. However, based on an Icelandic study, the energy density of capelin can be 2-3 times higher during mid-winter (Engilbertsson 2014). The energy value of krill also appears to be higher during winter, but seemingly not to the same degree as for capelin (Falk-Petersen et al. 2000). Furthermore, the mean wet mass of capelin was 7.16 g while only 0.35 g for the largest krill species (*M. norvegica*), and therefore capelin contributed with at least 20 times more energy per prey capture than krill. Besides the energy content of the prey, the profitability of feeding on a specific prey type also depends on the energetic costs involved. This is likely a trade-off between predictability of the prey, prey density, prey escape capabilities and how deep the murres have to dive to feed on them (Elliott et al. 2008). According to acoustic surveys in March 2019 and 2021, krill are consistently distributed at greater depth than capelin in the area around Nuuk (T. Jansen, unpublished data).

Changes in krill composition

Besides the decreased contribution of capelin in the diet in the 2010s, a marked shift in the krill composition has been observed in the murre diet. *M. norvegica* was absent in the 1980s (Falk and Durinck 1993), almost absent in the 1990s (this study), but accounted for 51% of the wet mass in the 2010s (this study, Tab. 1). *T. inermis* was important in all three sampling decades. In contrast, *T. raschii* was reported only in the 1980s (Falk and Durinck 1993), although we cannot rule out the possibility that some were present among the unidentified euphausiids in this study (Tab. 1). The fact that both *M. norvegica* and *T. inermis* are larger species than *T. raschii* (Agersted and Nielsen 2016 and references therein), resulting in a higher energy gain per prey item for the murres, could perhaps be part of the explanation why *T. raschii* was absent. A study by Agersted and Nielsen (2014) showed that all three species coexist in the Nuuk area, but did not show how they are distributed during winter. However, *T. raschii* is known as a coastal species,

[1] See Supplementary Material

whereas *M. norvegica* and *T. inermis* are known to inhabit shelf-regions (see references in Agersted and Nielsen 2014), and this may indicate that the murres collected for this study were feeding far from the coast. We do not know how far from the coastline the murres were shot, but we know that hunting usually takes place beyond the coastal archipelago. Furthermore, according to local hunters from Nuuk, it happens more and more that murres cannot be reached within a safe boating distance (Haastrup 2017).

Krill are considered as a good indicator of changes in the food web composition from a bottom-up as well as a top-down perspective (Hempel 1970), and the larger contribution of *M. norvegica*, a boreal Atlantic species, may be a consequence of general "borealization" of the generally warming sub-Arctic (e.g. Vihtakari et al. 2018; Post et al. 2021). A shift towards more Atlantic krill species has been observed in Svalbard and farther east in the Barents Sea, including *M. norvegica* (Eriksen and Dalpadado 2011; Buchholz et al. 2012). A northerly shift has also been documented for Atlantic copepods, the main prey for *M. norvegica*, including in the waters off central West Greenland (Hatun et al. 2009; Møller and Nielsen 2019).

Conclusion

The shift in diet towards boreal Atlantic krill species is in line with the expectations and observations of how global warming affects the sub-Arctic and Arctic regions of the North Atlantic (e.g. Vihtakari et al. 2018; Møller and Nielsen 2019; Post et al. 2021). It is currently not known whether this shift affects the fitness of thick-billed murres in our study area, but combined with the observed smaller contribution of the high-energy capelin, the results suggest deteriorating winter conditions for the murres, thus supporting earlier, more indirect studies spanning the North Atlantic (Descamps et al. 2013; Frederiksen et al. 2016; Fluhr et al. 2017). Clearly, our results should be treated with caution since they are based on small sample sizes, relatively few sampling years as well as unequal sampling between years and months. Efforts should be made to collect more data in the near future to better understand the temporal and spatial dynamics of these prey species, including their size and energy value, and the consequences for seabird fitness. More data on seabird winter diet can also provide useful indices of fish or invertebrate abundance to supplement

the more traditional ship-based surveys in seasons and areas that are difficult to cover. Until then, this study provides a valuable contribution to the limited knowledge about winter diet of seabirds in the Northwest Atlantic.

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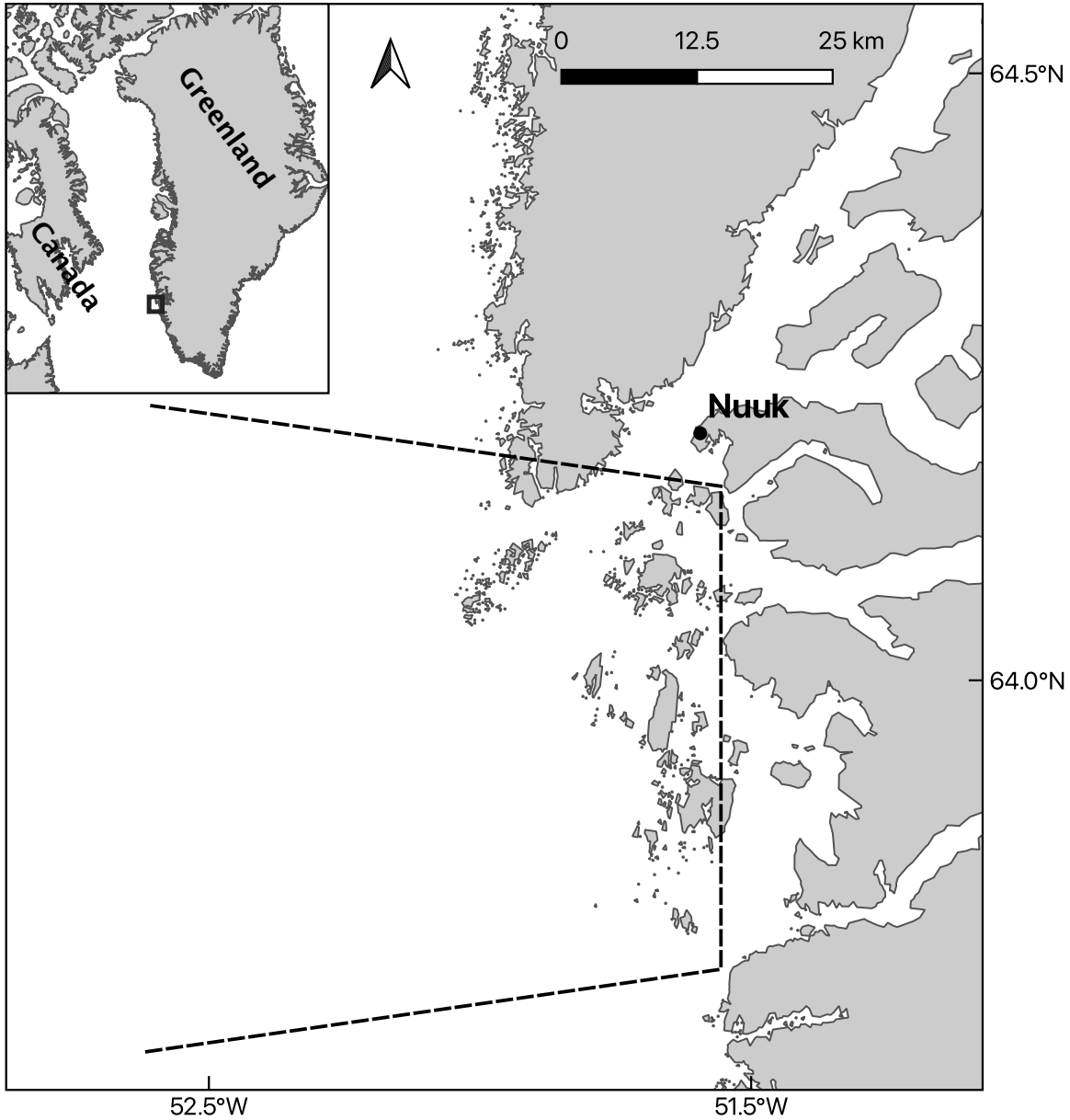
Figure captions

Fig. 1. Map of the study area in Southwest Greenland (dashed line), where thick-billed murres (*Uria lomvia)* were shot by local hunters. The western demarcation is unknown, but most likely does not extend beyond the map. Figure was created using QGIS version 3.16 (QGIS Development Team, 2021. QGIS Geographic Information System. Open Source Geospatial Foundation Project http://qgis.osgeo.org), using base maps from QGreenland version 1.0.0 (Moon et al. 2021). Map projection is EPSG: 3413.

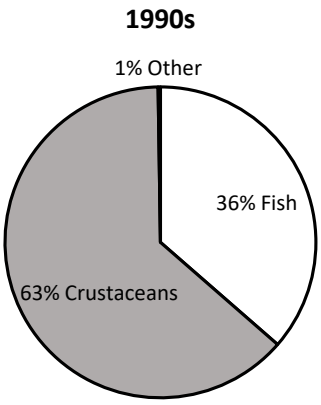
Fig. 2. The wet mass contribution of crustaceans, fish and other diet in 140 proventriculi samples of thick-billed murres (*Uria lomvia*) collected west of Nuuk, Southwest Greenland, in January – March 1996 and 1997 (1990s, n=85) and in January-February 2012 and 2017 (2010s, n=55).

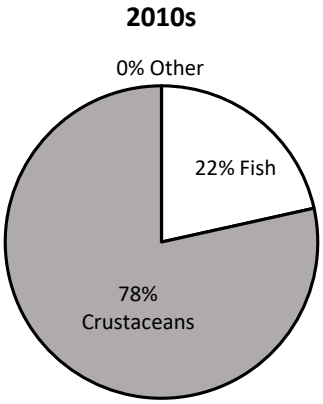
Fig. 3. Frequency distribution of capelin (*Mallotus villosus*) sizes from the diet of thick-billed murres (*Uria lomvia*) collected west of Nuuk, Southwest Greenland, in January – March 1996 and 1997 (1990s) and in January-February 2012 and 2017 (2010s).

Fig. 4. Proportions of the three most important prey species in the diet of thick-billed murres (*Uria lomvia*) from Nuuk during mid-winter, calculated as the aggregate percentage of wet mass for all the diet and grouped according to months and sampling decades.



	1990s	2010s
Fish	36%	22%
Crustacear	63%	78%
Other	0%	0%
TOTAL	3903	2537.8





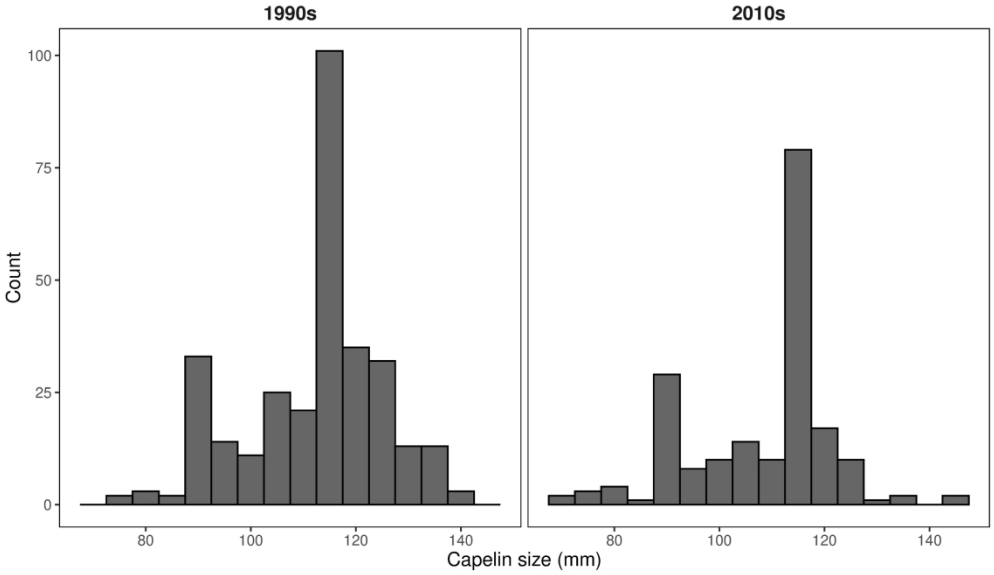


Fig. 3. Frequency distribution of capelin (Mallotus villosus) sizes from the diet of thick-billed murres (Uria lomvia) collected west of Nuuk, Southwest Greenland, in January – March 1996 and 1997 (1990s) and in January-February 2012 and 2017 (2010s).

238x140mm (300 x 300 DPI)

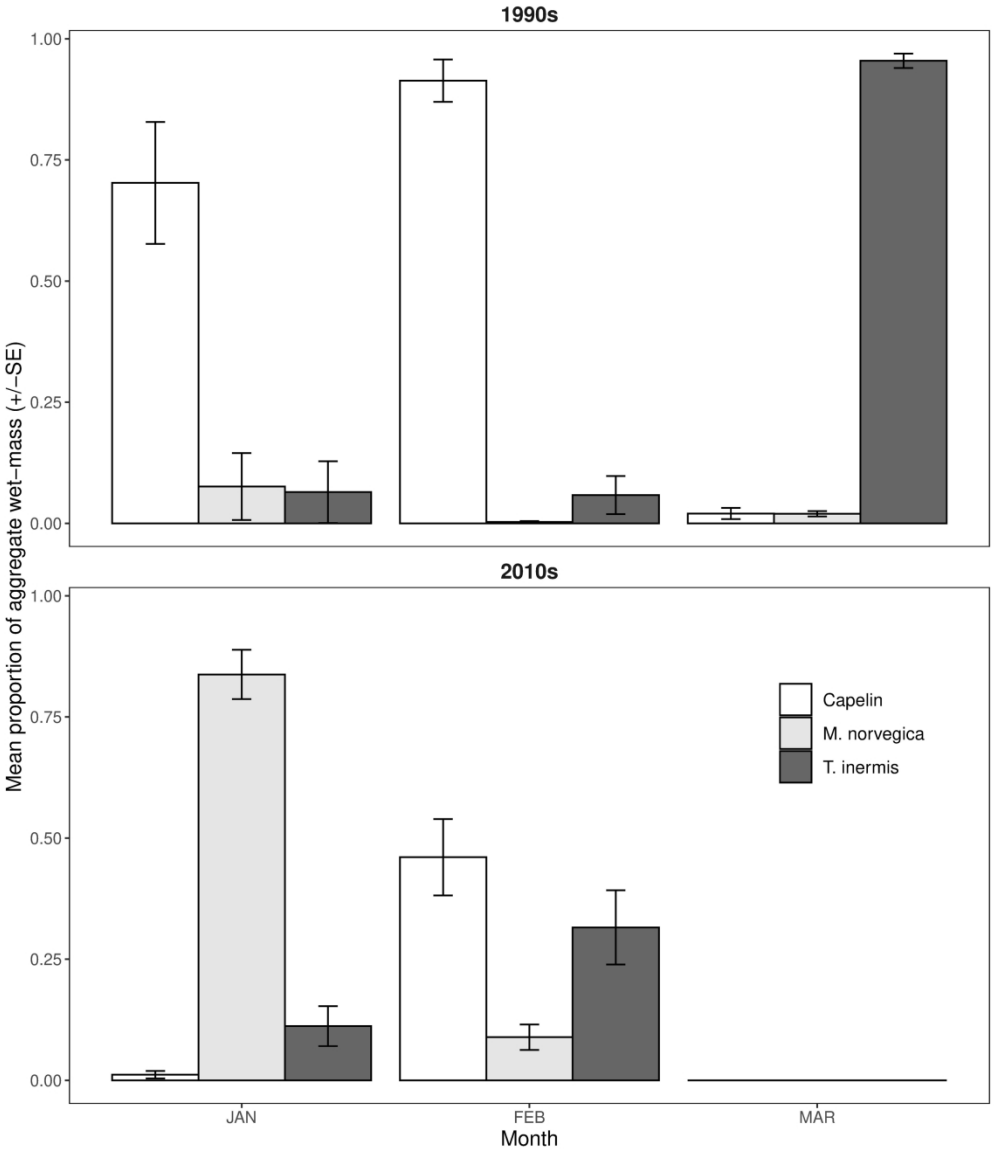


Fig. 4. Proportions of the three most important prey species in the diet of thick-billed murres (Uria lomvia) from Nuuk during mid-winter, calculated as the aggregate percentage of wet mass for all the diet and grouped according to months and sampling decades.

238x277mm (300 x 300 DPI)

Tab. 1. The number of prey items, the frequency of occurrence and the estimated wet mass of the diet of thick-billed murre (*Uria lomvia*) from 140 proventriculi and gizzard samples, collected in January – March 1996 and 1997 (1990s, n=85) and in January – February 2012 and 2017 (2010s, n=55) west of Nuuk, Southwest Greenland

	Number	Frequency of occurence				Estimated Wet Weight (g)			
		1990s		2010s		1990s		2010s	
	Indv. prey	N birds	%	N birds	%	Total ww	%	Total ww	%
Proventriculus samples									
Fish									
Mallotus villosus	259	43	51	18	33	1421.5	36	474.3	19
Unid. codfish	2			1	2			72.0	3
Crustaceans									
Meganyctiphanes norvegica	3813	33	39	49	89	38.9	1	1296.8	51
Thysanoessa inermis	23481	46	54	29	53	2415.7	62	584.6	23
Unid. euphausiids	238	2	2	4	7	0.4	<1	82.3	3
Themisto libellula	170	23	27	25	45	9.3	<1	25.9	1
Anonyx lilljeborgi	1			1	2			0.2	<1
Unid. gammarids	5			2	4			1.1	<1
Unid. amphipods	4	1	1	3	5	0.2	<1	0.6	<1
Pasiphaea tarda	1	1	1			2.0	<1		
Unid. decapods	3	2	2			6.0	<1		
Calanus sp.	11	2	2	3	5	0.0	<1	0.1	<1
Harpacticoida sp.	1			1	2			0.0	<1
Other taxa									
Unid. cephalopods	6	4	5			9.0	<1		
Nereis sp.	1	1	1			0.5	<1		
Gizzard samples									
Fish									
Mallotus villosus	319	50	57	19	35	1581.6	79	723.3	79
Benthosema glaciale	20	5	6	1	2	144.0	7	16.0	2
Unid. codfish	3	2	2			108.0	5		
Unid. fish	6	1	1	2	4	16.0	1	32.0	3
Crustaceans									
Meganyctiphanes norvegica	102	5	6	16	29	4.2	<1	31.5	3
Thysanoessa inermis	159	4	5	7	13	10.0	1	10.3	1
Unid. euphausiids	801	41	47	27	49	77.2	4	69.0	8
Themisto libellula	17	6	7	3	5	2.9	<1	0.6	<1
Unid. amphipods	1			1	2			0.2	<1
Pandalus borealis	1	1	1			2.0	<1		
Penaeid shrimps	2	1	1	1	2	2.0	<1	2.0	<1
Other taxa									
Unid. cephalopods	47	13	15	13	24	40.5	2	30.0	3
Nereis sp.	4	3	3	1	2	1.5	<1	0.5	<1
Proventriculus + gizzard									
Fish									
Mallotus villosus	578	51	57	21	38	3003.1	51	1197.6	35
Benthosema glaciale	20	5	6	1	2	144.0	2	16.0	<1
Unid. codfish	5	2	2	1	2	108.0	2	72.0	2
Unid. fish	6	1	1	2	4	16.0	<1	32.0	1

Crustaceans									
Meganyctiphanes norvegica	3915	35	39	49	89	43.1	1	1328.4	38
Thysanoessa inermis	23640	46	52	29	53	2425.6	41	594.9	17
Remaining species/taxa	1314					153.5	3	212.4	6

TABLES

Tab. 2. Percentage of proventriculus from thick-billed murre (*Uria lomvia*) containing between one and six different prey species, calculated by sampling decade and for all birds (sample sizes in parentheses).

No. of prey species	1990s (85)	2010s (55)	All birds (140)
1	37.2	18.2	29.8
2	37.2	40.0	38.3
3	19.8	21.8	20.6
4	5.8	12.7	8.5
5		5.5	2.1
6		1.8	0.7

Tab. 3. Comparison of models fitted for capelin (*Mallotus villosus*) and *Meganyctiphanes norvegica*. All models including month as predictor for *Thysanoessa inermis* failed to converge. Values shown are differences in elpd, or expected log pointwise predictive density, between each model and the best approximating model (Vehtari et al. 2017), and the associated standard error. Differences between models are meaningful if they are several times larger than their standard error.

Model	Prey type	
	Capelin	*M. norvegica*
Null	73.0 (SE 9.8)	63.6 (SE 15.5)
Decade	59.7 (SE 9.0)	30.2 (SE 13.1)
Month	34.1 (SE 6.8)	29.2 (SE 12.6)
Month + Decade	14.0 (SE 5.6)	1.4 (SE 3.4)
Month * Decade	0	0