SEABIRD BASELINE STUDIES IN BAFFIN BAY 2008-2013

Colony-based fieldwork at Kippaku and Apparsuit, NW Greenland

Scientific Report from DCE – Danish Centre for Environment and Energy No. 110 2014

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Morten Frederiksen[1]
Knud Falk[1]
Nicholas Per Huffeldt[1]
Kasper Johansen[1]
Aili Lage Labansen[2]
Jannie Fries Linnebjerg[1]
Flemming Merkel[1,2]
Anders Mosbech[1]

[1] Aarhus University, Department of Bioscience
[2] Greenland Institute of Natural Resources

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Data sheet

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Authors: Morten Frederiksen[1], Knud Falk[1], Nicholas Per Huffeldt[1], Kasper Johansen[1], Aili Lage Labansen[2], Jannie Fries Linnebjerg[1], Flemming Merkel[1,2] & Anders Mosbech[1]
Institutions: [1]Aarhus University, Department of Bioscience & [2]Greenland Institute of Natural Resources

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Abstract: As part of the environmental studies in connection with oil exploration in Baffin Bay, baseline studies of seabird ecology were carried out at colonies north of Upernavik during the summers of 2008-13. The main study species were thick-billed murre and black-legged kittiwake. GPS tracking of both species showed that important foraging areas during the breeding season (July) included fiords and archipelagoes as well as the open Baffin Bay up to 40 km offshore. These areas overlapped with existing exploration licenses. Conditions for breeding murres and kittiwakes in the study area were very good in 2008-13. This indicates that the availability of high-quality food in the area was good.
The results of the baseline studies provide a benchmark, which will allow the evaluation of impacts of future oil activities or other environmental changes.

Keywords: Baffin Bay, baseline studies, black-legged kittiwake, Greenland, oil exploration, *Rissa tridactyla*, seabird ecology, thick-billed murre, *Uria lomvia*

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Preface

In 2006, the Greenland Bureau of Minerals and Petroleum decided to initiate a decision granting process towards hydrocarbon exploration licenses in Baffin Bay. In order to support this process, a number of background studies of important environmental aspects were initiated, including the present study of breeding seabirds. Following granting of licenses in Baffin Bay in late 2010, a further strategic environmental study programme was initiated, including a continuation of the breeding seabird study. This report describes and presents results of the colony-based seabird study in the Upernavik area, mainly focused on the island of Kippaku.

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This study is part of the Baffin Bay Environmental Study Program conducted by the Danish Centre for Environment and Energy, Aarhus University (DCE) and the Greenland Institute of Natural Resources (GINR) for the Bureau of Minerals and Petroleum, Greenland Government, and financed by license holders in the area. Additional funding for the analysis of kittiwake migration was provided by the Danish Ministry of the Environment.

Summary

As part of the environmental studies in connection with oil exploration in Baffin Bay, baseline studies of seabird ecology were carried out at colonies north of Upernavik during the summers of 2008-13. Most of the field work took place at the small island of Kippaku, with additional studies at nearby Apparsuit in 2013. The main study species were thick-billed murre and black-legged kittiwake. Data collection was to a large extent carried out with bird-borne electronic data loggers and time-lapse cameras, supplemented by observations.

GPS tracking of both species showed that important foraging areas during the breeding season (July) included fiords and archipelagoes as well as the open Baffin Bay up to 40 km offshore. These areas overlapped with existing exploration licenses. Both study species overwintered mainly on and east of the banks of Labrador and Newfoundland, and in the Labrador Sea and Davis Strait.

Conditions for breeding murres and kittiwakes in the study area were very good in 2008-13. Breeding was early, parent birds did not have to work very hard, chicks grew rapidly and overall breeding success was high. These findings indicate that the availability of high-quality food (probably mainly capelin and polar cod) in the area was good. There were some differences among years, with later breeding in 2011 and 2013, probably due to later ice break-up.

The results of the baseline studies provide a benchmark, which will allow the evaluation of impacts of future oil activities or other environmental changes. Kippaku would be highly appropriate as a base for long-term monitoring of seabirds in Baffin Bay.

Sammenfatning

Som en del af miljøundersøgelsesprogrammet i forbindelse med olieefterforskning i Baffinbugten blev der udført basisundersøgelser af havfugleøkologi i kolonier nord for Upernavik i somrene 2008-13. Det meste af feltarbejdet fandt sted på den lille ø Kippaku, med supplerende undersøgelser på den nærliggende Apparsuit i 2013. De vigtigste studiearter var polarlomvie og ride. Dataindsamlingen blev i stort omfang udført med elektroniske dataloggere monteret på fuglene samt tidsstyrede kameraer, suppleret med observationer.

GPS-sporing af begge arter viste at de vigtigste fødesøgningsområder i ynglesæsonen (juli) omfattede fjorde og øgrupper såvel som den åbne Baffinbugt op til 40 km fra kysten. Disse områder overlappede med eksisterende efterforskningslicenser. Begge studiearter overvintrede i hovedsagen på og øst for bankerne ved Newfoundland og Labrador, samt i Labradorhavet og i Davisstrædet.

Forholdene for ynglende lomvier og rider i undersøgelsesområdet var meget gode i 2008-13. Fuglene ynglede tidligt, forældrefuglene måtte ikke arbejde særligt hårdt, ungerne voksede hurtigt og ynglesuccesen var høj. Disse resultater indikerer at tilgængeligheden af højkvalitetsføde (formodentlig overvejende lodde og polartorsk) var god. Der var visse forskelle mellem årene, med senere ynglen i 2011 og 2013, formodentlig på grund af at isen brød op senere.

Resultaterne fra basisundersøgelserne udgør et udgangspunkt, som muliggør en vurdering af påvirkninger fra fremtidige olieaktiviteter eller andre miljøændringer. Kippaku vil være yderst velegnet som basis for et langtidsovervågningsprogram for havfugle i Baffinbugten.

Eqikkaaneq

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1 Introduction

Seabirds are among the most visible components of marine ecosystems, and particularly in Arctic systems they are among the most important consumers of fish and zooplankton. They are therefore regarded as good indicators of the state of marine ecosystems. In Greenland, seabirds are also traditionally important hunting objects. Furthermore, they are well known to be extremely vulnerable to pollution in the form of oil spills, chiefly because smearing with even tiny amounts of oil destroys the waterproofing of their plumage and quickly leads to death through hypothermia, drowning or starvation. Most seabirds breed highly concentrated in large colonies, increasing the potential for serious impact on populations in case of major oil spills. The Greenland shores of Baffin Bay house very large breeding seabird populations, and a good knowledge of their distribution and ecology is important for assessment of the risks related to hydrocarbon exploration and exploitation in the area, for planning to mitigate risks, and for evaluating potential impacts.

Fieldwork at Kippaku has focused on two cliff-nesting seabird species of high importance in Greenland. The thick-billed murre (or Brünnich's guillemot) *Uria lomvia* is a medium-sized pursuit-diving alcid with a circumpolar Arctic distribution (Gaston & Hipfner 2000). It is ecologically important as a major consumer of fish and large zooplankton, and traditionally the most important seabird for hunters in Greenland. The species is widely distributed in West Greenland, but has declined dramatically (Kampp et al. 1994) and is now red-listed as Vulnerable (Boertmann 2007). A recent overview shows that the decline continues, and that only populations in northern Baffin Bay can be regarded as stable (Merkel et al. 2014). The black-legged kittiwake *Rissa tridactyla* is a surface-feeding pelagic gull, distributed from Arctic to boreal waters in the Atlantic and Pacific (Hatch et al. 2009). It is a numerous species and an important quarry for seabird hunters in Greenland. Despite the wide distribution, the species is declining in Greenland (Labansen et al. 2010) and elsewhere in the North Atlantic (Frederiksen 2010), and it is red-listed as Vulnerable (Boertmann 2007). Some data have also been collected on the black guillemot *Cepphus grylle*, which is a common and widespread alcid in West Greenland, breeding under boulders in loose colonies and mainly feeding on benthic fish.

Murres and kittiwakes were selected for study because they are among the most numerous seabirds in the Baffin Bay, often breed together, are relatively easy to study, and are an important resource for local hunters. In addition, as respectively deep-diving (murre) and surface feeding (kittiwake) foragers, they serve as indicators for different aspects of the marine environment. The aim of the study was to establish an ecological baseline, i.e. sufficient knowledge on the 'normal' situation and the year-to-year variability to enable assessment of potential effects of future hydrocarbon-related activities. We focused on the following aspects:

- Documenting the space use of seabirds throughout the annual cycle, i.e. both during the breeding season when they are limited by the need to return to the colony several times per day to feed their offspring, and outside the breeding season when they are independent of land, range widely at sea and migrate substantial distances to escape winter darkness and complete ice cover in the region.

- Quantifying time budgets of breeding birds (mainly murres), in order to evaluate how hard birds have to work to provide their offspring with sufficient food. Time budgets are a sensitive indication of prey availability in the area (Cairns 1987, Piatt et al. 2007).
- Evaluating fundamental population parameters such as population size, timing of breeding (phenology), breeding success, survival, chick growth and diet.

Fieldwork on remote islands in the Arctic is logistically challenging and expensive, and furthermore the main study site at Kippaku is subject to specific limitations, viz. lack of fresh water and a good landing site. We were therefore constrained to have relatively short field seasons. This made data collection challenging, e.g. we were not able to be present in the colony throughout the breeding cycle and thus directly observe breeding success. For this reason and because of the rapid development of suitable technology, there was a strong emphasis on automated collection of data through bird-mounted data loggers, time-lapse photography and video recording.

The fieldwork carried out in 2008-2013 has provided a detailed and very useful ecological baseline for some of the most important seabird populations in Baffin Bay. However many of the data collected have not yet been fully analysed, and there is thus potential for further analysis, including a better assessment of natural year-to-year variation in foraging conditions.

To date, the fieldwork at Kippaku has provided input to the Strategic Environmental Impact Assessment of the Baffin Bay area (Boertmann & Mosbech 2011) and the forthcoming update of this SEIA.

2 Study site

2.1 The Baffin Bay study area

There are few major colonies of cliff-nesting seabirds along the Greenland coast of Baffin Bay south of 76° N. By far the largest murre colony is at Apparsuit (formerly known as Cape Shackleton), where nearly 100,000 birds were counted in 2008 (Labansen et al. 2013). However, this colony is situated on a huge near-vertical cliff, and most of it is practically impossible to access for researchers (but see below). Much more practical to work in is the nearby colony on the small island Kippaku, which houses the only other extant murre colony between 73° N and 76° N (Merkel et al. 2014), as well as the largest kittiwake colony in this part of Greenland (Labansen et al. 2010).

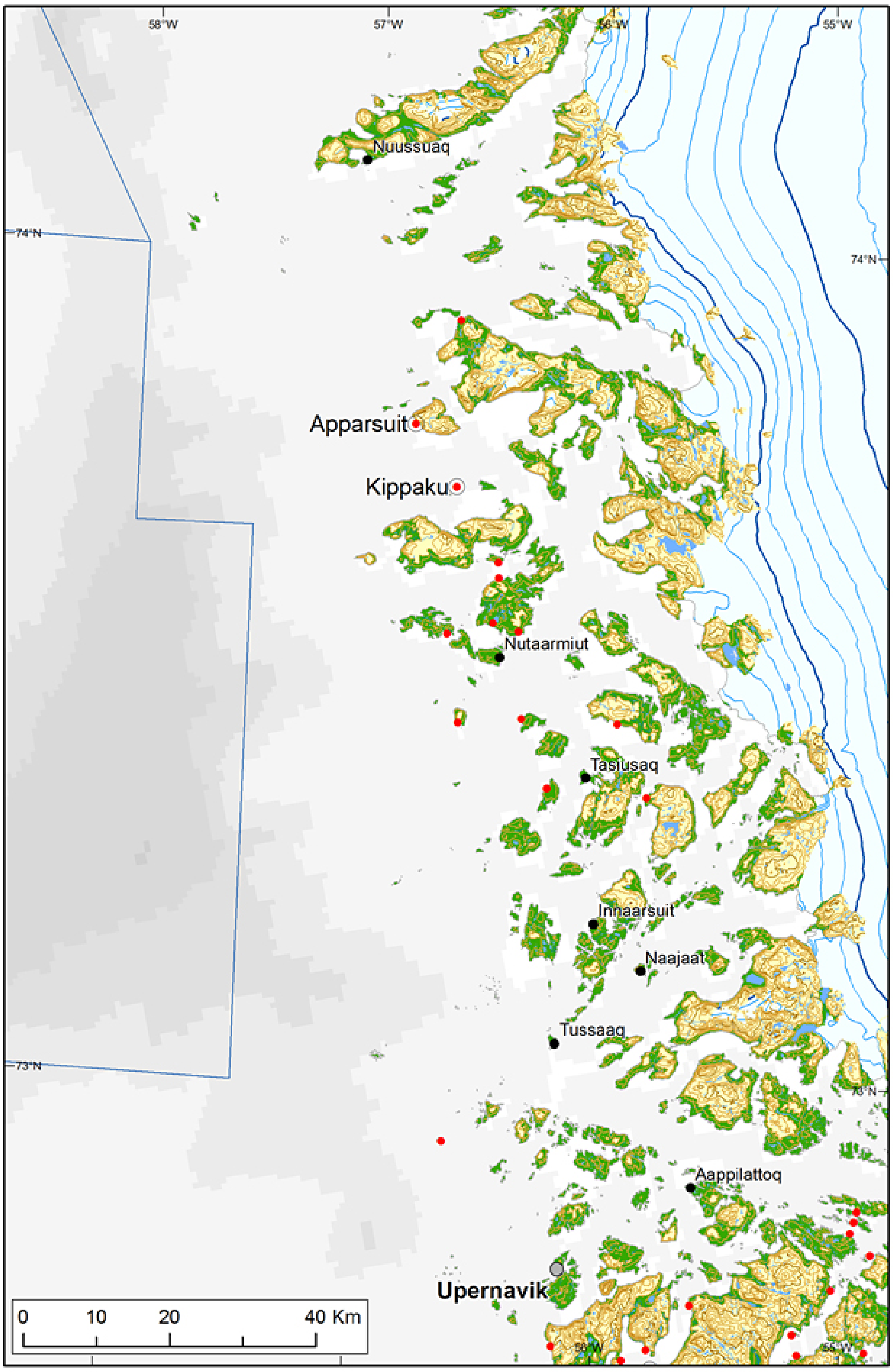
The coastal zone between Upernavik and Kullorsuaq (73-75° N) consists of a complex archipelago of variously sized islands, peninsulas and a narrow coastal strip where the ice cap reaches the shore in many locations (Fig. 2.1). The fiords and bays in the area are very poorly surveyed, and in particular the bathymetry is almost unknown. However, depths of several hundred meters are likely to be common. The fiords as well as the coastal part of the Baffin Bay are typically ice-covered from November until early June. Due to the many calving glaciers in the area, icebergs and smaller pieces of glacial ice are common throughout the summer.

2.2 Study locations

Kippaku (73° 43′ N, 56° 37′ W) is a small rocky island (ca. 7.5 ha) in the outer part of Giesecke Ice Fiord (Kangerlussuaq), approx. 100 km north of Upernavik town. The north and east sides of the island are near-vertical cliffs, up to 70 m high, while the south side slopes steeply to a rocky coastline without good landings (see cover photo). Murres and kittiwakes breed on the steep cliffs, right up to the cliff edge. Access to the birds is therefore relatively simple, and in many places it is possible to capture substantial numbers of birds from the cliff edge or immediately below. There are also a number of good observation points, where large numbers of birds can be studied without causing disturbance. A number of study plots and sites have been established around the island (see Appendix 1).

Apparsuit is a relatively large island (6 x 4 km), situated 10 km NNW of Kippaku (73° 48′ N, 56° 47′ W). The murre colony is divided into several non-contiguous subcolonies, spread over the entire south and southwest side of the island, with a total extent of approx. 7 km (Falk & Kampp 1997). The cliff is up to 600 m high, and access to the birds is generally very difficult. However, in 2013 fieldwork was carried out in one small subcolony (B) near the eastern end of the colony, which is accessible from the sea (see details in Appendix 1).

Figure 2.1. Map of the study area north of Upernavik, West Greenland. Red dots show kittiwake colonies and open circles murre colonies (Kippaku and Apparsuit). Settlements are indicated by black dots, and the town of Upernavik by a grey dot. Hydrocarbon license areas in Baffin Bay are also shown. Note that the symbol location indicates the western part of the Apparsuit colony; the colony stretches 7 km along the southwest and south coast of the island.



2.3 Breeding and visiting birds

Kippaku houses approx. 14,000 pairs of murres and 3,500 pairs of kittiwakes (Labansen et al. 2013), and is thus one of the most important seabird cliffs in West Greenland. Other breeding birds include black guillemot (100-200 pairs), razorbill *Alca torda* (perhaps 10-15 pairs), glaucous gull *Larus hyperboreus* (approx. 10 pairs), common eider *Somateria mollissima* (1-5 nests), red-breasted merganser *Mergus serrator* (1-5 nests), snow bunting *Plectrophenax nivalis* (common), and in 2013 one pair of common raven *Corvus corax*. Frequent (daily) visitors to the islands include raven (when not breeding on the island), gyrfalcon *Falco rusticolus* and peregrine *Falco peregrinus*. Other birds regularly or occasionally seen on or near the island during summer include northern fulmar *Fulmarus glacialis*, Atlantic puffin *Fratercula arctica* and great cormorant *Phalacrocorax carbo*. The presence of numerous droppings indicates that ptarmigan *Lagopus mutus* is a common visitor when the fiord is ice-covered.

At Apparsuit, breeding birds include the very large murre colony and a small kittiwake colony (respectively approx. 72,000 and 600 pairs, Labansen et al. 2013), and also glaucous gull, Iceland gull *Larus glaucoides*, black guillemot and raven.

Glaucous gulls, ravens and both species of falcons are presumably dependent on the cliff-nesting seabirds for food. Every year, dozens of corpses of adult kittiwakes taken by falcons were found at Kippaku, gulls have been observed killing and eating chicks of both kittiwakes and murres, and murre eggs taken by gulls or ravens were also frequent. In 2013, more than 100 murre eggs taken by ravens were found in a small area of Apparsuit.

2.4 Previous studies

The murre and kittiwake colonies at Kippaku and Apparsuit have been counted several times over the recent decades, as summarised in Labansen et al. (2013). The two most recent counts were carried out as photo surveys by GINR in connection with colony-based fieldwork in 2008 and 2013. The 2008 survey was reported by Labansen et al. (2013), while the results of the 2013 survey have only been partially analysed.

Apart from counts, the only previous studies of seabirds at Kippaku and Apparsuit took place under the auspices of the World Wildlife Foundation in 1987-1989 when concerns were raised about murre populations in Greenland. In 1987, a British expedition spent about two months in both colonies and made a thorough study of breeding biology, including observations of attendance and chick feeding (Evans 1987). A smaller Danish expedition spent one month at Kippaku in 1988 and again studied murre breeding biology, attendance and chick feeding (Kampp & Lyngs 1989). A few additional observations were made during a short stay at Kippaku early in the breeding season 1989 (Durinck 1989).

3 Methods

3.1 Field methods

Researchers were present at Kippaku 23 July – 3 August 2008, 23-31 July 2009, 27 June – 12 July and 20-30 July 2010, 14-26 July 2011, 10-31 July 2012 and 12-29 July 2013. Apparsuit was visited in 2013, during fieldwork at Kippaku.

3.1.1 Basic field methods

Capture and handling

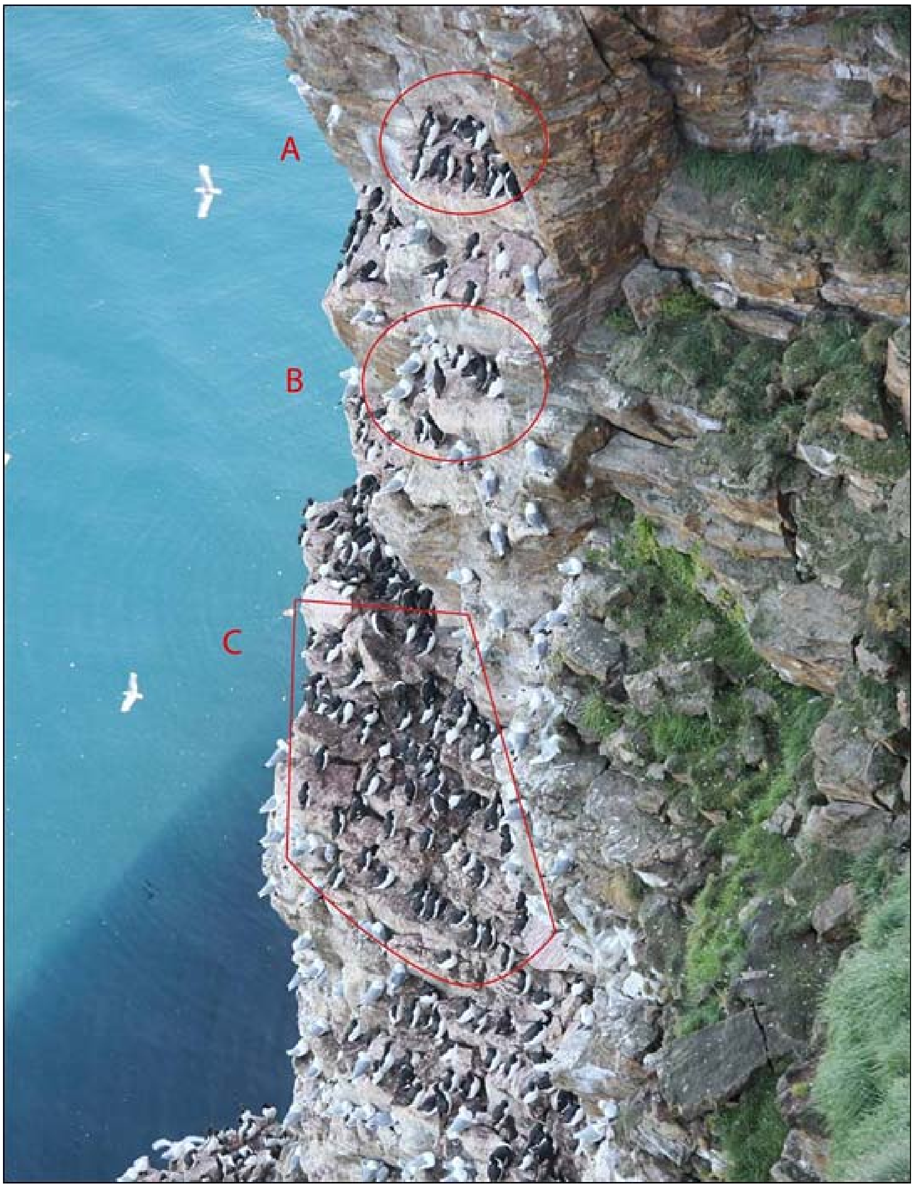
Breeding adult murres and kittiwakes were caught on the nest using 9 m extendable (telescopic) noose poles, equipped with a variety of nooses (monofilament nylon, stainless steel wire, string). Most captures took place from the cliff top, but occasionally abseiling a short distance down the cliff was necessary. Black guillemots were caught in the nest chamber by hand. All birds were handled by trained personnel and kept in bird bags or the like to reduce stress. Handling times were typically short (median = 7 min, range = 0-21 min, n = 212). Unless already ringed, all birds were equipped with a uniquely numbered stainless steel ring supplied by the Danish Ringing Centre at the Zoological Museum, University of Copenhagen. The following measurements were typically taken: wing length (flattened chord, mm) using a stopped wing ruler for murres and black guillemots, head & bill (mm) using a vernier calliper for kittiwakes and black guillemots, and body mass (g) using Pesola® spring balances for all species. Blood or feather samples were taken for molecular sexing.

Starting in 2009, breeding adult murres in Plot 2 (Fig. 3.1) were colour-ringed using uniquely numbered engraved red plastic rings (Pro-Touch, Saskatoon, Canada). Birds captured for colour-ringing were not measured, and handling time was very short (1-2 min). Observations of colour-ringed birds were recorded during several dedicated sessions each season in 2011-2013. These observations used the same vantage point as the feeding and attendance watches (see below). No other fieldwork took place in Plot 2, with the exception that two breeding pairs were equipped with time-depth recorders in 2010. Colour-ringing of kittiwakes was also attempted at Ridepynten, but it was quickly decided that observation conditions were too poor to obtain useful data.

Weighing of murre chicks

Samples of chicks were measured and weighed in years (2008, 2010, 2012) when murre chicks had an appropriate age (i.e. well-grown chicks > 2 weeks old were present, but few or no chicks showed signs of imminent fledging). Researchers abseiled on to ledges 10-20 m below the cliff top, captured all chicks present, and measured their wing length and body mass as above. Handling time for individual chicks was very brief, but chicks were kept penned for up to 20 min, and released in batches to minimise disturbance. Chick weighing only took place in appropriate weather conditions (dry, no direct sun on the ledges).

Figure 3.1. Plot 2 at Kippaku, seen from the vantage point used for colour ring observations, feeding and attendance watches of thick-billed murres. Murres were colour-ringed in subplots A, B, and C, while feeding and attendance watches concentrated on subplot C.



Feeding and attendance watches of murres

Plot 2 was considered ideal for feeding and attendance watches of murres, because it was possible to observe a good sample (approx. 25) of active nest-sites at a suitable distance and angle. In 2008, two 24-h feeding watches were carried out on 29 and 31 July, covering subplots A, B and C (Fig. 3.1). The intention was to record all feeding events and attempt to identify the prey delivered to the chick. In 2010, detailed attendance watches took place in three 66-h blocks during 4-10 July and one 24-h block during 21-27 July in subplot C, where arrivals, departures, changeovers and feedings were recorded (Huffeldt et al. in revision). Similar 24-h attendance watches were carried out in 2011 (24-25 July) and 2012 (23-24 and 29-30 July), whereas only a 24-h feeding watch in subplot C took place in 2013 (25-26 July).

Kittiwake nest checks

In years (2008, 2009, 2010, 2012) when many kittiwake chicks were well grown (3-4 weeks old) before researchers left the island, a large number of nests in different sections of the colony were checked for content using binoculars and telescope. The number and age (following Walsh et al. 1995) of chicks in each nest was recorded, and attempts were made to record empty nests, likely to have been active that year. All checks were carried out by one observer (MF).

3.1.2 Time-lapse photography and video recording

Time-lapse photography

Time-lapse photography (using Canon digital SLR cameras, with 1-h, 2-h or 4-h intervals) was used to record the number of murres present in Plot 1 from July 2008 to July 2009, and in Plot 2 from July 2010 to July 2013. Due to disturbance from illegal egg collection near Plot 2, a new photo plot was established in 2013. These photos contribute information on phenology as well as daily and seasonal attendance patterns (Huffeldt & Merkel 2013), which are used to calibrate colony counts (Labansen et al. 2013). They are also used to estimate breeding success through advanced image analysis (see below).

Video recording

Video recordings of murres in subplot 2C were used to extend and confirm manually recorded attendance and arrival/departure times in 2010 (Linnebjerg et al. 2014, Huffeldt et al. in revision). In 2013, video recordings (75 h) were made of a small sample (5 pairs) of murres, where one member of each pair was simultaneously equipped with both a GPS logger and a time-depth recorder. These recordings have not yet been analysed. Cameras used were standard consumer models (JVC GZ-HM200 in 2010 and JVC GZ-EX515BE in 2013).

3.1.3 Deployment of data loggers and transmitters

GPS loggers

Foraging movements of murres were tracked using GPS loggers in 2009, 2010, 2012 and 2013. In 2009, 2012 and 2013, commercially available loggers (i-gotU GT-120, Mobile Action Technology) were used. The loggers were stripped of their housing and waterproofed using two layers of clear shrink tubing (FiniTube CLR-20/50, Finishrink), and attached to the back feathers of the birds using strips of black Tesa® cloth tape. In 2010, TM-Tag GPS loggers (e-Shepherd Solutions) were used; they were waterproofed and attached in the same way. In 2013, some birds at Kippaku and all birds at Apparsuit were tracked using URIA-III GPS loggers (Ecotone). These loggers are embedded in epoxy and contain a UHF unit that allows download of data remotely to a base station. They were attached in the same way as other GPS loggers. Including attachment material, the mass of all types of GPS loggers was approx. 15-16 g.

Similarly, kittiwake foraging movements were tracked in 2012 and 2013 using i-gotU GT-120 loggers, waterproofed with a single layer of shrink tubing and attached with white or grey cloth tape. Total mass was approx. 13 g.

Geolocators (GLS)

Three types of geolocators (loggers recording time and light intensity) were deployed on murres: Lotek LAT2500 (mass 3.6 g, Lotek Wireless Inc.) in 2008-2013, Lotek LAT2800 (mass 5.5 g) in 2012-2013 and British Antarctic Survey (BAS) Mk9 (mass 2.5 g) in 2008-2009. All types were attached to a metal leg ring. On kittiwakes, BAS Mk13, Mk14 and Mk18 loggers (mass 1.3-1.5 g) were deployed in 2008-2011; they were attached to coloured plastic leg rings. BAS Mk18 loggers were deployed in the same way on black guillemots in 2012.

Time-depth recorders (TDR)

Lotek LAT2500 and LAT2800 loggers (combined geolocator and time-depth recorder) were deployed on murres in 2008-2013 at Kippaku to investigate foraging behaviour and time budgets, both short-term during the breeding season and long-term over winter. In 2013, these loggers were also deployed on murres at Apparsuit.

Combined GPS-TDR deployments

In 2009, 2012 and 2013, Lotek LAT2500 TDRs were deployed concurrently with GPS loggers (see above) on murres at Kippaku and Apparsuit (only 2013).

3.2 Analytical methods

3.2.1 Molecular sexing

Sex was determined after extracting DNA from either blood or feathers. DNA was extracted from blood using a modified CTAB method with Proteinase K (Andersen et al. 2004), while DNA was extracted from feathers using Qiagen DNeasy® Blood & Tissue Kit following a user-developed protocol (http://www.qiagen.com/resources). After extraction, homologous sections of the chromo-helicase-DNA-binding (CHD) genes, which are located on the Z and W chromosome, were PCR amplified using primers P2 and P8 (Griffiths et al. 1998). The amplified sections incorporate introns which differ in length, specifying the W chromosome unique to females and Z chromosome which occurs in both females and males (ZW and ZZ respectively) (Griffiths et al. 1998). After amplification, the products were visualized on a 2% agarose gel. Two bands of ~ 300 bp and 400 bp were observed for females and one band of ~ 300 bp for males.

3.2.2 Geolocation data

Geolocators collect data on light intensity, which are used to estimate the timing of sunrise and sunset and thus geographical position (Wilson et al. 1992). Data from BAS geolocators on kittiwakes and black guillemots were treated as described in Frederiksen et al. (2012). A light threshold value of 10 was used, and the most appropriate sun angle selected by inspecting data from periods with known positions (immediately after breeding): -3° for kittiwakes and -3.5° for black guillemots. Data from breeding and equinox periods were removed, and remaining positions smoothed slightly (3-position running mean).

With regard to Lotek geolocators on thick-billed murres, positions from thes on-board processing of light data were used. Data from periods with continuous daylight (e.g. breeding season) were removed, as were latitudes during equinox periods. Following the procedures of Boertmann & Mosbech (2011, Box 4), daily positions during the whole non-breeding season were then estimated for each bird by smoothing remaining latitudes and longitudes as a function of time using Generalized Additive Models (GAMs). Finally, estimated daily positions were pooled by sex and month, and 30, 60 and 90% kernel density contours were calculated using the Animal Movement extension (Hooge & Eichenlaub 1997) to ArcView 3.1 (ESRI).

Individual positions derived from geolocation are subject to considerable error, particularly in latitude (Fudickar et al. 2012), but means over longer periods should be unbiased.

3.2.3 Time budgets

Murre time budgets were quantified from TDR data using MultiTrace Dive (Jensen Software Systems). Time spent on various activities (colony attendance, rest at-sea, dive pause (time spent in between dives), time underwater (diving), and flight) was estimated by visually comparing pressure, temperature and wet/dry readings simultaneously, following Linnebjerg et al. (2014).

3.2.4 Quantification of murre breeding success

Murre breeding success was quantified in 2011 from a time-lapse photo series consisting of 600 images (4 Jun – 26 Aug) and in 2012 from a series of 1320 images (1 Jun – 22 Aug), both representing the entire breeding season. Several steps of image analyses were carried out in ImageJ (ver. 1.47, W. Rasband, http://imagej.nih.gov/ij); one of these steps identified sites that were constantly attended by a bird (breeding sites), as opposed to sites where birds were absent for shorter or longer periods (non-breeding sites). When executed for the entire breeding period, this method can determine approximately when breeding attempts succeed (chick fledging) or fail (F. Merkel, unpubl.) The exact date of chick fledging or breeding failure was subsequently recorded by inspecting relevant individual photos. The date of egg laying was defined as the first day when a sitting adult permanently occupied a potential breeding site. The shortest period recorded as a breeding attempt was 5 days in 2011 (constantly incubating) and 2 days in 2012 (constantly incubating, egg seen). Due to missing photos in the period 7-14 June 2011, the date of egg laying could not be accurately determined for all breeding birds this year.

3.2.5 Statistics

Age of murre chicks was estimated based on wing length following Gaston & Nettleship (1981, p. 176), and hatch dates back-calculated. Non-linear growth curves were fitted to measurement data (wing length and body mass) of murre chicks using the nls package in R 3.01 (R Core Team 2013). These curves were formulated as an exponential approach to an asymptotic fledging mass (re-parameterised von Bertalanffy curves), with the following parameters estimated: hatching mass (at wing length = 23 mm), fledging mass (at wing length = 90 mm), and exponential growth rate.

Survival was estimated based on capture-mark-recapture (CMR) data in MARK (White & Burnham 1999). For the resighting data on colour-ringed murres, we used standard CMR models (Lebreton et al. 1992) which estimate annual probabilities of survival and resighting. The resighting probability is the probability that a ringed bird is observed, given that it is alive. Birds not seen may either have been missed or absent from the colony, e.g. because they have failed early in the breeding cycle. To estimate whether birds were likely to have been missed, we also ran closed-population CMR models for each season 2011-2013. These models estimate the size of the marked population each year, and thus indirectly the probability of missing a bird given it is present in the colony. In addition, we estimated survival based on year-to-year recapture data of birds equipped with geolocators (both murres and kittiwakes). In these models, information was only used for periods when birds were equipped with loggers, because recapture effort was only directed at these individuals. If a bird was released again with the same or a new logger, it was included in the analysis as a new dummy individual.

Unless otherwise noted, statistical analyses were performed in SAS 9.4 (Statistical Analysis Systems). All means are shown with 95% confidence intervals. Annual mean breeding success of kittiwakes was estimated using a generalized linear model with Poisson error and log link.

3.2.6 GIS

All maps were created in ArcGIS 10.1 (ESRI).

4 Results

4.1 Thick-billed murre

4.1.1 Ringing and recapture

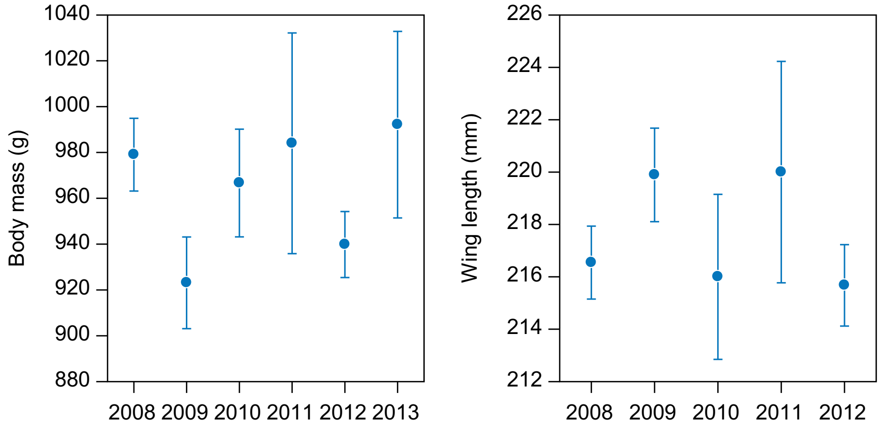
From 2008 to 2013, 265 murres were ringed at Kippaku, including 81 confirmed females and 131 confirmed males. In addition, several previously ringed birds were recaptured: On 25 July 2008, a breeding bird with an extremely worn aluminium ring was captured; the ring number was later determined to be probably 4300206, which was ringed at Kippaku as an adult 27 June 1989. The mate of this bird was also captured on the same date and was found to carry three colour rings but no metal ring. This bird was likely marked at Kippaku by the British expedition in 1987 (Evans 1987), although it has not been possible to obtain confirmation that they used colour rings. Both birds were re-ringed and entered our study population. The previously aluminium-ringed bird was last seen in 2011, at a minimum age of 26 years, whereas the previously colour-ringed bird was never seen again. Another bird, 4126836, was caught as a breeder 21 July 2010 outside the study plots; this bird was ringed as an adult 15 August 1988 at Kippaku, and was thus at least 26 years old. Finally, a Canadian-ringed bird (996-89747) with a prominent red colour ring was caught 29 July 2010 as a non-breeder. This bird (a male) was ringed as a chick on Coats Island (62° 57' N, 82° 00' W, approx. 1600 km SW of Kippaku) 4 August 2004 and was thus six years old (A.J. Gaston, pers. comm.). It has not been observed since. Two other Canadian colour-ringed birds were observed as non-breeders in 2010; they were presumably ringed as chicks on Coats Island in 2006 and 2007 (A.J. Gaston, pers. comm.).

We observed a biased sex distribution among handled birds and found it to be related to different diurnal attendance rhythms for males and females (cf. Huffeldt et al. in revision). Of 147 known-sex birds caught for the first time between 06:00 and 18:00 local time, 42 were females and 105 males (71% males), whereas of 66 known-sex birds caught for the first time between 18:00 and 06:00, 39 were females and 27 males (41% males).

4.1.2 Measurements

Mean body mass at first encounter was 955 g (SD = 58 g, range 820-1100 g, n = 164). Mean body mass differed between years ($F_{5,158}$ = 5.77, P < 0.0001), with birds being heaviest in 2013 and lightest in 2009 (Fig. 4.1); there was no difference between males and females ($F_{1,127}$ = 2.01, P = 0.16). Mean wing length was 217 mm (SD = 5.0 mm, range 205-231 mm, n = 125), with a significant difference between years ($F_{4,120}$ = 3.95, P = 0.0048, Fig. 4.1), but no difference between males and females ($F_{1,106}$ = 0.96, P = 0.33).

Figure 4.1. Body mass (left) and wing length (right) of murres at Kippaku 2008-2013 (only first encounter). Means and 95% confidence intervals are shown.



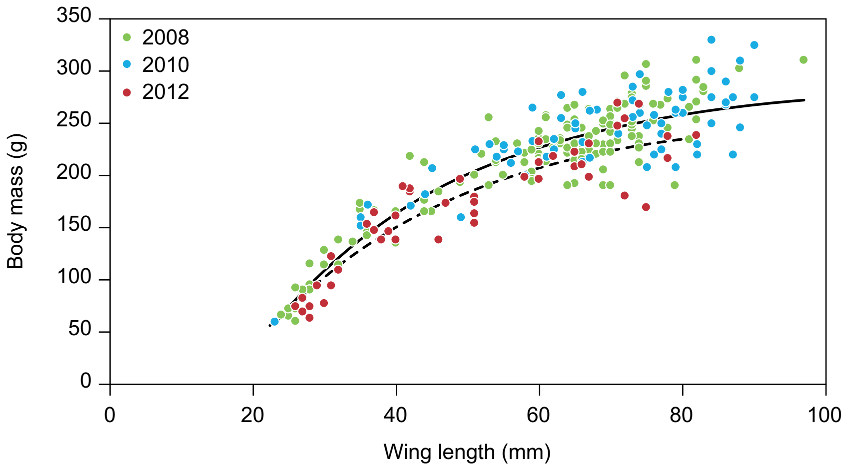
4.1.3 Phenology

Wing length and body mass was recorded for 140 chicks in 2008, 69 in 2010 and 50 in 2012. Three records from 2012 were discarded due to likely recording errors (unrealistic values of body mass). Mean back-calculated hatch date differed among years ($F_{2,253}$ = 71.24, P = 2*10^{-16}), being 12 July in 2008, 5 July in 2010 and 15 July in 2012. Breeding is likely to have been even later in 2011 and 2013, as chicks were still too small for measurements when researchers left the island. This was confirmed by time lapse photography, which estimated median hatching date as 24 July in 2011 and 16 July in 2012.

4.1.4 Chick growth

Fitting of nonlinear growth curves to measurements of wing length and body mass showed that fledging mass (at wing length = 90 mm) differed among years ($F_{2,251}$ = 13.02, P = 4*10^{-6}), but controlling for this there was no difference in growth rate ($F_{2,249}$ = 0.41, P = 0.67). Chicks achieved a lower mean fledging mass in 2012 (243 g) than in 2008 and 2010 (267 and 274 g, respectively), see Fig 4.2. Mean hatching mass was estimated as 58.5 g.

Figure 4.2. Wing length and body mass of murre chicks at Kippaku in 2008, 2010 and 2012. Lines indicate fitted growth curves (2008: solid line, 2010: dotted line, 2012: dashed line).



4.1.5 Breeding success

Breeding success was estimated in Plot 2 from time lapse photos in 2011 and 2012 (see Table 4.1). All parameters were higher in 2012 than in 2011, with a particularly large difference in hatching success.

Table 4.1. Breeding success of murres in Plot 2 in 2011 and 2012. The same area was followed using time-lapse photos in both years.

	2011	2012
Eggs laid	47	53
Chicks hatched	28	43
Chicks fledged	25	41
Hatching success	60%	81%
Fledging success	89%	95%
Overall breeding success	0.53	0.77

4.1.6 Survival

From 2009 to 2013, 98 murres were colour-ringed in Plot 2. Resightings were made during chick rearing in 2011-2013. Simple CMR models gave an estimated constant annual survival probability of 0.843 (95% C.I. 0.767-0.898), somewhat lower than expected for the species (see Discussion). Annual estimated resighting probabilities were high in 2011-2013 (respectively 92%, 100% and 78%). However, closed population models indicated that in all years, all or very nearly all colour-ringed birds present in the plot were observed. The lower estimates of resighting probability from the open model in two of three years likely indicate that some birds had already failed in their breeding and left the colony, or had never attempted to breed. Recapture data on birds equipped with geolocators gave an estimated constant annual survival probability of 0.825 (95% C.I. 0.756-0.883), and a constant annual recapture probability of 77%.

4.1.7 Logger effects

On average, murres equipped with a logger lost body mass (mean mass change = -10 g, SD = 52 g, range -150-170 g, n = 144). There was no effect of deployment duration (long vs. short, $F_{1,142}$ = 2.46, P = 0.12) or logger type ($F_{4,139}$ = 0.33, P = 0.86). No birds at Kippaku were observed to lose eggs or chicks after being caught and equipped with a logger, and retrieval success was high for long-term geolocator deployments (81% for BAS Mk9, 71% for Lotek LAT2500, and 100% for Lotek LAT2800), indicating that any extra mortality due to loggers must have been small (see also survival estimate above). At Apparsuit in 2013, 3 of 6 incubating murres equipped with Ecotone GPS loggers as well as Lotek TDRs failed during deployment; this may be related to the low density of breeding birds in this subcolony, allowing easy access for egg predators during and after investigator disturbance. All 3 failed birds nested on the same narrow ledge.

4.1.8 Foraging areas and behaviour

Chick-feeding murres from Kippaku foraged both within the archipelago to the southeast, and in the open Baffin Bay up to 60 km southwest of the colony (Figure 4.3, cf. Box 3 in Boertmann & Mosbech (2011). Foraging areas were remarkably similar between years, and in several cases the same individual used both types of areas.

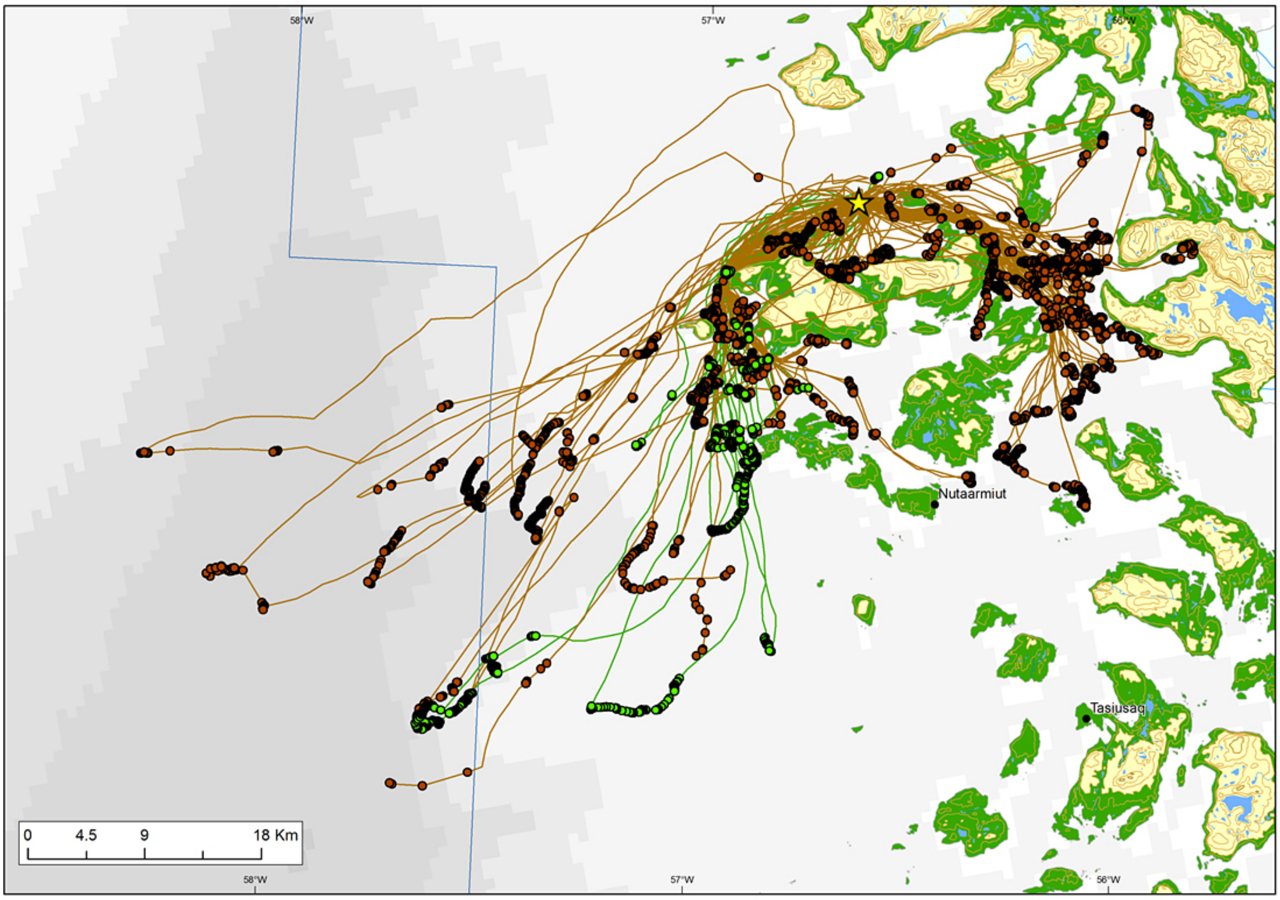
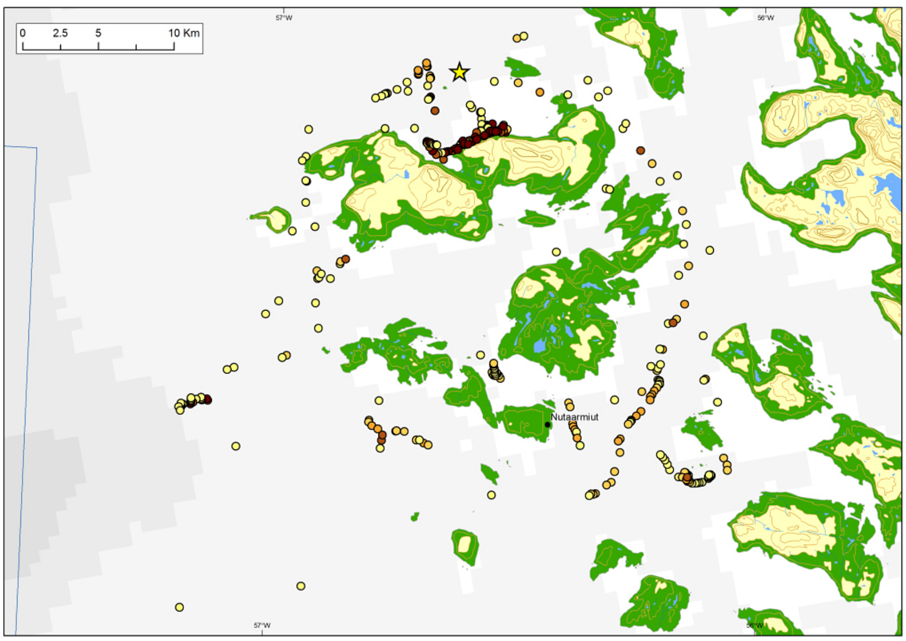


Figure 4.3. GPS tracks of foraging murres from Kippaku (indicated by yellow star) equipped with i-gotU loggers in 2012 (*n* = 22 deployments) and 2013 (*n* = 2 deployments). Circles show locations where the recorded speed was < 2 km/h (presumed foraging locations). This cut-off point was selected based on histograms of recorded speed at all locations. Brown lines and circles show data from 2012, and green lines and circles data from 2013. Note that some tracks from 2012 are incomplete and some straight lines connecting points are misleading.

Dive depth varied widely between foraging locations, with some of the deepest dives occurring very close to land 5 km south of the colony, where the coastline slopes very steeply (Figure 4.4).

Figure 4.4. Dive depth of three murres equipped with both GPS loggers and TDRs in 2009. For each GPS location (with 10-minute intervals), the maximum depth recorded within 5 minutes before or after is shown. Darker colours indicate deeper dives, with maximum recorded depth 137 m. Note that non-foraging locations are included.



In 2013, murres at Apparsuit made much longer trips than those at Kippaku (Figure 4.5). Mean trip duration based on Ecotone GPS loggers was 10.3 h (*n* = 6 deployments, 19 trips) at Apparsuit and 3.7 h (*n* = 4 deployments, 34 trips) at Kippaku (see also below). However, this difference was almost certainly related to a difference in breeding stage: Apparsuit birds were all incubating, whereas Kippaku birds were feeding chicks. Furthermore, 3 of 6 birds at Apparsuit failed in their breeding attempt during deployment. The longest trip made by an Apparsuit murre was 94 km to the southwest. Generally, Apparsuit birds used similar areas to those at Kippaku, but one bird made one trip to the northwest (Figure 4.5).

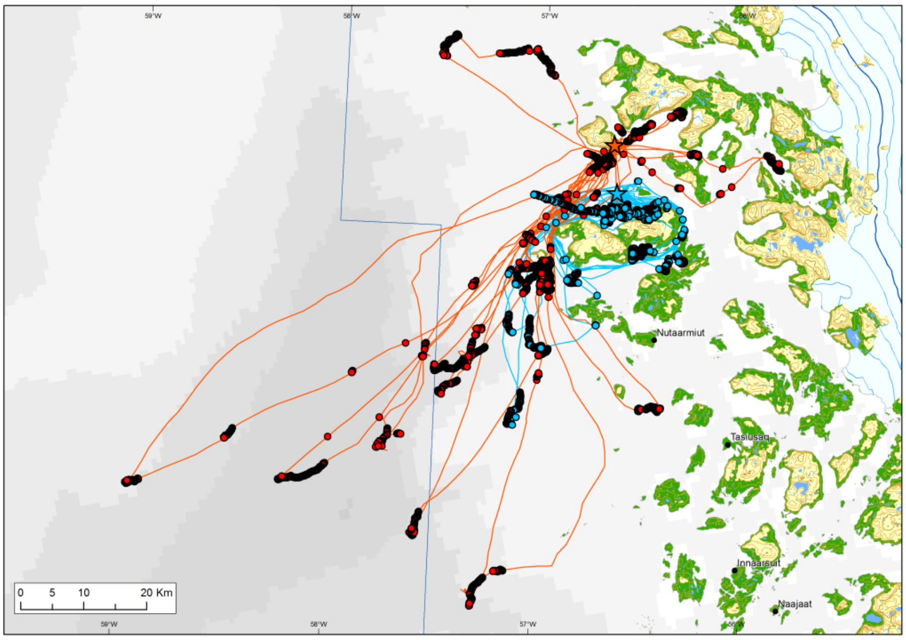


Figure 4.5. Foraging trips and locations of breeding murres equipped with Ecotone GPS loggers at Apparsuit (red symbols and lines) and Kippaku (blue symbols and lines) in 2013. Colony locations are indicated by asterisks. Deployment was near-simultaneous at the two colonies (18-21 July at Apparsuit, 23-26 July at Kippaku). Note that Apparsuit birds were incubating eggs, whereas Kippaku birds were feeding chicks.

Foraging trip duration at Kippaku varied widely, up to 15 h. Based on TDRs, mean duration was 4.1 h in 2008-09 (Figure 4.6), whereas GPS-recorded trips (using igot-U loggers) averaged 4.9 h in 2012 (*n* = 14 deployments, 44 trips) and 3.9 h in 2013 (*n* = 2 deployments, 12 trips). Birds dived to maximum depths of 150 m, but most dives were between 40 and 60 m (Figure 4.6). Shallow dives of 5-15 m were also common.

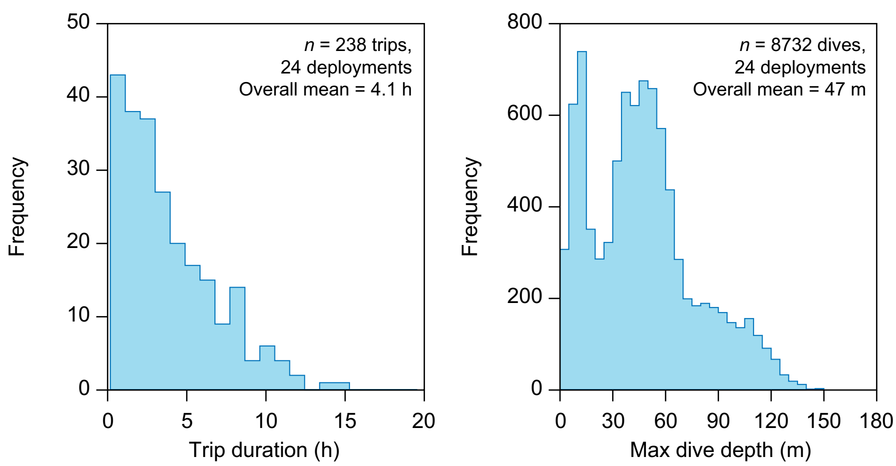


Figure 4.6. Trip duration and maximum dive depth, estimated from 24 TDR deployments at Kippaku in 2008 and 2009.

Time budgets of chick-rearing murres were remarkably similar in 2008-2010 (Fig. 4.7). Birds spent 55-60% of their time at the colony, about 7% flying, 11-14% underwater, 5-8% recuperating between dives, and 14-19% resting at sea between and after dive bouts.

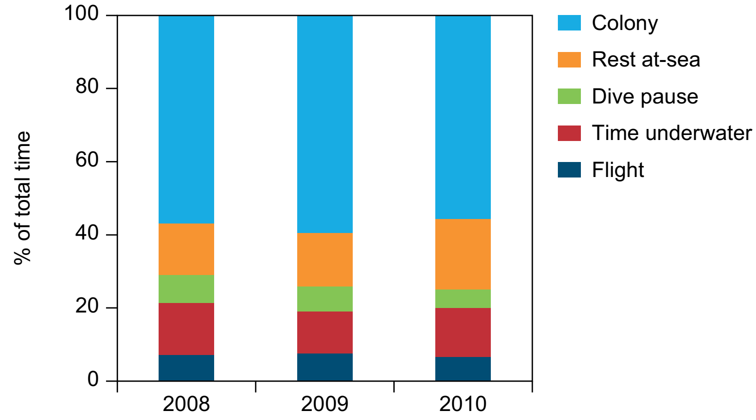


Figure 4.7. Mean time budgets of chick-rearing murres at Kippaku 2008-2010, based on respectively 16, 12 and 14 TDR deployments.

4.1.9 Diet and feeding rates

Observations of prey delivered to chicks were fragmentary, mainly because feedings happened very rapidly and observers had to be experienced to identify fish species. Therefore, no quantitative treatment of diet is included. However, it was clear that the vast majority of prey items delivered were fish, with a few crustaceans also observed. The most common fish species identified was polar cod, but this may partly reflect that this species is comparatively easy to identify.

Mean feeding rates varied somewhat from year to year (Table 4.2). Chick age varied considerably between years (e.g. very few and young chicks in 2011), and observer experience may have increased over time. In 2008, the area and number of chicks studied were so large that substantial numbers of feeds may have been missed.

Table 4.2. Feeding rates of murre chicks at Kippaku, 2008-2013. 'Site-days' refers to the sum across observation days (24-h periods) of the number of sites observed.

Year	Dates	Site-days	Total feeds	Feeding rate (feeds/chick/day)
2008	29 & 31 Jul	87	247	2.84
2010	26-27 Jul	13	54	4.15
2011	24-25 Jul	6	26	4.33
2012	22 & 29 Jul	61	303	4.97
2013	25 Jul	18	104	5.78

4.1.10 Migration

A large amount of information from geolocators has been collected since 2008, in all 103 successful deployments representing 123 bird-years (2008/09: 24 birds, 2009/10: 45 birds, 2010/11: 21 birds, 2011/12: 15 birds, 2012/13: 18 birds). However, most of these data have not yet been analysed in detail and the results presented here are thus quite preliminary. Murres from Kippaku appear to migrate rapidly south in September and October, and then spend the winter on the banks east and south of Newfoundland. Northward migration occurs quite late, in early May.

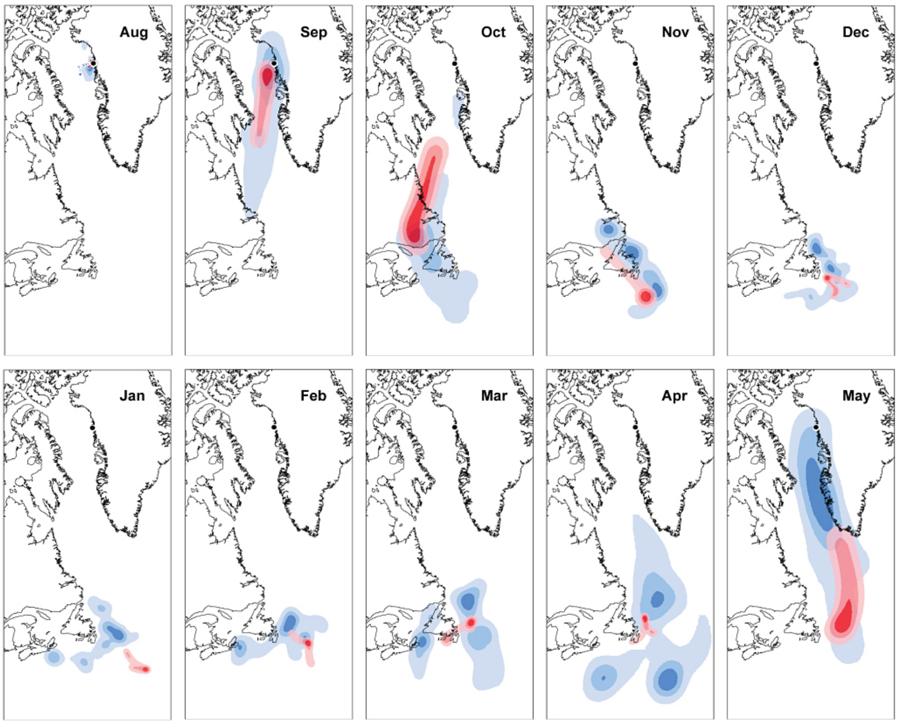


Figure 4.8. Migration of murres from Kippaku, 2008/09. Data are shown as 30, 60 and 90 % kernels for 7 males (blue) and 1 female (red).

4.1.11 Egg collection

On several occasions over the years, we made observations indicating that illegal collection of murre eggs takes place regularly at Kippaku. Ropes were found in several locations when we first arrived in 2008, and the easily accessible area below Plot 1 (see Appendix 1) has in most years either been deserted, or birds have been incubating eggs late in the season when murres on other ledges were feeding chicks. Furthermore, our time-lapse camera monitoring Plot 2 has been obstructed during several seasons (2009, 2012, 2013). The view from this camera also includes the easiest access route to the area below Plot 1, and probably for this reason the camera was blocked (using plastic bags or rocks) for shorter or longer periods. In 2013, Plot 2 appeared more disturbed than usually, and the deserted area below Plot 1 had expanded (see Appendix 2). Because of this, we decided to move the camera and establish a new and inaccessible photo monitoring plot.

4.2 Black-legged kittiwake

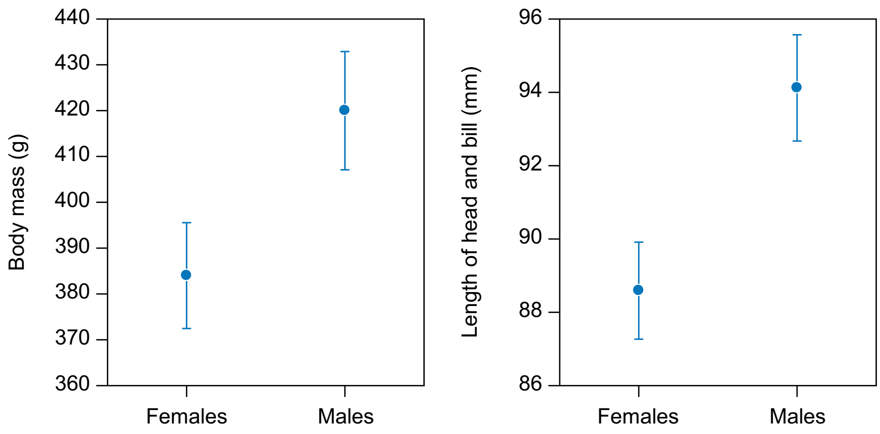
4.2.1 Ringing

Over the years, 69 kittiwakes were ringed at Kippaku, including 20 confirmed females and 16 confirmed males.

4.2.2 Measurements

Mean body mass at first encounter was 401 g (SD = 32 g, range 350-470 g, n = 69). There was no difference between years ($F_{4,64}$ = 1.41, P = 0.24), but sexes differed in body mass ($F_{1,34}$ = 17.86, P = 0.0002), with males being heavier than females (Fig. 4.9). Mean length of head and bill was 90.9 mm (SD = 3.74 mm, range 80.5-100.6 mm, n = 53), with males being significantly bigger than females ($F_{1,31}$ = 33.01, P < 0.0001, Fig. 4.9) and no difference between years ($F_{4,48}$ = 0.82, P = 0.52).

Figure 4.9. Body mass (left) and length of head and bill (right) of female and male kittiwakes at Kippaku (only first encounter). Means and 95% confidence intervals are shown.



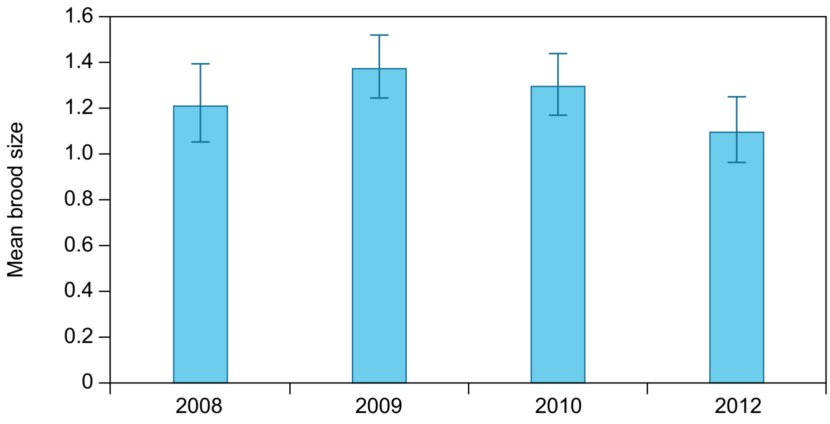
4.2.3 Phenology

The timing of breeding was assessed from checks of nest contents in 3-4 plots in 2008, 2009, 2010 and 2012 (annual n = 161-281). Chick ages were estimated and hatch dates back-calculated. Only in one year (2009) was there a difference in estimated hatch date between plots, with one plot being approx. 10 days later than the others. For comparing between years, we pooled data across plots. Timing of breeding differed among years ($F_{3,692}$ = 37.90, $P < 0.0001$), with breeding being later in 2012 (mean estimated hatch date 9 July) than in the first three years (all 4 July). In 2011 and 2013, chicks were still too young when researchers left the island (respectively 26 and 29 July) to make efficient nest checks, and breeding is likely to have been even later than in 2012.

4.2.4 Breeding success

Breeding success was assessed by counting the number of chicks in a large number of nests in 3-4 plots in 2008, 2009, 2010 and 2012 (annual n = 161-281); empty nests were as far as possible also recorded. Only in one year (2009) was there a difference in mean brood size between plots. For comparing between years, we pooled data across plots. Overall mean brood size was 1.26, and three-chick broods were relatively common (1-7% of all nests). Apparent breeding success differed among years (χ^2_3 = 7.85, P = 0.049), with mean brood size being slightly lower in 2012 than in 2009 and 2010 (Fig. 4.10). Excluding empty nests, the mean number of chicks per nest varied between 1.51 in 2012 and 1.73 in 2009. In 2011 and 2013, chicks were too young to perform nest checks before researchers left the island, and no data on breeding success are available. However, in both years most non-empty nests held two chicks, and the impression was that breeding success would be reasonably high.

Figure 4.10. Mean brood size of kittiwakes at Kippaku, with 95% confidence limits.



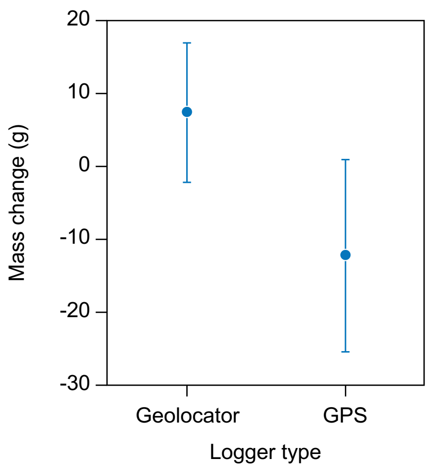
4.2.5 Survival

Recapture data on birds equipped with geolocators gave an estimated constant annual survival probability of 0.911 (95% C.I. 0.626-0.984), with annual recapture probabilities between 26% and 57% (0 in 2013, when no effort was made to recapture kittiwakes).

4.2.6 Logger effects

On average, kittiwakes equipped with a logger did not lose body mass (mean mass change = 0.6 g, SD = 31 g, range -50-100 g, n = 58). However, there was a significant effects of logger type/duration: birds equipped with GPS loggers (short-term) lost body mass, while those equipped with geolocators (long-term) gained mass ($F_{1,56}$ = 5.82, P = 0.019, Fig. 4.11). No birds equipped with GPS loggers lost chicks during short-term deployments, and no losses were observed after deployment of geolocators. Retrieval rates of geolocators deployed in 2008 and 2009 were high (70%), but much lower (30%) for those deployed in 2011 in the same study plot (Ridepynten). In 2012 and 2013, this plot appeared very disturbed, either because birds were affected by repeated recapture efforts over the years, or due to possible egg collection on nearby murre ledges. Survival estimates (see above) indicated no long-term effect of loggers.

Figure 4.11. Mass change of kittiwakes at Kippaku during logger deployment. Means and 95% confidence intervals are shown.



4.2.7 Foraging areas and behaviour

We tracked 9 chick-rearing kittiwakes in 2012 and 11 in 2013 with GPS loggers for a total of respectively 18.3 and 16.2 days. Complete foraging tracks were obtained from 8 birds (44 trips) in 2012 and 11 birds (48 trips) in 2013. Mean trip duration was similar in the two years, 4.1 h (SD 1.8 h) in 2012 and 3.4 h (SD 2.5 h) in 2013, but in 2013 there were many more short trips (1-2 h) as well as a few very long trips (10-12 h), see Fig. 4.12. Birds were absent from the colony (> 500 m away, including incomplete trips) for on average 46% of the time in 2012 and 44% of the time in 2013. Parents thus spent little time together at the nest.

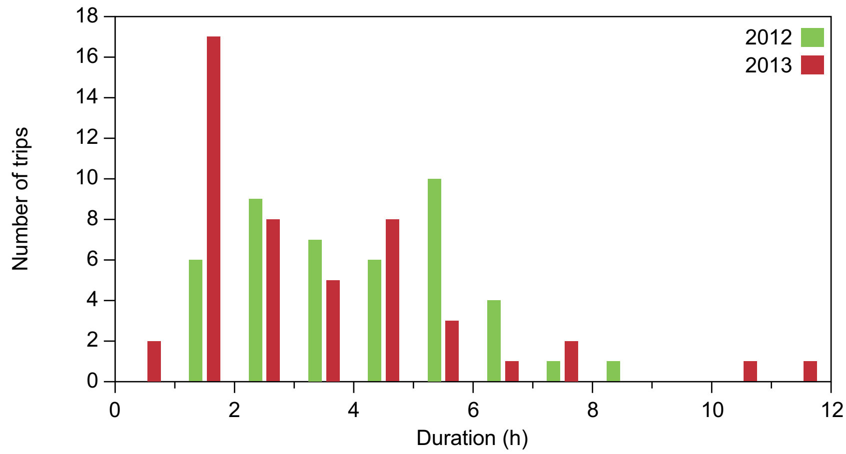


Figure 4.12. Histogram of foraging trip duration of kittiwakes at Kippaku in 2012 and 2013. Trips were included if the bird left the colony for at least 20 min and maximum distance from the colony was at least 2 km.

Birds foraged both in the archipelago and offshore in Baffin Bay, up to 75 km from the colony (Fig. 4.13). At least three types of foraging areas and associated behaviour could be distinguished: i) sheltered bays and fiords east of the colony, where birds foraged very close to land and presumably caught spawning capelin (both years); ii) offshore areas in Baffin Bay, where birds performed long meandering trips indicating active search for ephemeral food patches, probably schools of e.g. polar cod driven to the surface by other predators (both years); iii) the glacier front at Ussing Ice Fiord 38 km northeast of the colony, where birds appeared to spend much time sitting on the edge of the glacier, approx. 200 m above sea level, perhaps waiting for episodic feeding opportunities (only in 2012).

4.2.8 Diet

No systematic data were collected on kittiwake diet, but newly caught birds often regurgitated semi-digested crop contents, and some information is thus available. Polar cod occurred regularly, mostly fish between 5 and 10 cm in length, but occasionally bigger. Capelin was not recorded, and may be more difficult to recognize when partially digested. Large numbers of crustaceans were recorded on a few occasions, probably large amphipods or krill.

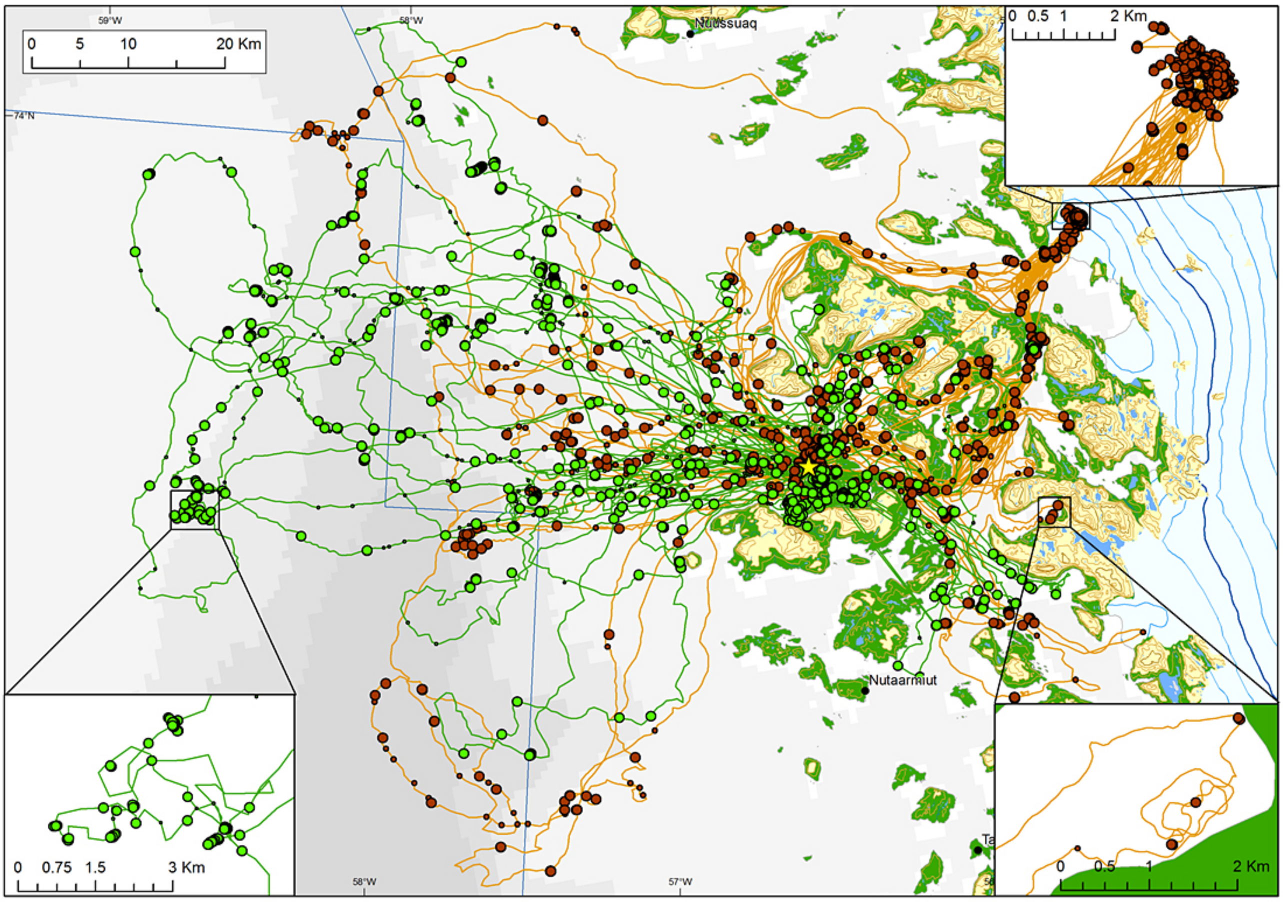


Figure 4.13. GPS tracks of foraging kittiwakes from Kippaku (indicated by yellow star). Large circles show locations where the recorded speed was < 8 km/h (presumed foraging locations), and small dots locations with recorded speed 8-20 km/h. These cut-off points were selected based on histograms of recorded speed at all locations. Brown lines and circles show data from 2012, and green lines and circles data from 2013. Insets illustrate three types of foraging areas and behaviour (see main text).

4.2.9 Migration

Data were retrieved from 38 geolocators, representing 60 bird-years (2008/09: 13 birds, 2009/10: 22 birds, 2010/11: 12 birds, 2011/12: 13 birds). Not all data have been processed yet, and the results presented here represent 11 birds from 2008/09, 9 birds from 2009/10 and 5 birds from 2010/11.

All positions obtained from geolocators are shown in Fig. 4.14. Immediately after the breeding season, kittiwakes dispersed throughout Baffin Bay, with some birds moving northwest to Lancaster Sound and the North Water polynya. When positions became available after the equinox period (22 October), most birds were migrating south, but some individuals remained in Baffin Bay until early or mid-November. Kittiwakes wintered from Davis Strait south to Newfoundland, with many birds occurring in the Labrador Sea. Northward migration started around 1 April, and in 2010 some birds reached the vicinity of the colony already in mid-April (Fig. 4.8). In other years, arrival at the colony occurred after positions became impossible to obtain due to constant daylight (approx. 25 April).

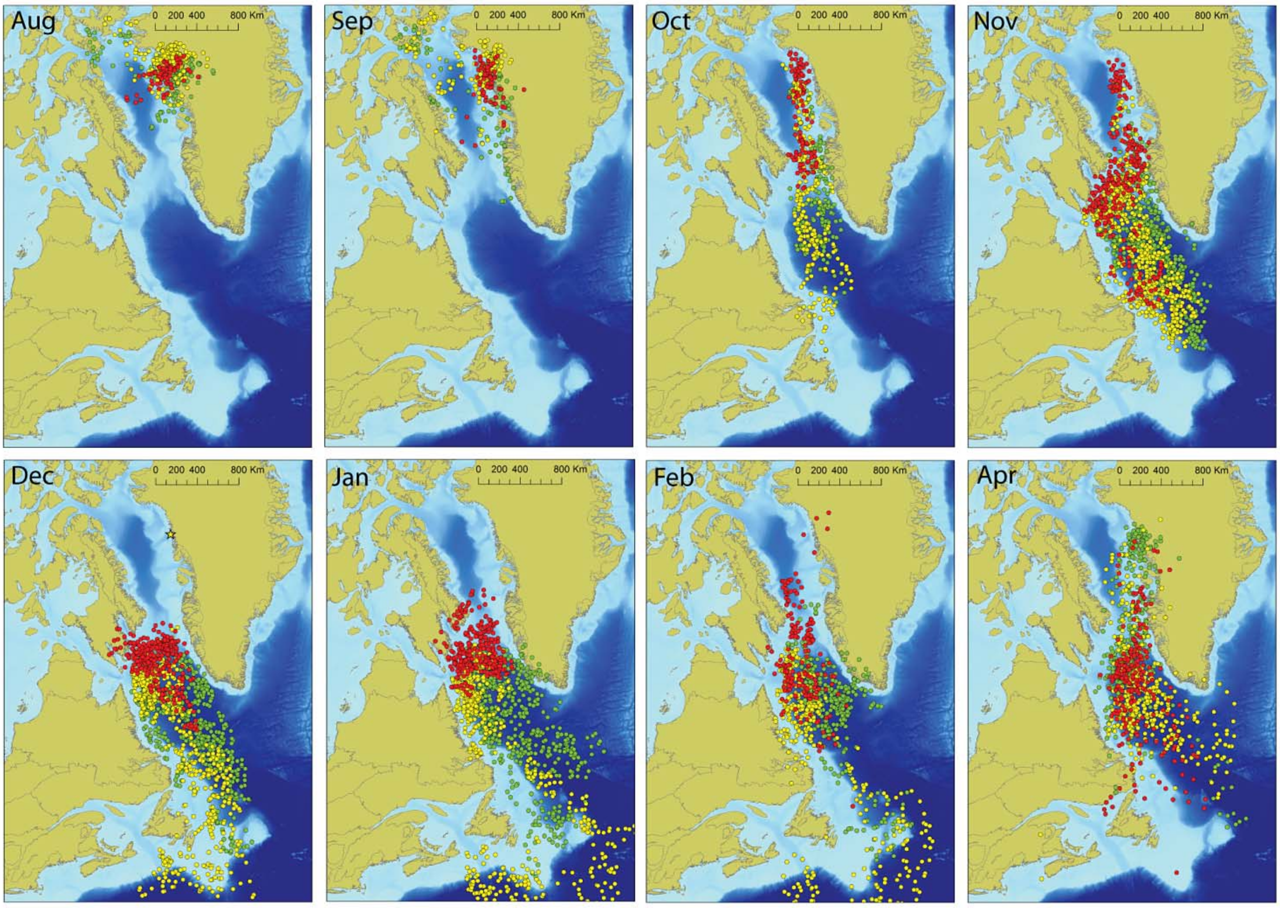


Figure 4.14. Positions derived from geolocators of migrating kittiwakes in 2008/09 (yellow symbols), 2009/10 (green symbols) and 2010/11 (red symbols). Note that the mean error of individual positions is large (~185 km), but the overall picture should be reliable. The location of the colony is indicated by the yellow asterisk in the December panel.

Both the timing of migration and the spatial distribution outside the breeding season differed markedly among years (Figs 4.14 and 4.15). For instance, birds returned very early to the vicinity of the colony in 2010, and after the 2010 breeding season they remained close to the colony throughout August and early September and migrated south later than in other years. During the 2010/11 winter, birds stayed much further north (in the Davis Strait) than in the two previous years, but by early April they had moved south in the Labrador Sea. They then migrated north over the next weeks, but subsequently returned south to the Davis Strait in the first half of May, before positions became unavailable. Conversely, during the 2008/09 winter, some birds migrated as far south as Georges Bank south of Newfoundland, an area that was not visited during the two subsequent winters.

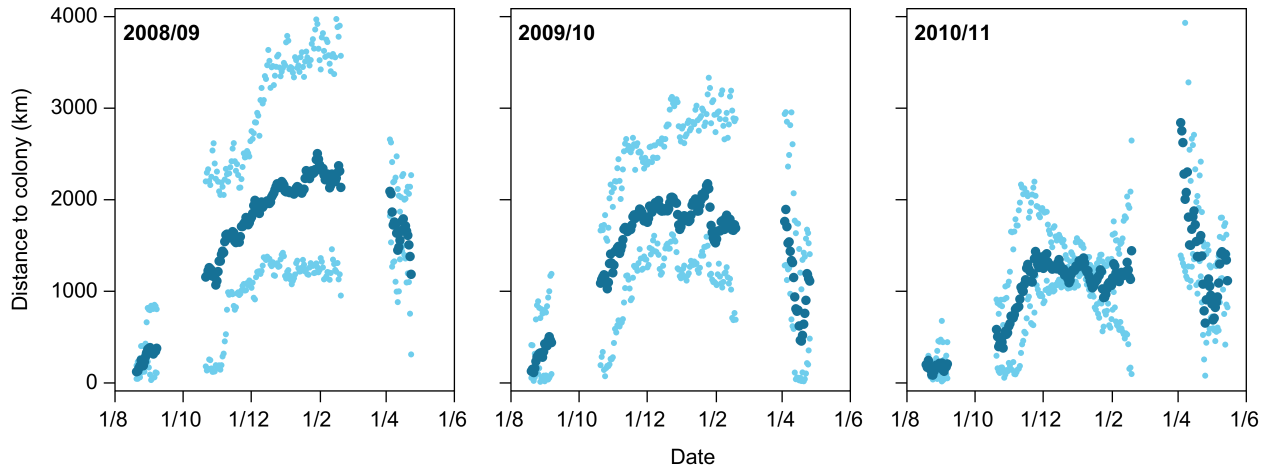


Figure 4.15. Migration of kittiwakes from Kippaku, 2008-2011. For each day of the year, the dark blue symbols show the mean distance to the colony for all available geolocation positions, and the light blue dots show the minimum and maximum distance recorded. Data from equinox periods and from periods of constant daylight have been removed (see Frederiksen et al. 2012).

4.3 Black guillemot

4.3.1 Ringing

Over the years, 17 adult black guillemots and 9 chicks were ringed. None of these birds were sexed.

4.3.2 Measurements

Mean adult body mass at first encounter was 388 g (SD = 24 g, range 340-430 g, n = 15), mean wing length 167 mm (SD = 2.9 mm, range 162-172 mm, n = 15), and mean length of head and bill 77.7 mm (SD = 1.58 mm, range 75.8-81.0 mm, n = 14).

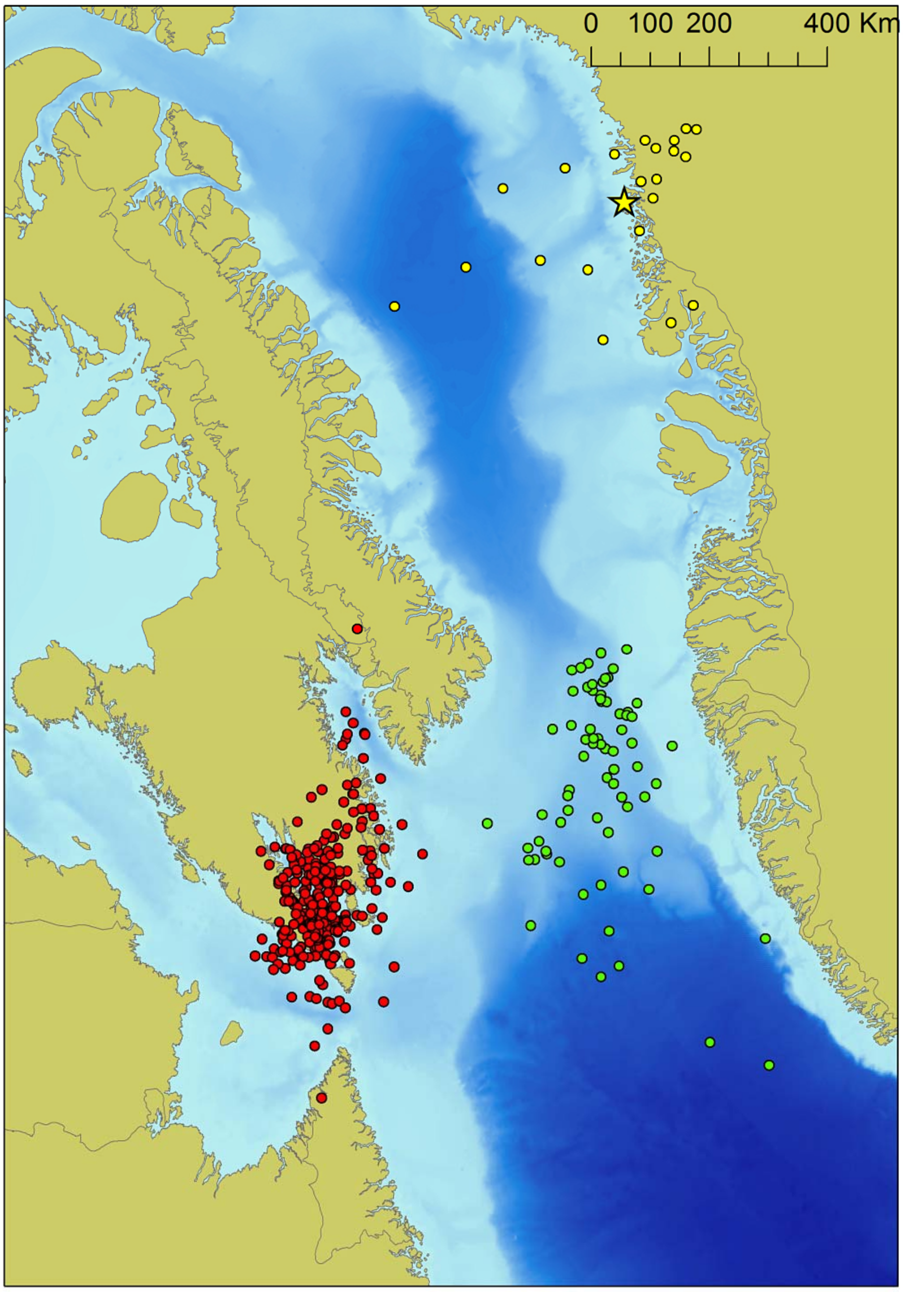
4.3.3 Logger effects

Of 13 geolocators deployed on black guillemots in 2012, only one was retrieved in 2013. One additional bird was recaptured, but had lost its logger. This low recapture success was disappointing, and may have been due to either logger effects on survival or breeding propensity, or general handling effects causing birds to skip breeding and/or become extremely shy.

4.3.4 Migration

The single bird for which migration data were available spent late August near the colony, appeared to be resident in Frobisher Bay, southern Baffin Island (approx. 1300 km from the colony) all winter, and in spring (April) occurred in the central Davis Strait, presumably near the ice edge (Fig. 4.16).

Figure 4.16. Positions derived from one geolocator on a black guillemot, 2012/13. Yellow dots indicate positions before the autumn equinox period (19 Aug – 3 Sep), red dots positions between autumn and spring equinox (13 Oct – 22 Feb), and green dots positions after the spring equinox period (26 Mar – 30 Apr). Note that the mean error of individual positions is large (~185 km), but the overall picture should be reliable. The location of the colony is indicated by the yellow asterisk.



5 Discussion

5.1 Identification of important areas

5.1.1 Breeding season

Murres breeding at Kippaku used foraging areas both in the archipelago southeast of the colony, and offshore in the Baffin Bay to the southwest, confirming preliminary results from satellite tracking (Box 3 in Boertmann & Mosbech 2011). The offshore foraging areas were located in deep waters up to 60 km from the colony, in many cases inside the hydrocarbon license areas. It is highly conspicuous that murres from Kippaku avoided areas to the northwest. Ship-based counts of murres at sea in 2008 indicated that high densities were present in this area (Box 3 in Boertmann & Mosbech 2011), so it is likely that Kippaku breeders avoided the area to reduce competition with the much larger numbers of murres breeding at Apparsuit, particularly the western end. The limited sample of tracks from murres breeding at the eastern periphery of the Apparsuit colony indicated that these birds used similar areas as the Kippaku birds (with one trip extending 94 km from the colony), although one individual made one trip to the northwest. Overall, important breeding season foraging areas for murres in the study area included the archipelago as well as the open Baffin Bay up to at least 40 km offshore.

Kittiwakes breeding at Kippaku used a variety of foraging areas in all directions and extending up to 75 km from the colony. These areas included both shallow bays in the archipelago, ice glacier fronts in ice fiords, and deep offshore areas. As for the murres, kittiwake foraging areas extended well inside hydrocarbon license areas in Baffin Bay.

5.1.2 Non-breeding season

Murres breeding at Kippaku wintered mainly on the banks east and south of Newfoundland. Here, they mix extensively with murres from Canadian colonies (McFarlane Tranquilla et al. 2013). These results concur with conclusions based on traditional ringing, namely that the majority of murres from the Upernavik area are found in Canadian waters in winter, with a smaller proportion wintering off Southwest Greenland (Lyngs 2003). Data have not yet been processed to the extent that it is possible to assess the extent of interannual variation in wintering areas, but such analyses are planned as part of a pan-Atlantic project.

Kittiwakes breeding at Kippaku wintered mainly in Canadian or international waters, on and east of the banks surrounding Newfoundland, as well as in the Davis Strait and the Labrador Sea. Here, they mix extensively with kittiwakes from many other populations in Canada and Europe (Frederiksen et al. 2012). We found substantial inter-year variation in the wintering areas used, with birds occurring further north in 2010/11 than in the two previous winters. This may be related to the extremely low sea ice extent in the Northwest Atlantic in the 2010/11 winter (see e.g. http://nsidc.org/arcticseaicenews/2011/01/). Traditional ringing has provided few recoveries of Greenland kittiwakes (Lyngs 2003), including only one bird from the Upernavik area, which was recovered off Nova Scotia in its third winter.

We only managed to obtain migration data from one black guillemot. This bird spent the winter in Frobisher Bay, southern Baffin Island, presumably in leads in the ice. The only two recoveries of black guillemots outside Greenland are from the west side of Baffin Island, where they were shot near Cape Dorset (Lyngs 2003); both concern birds ringed in the Upernavik area. Our results are thus not unique, but nevertheless we are not sure how representative this bird is. Traditional ringing has shown that many black guillemots from the Upernavik area winter along the coast of West Greenland, particularly in the Disko Bay (Lyngs 2003). During late winter and early spring, the tracked birds appeared to use an area in central Davis Strait; the occurrence of black guillemots in these partly ice-covered waters is supported by aerial surveys in March 1981 and 1982 (Mosbech & Johnson 1999).

5.2 Baseline conditions for seabirds in Baffin Bay

Most of our results indicate that ecological conditions around the colonies north of Upernavik have been very good for breeding murres and kittiwakes in 2008-13. In the following paragraphs, we briefly discuss our results in relation to similar studies of the two species.

Many seabirds have been found to adjust their foraging behaviour in response to prey conditions, e.g. when food supplies decline birds spend more time foraging and less time at the colony (Cairns 1987). Thus, time-budgets of free ranging seabirds are a good proxy for resource availability (Uttley et al. 1994). The amount of time spent foraging in 2008-2010 by breeding thick-billed murre ranged between 11.5 % and 14.3 %. This is at the lower end of previous results for thick-billed murres in Greenland (13-17 %, Falk et al. 2000, Falk et al. 2002). However, the time spent foraging by thick-billed murres at Kippaku was quite high compared to closely related common murres *Uria aalge* in the northern part of the species' range (summarised in Tremblay et al. 2003), but similar to or slightly lower than common murres breeding in Scotland (Monaghan et al. 1994, Thaxter et al. 2009).

We recorded consistently high values of mean brood size of kittiwakes (>1 chick/nest, including empty nests). Such a high breeding success has rarely been recorded for the species, particularly over several years (Frederiksen et al. 2005, Hatch et al. 2009). We may have overestimated breeding success, partly because we may have missed some nests which had failed early, and partly because a few chicks are likely to have died after our surveys, but before fledging. Nevertheless, all indications are that kittiwakes achieved a very high breeding success at Kippaku in all the years when it was possible to collect data. Murre breeding success was so far only estimated in two years; the estimated value in 2012 (0.77 chick/egg laid) was among the highest recorded for the species, whereas 2011 was a more typical season (0.53 chick/egg laid) (Gaston & Hipfner 2000, Barrett et al. 2013).

The body condition and fledging mass of murre chicks was considerably higher than in most previous studies of the species (Gaston & Hipfner 2000). For example, the classic study of Gaston & Nettleship (1981) recorded mean fledging mass of 200-230 g, vs. 240-275 g at Kippaku. More northerly colonies in Greenland also showed lower fledging mass (Boertmann & Mosbech 2011), but at the colony Ritenbenk in Disko Bay, fledging mass was similar to the best year at Kippaku (F. Merkel et al, unpubl. data).

The murre chick feeding rates (2.84 to 7.78 meals/day) were normal to high compared to other studies around the Baffin Bay, except in 2008 when the observers may have missed several feedings due to the large study plot (sub-plots A and B were only included in 2008). At other colonies in Northwest Greenland, feeding rates were 2.72 meals/day at Ritenbenk (Mosbech et al. 2007), 4.92 at Saunders Island (Boertmann & Mosbech 2011) and 5.30 at Hakluyt Island (Falk & Kampp unpubl.), while studies at Canadian colonies in Baffin Bay showed feeding rates ranging from 3.5 up to 6-8 meals/day (Gaston & Nettleship 1981). Feeding rates may vary with chick age and typically peak when chicks are 10-15 days old (Gaston & Hipfner 2000), and considering the different average chick age during observation periods across years at Kippaku, the recorded feeding rates are remarkably constant.

The combination of high feeding rates, relatively relaxed time budgets and high fledging mass of chicks suggests that murres at Kippaku have enjoyed favourable foraging conditions during the study period.

The population trend for murres in northern Upernavik is somewhat peculiar, as the Kippaku colony is increasing in numbers while the larger Apparsuit colony only 10 km away is decreasing. Several colony surveys confirm this development and it is therefore unlikely that census errors can explain the contrasting trends (Labansen et al. 2013). Apparsuit is probably exposed to more disturbances as it is situated next to the inshore navigation route, but currently no data are available to explore whether this is important. The colony surveys indicate a similar contrasting population development for kittiwakes, with the larger colony at Kippaku increasing and the smaller colony at Apparsuit decreasing (Labansen et al. 2013).

The estimated mean annual survival probability for kittiwakes (0.91) was unusually high for Atlantic colonies (cf. Frederiksen et al. 2005), but given the small sample size and low precision this finding should not be given too much emphasis. For murres, the estimated mean survival (0.84 from colour rings, 0.83 from logger birds) was lower than expected; more typical values are around or above 0.90 (Gaston & Hipfner 2000, Sandvik et al. 2005). Estimates from colour-ringed birds may be biased low because of ring loss or wear (Breton et al. 2006), or because of skipped breeding attempts of established breeders (Prévot-Julliard et al. 1998). Despite many hours of observations, murres only equipped with a metal ring have never been observed in the study plot, so colour ring loss does not appear to be a major problem. Given that the study period mainly has covered the later part of the breeding season, it is certainly possible that birds not breeding in a given season, or failing early, have been missed. The same reservation applies to the logger birds. Further years of study should improve the survival estimates, allowing improved evaluation of both baseline survival and potential logger effects.

Although conditions thus in general appeared to be very good, there was some variation between years. In particular, breeding was substantially later for both murres and kittiwakes in 2011 and 2013 than in the other years, and this hampered our data collection somewhat. Non-systematic observations of hatching and chick age indicated that mean hatching date for murres was around 20-22 July in 2013, and around 13-15 July for kittiwakes in both years. Overall phenology thus appeared to be 10-14 days delayed compared to the other study years. Breeding success for murres was considerably lower in 2011 than in 2012, and the number of pairs attempting breeding in the monitoring plot was lower as well. It thus appears that at least for murres, delayed breeding had consequences for overall productivity. It is most likely that the delayed breeding in these two years was related to relatively late breakup of sea ice in Northwest Greenland (see e.g. http://ocean.dmi.dk/arctic/icecharts.php or http://ocean.dmi.dk/arctic/upernavik.php).

5.2.1 Comparison with 1980s studies

Many aspects of murre biology were also studied as part of the WWF project in the 1980s (Table 5.1). A comparison with our results shows that in 4 of the 6 six years we collected data, breeding was much earlier than previously recorded, with the two remaining years (2011 and 2013) being more similar to the 1980s. Hatching success was lower in 2011 than previously recorded, whereas fledging success was similar in all years. Feeding frequency and main prey were also similar in all years. Chick fledging mass was higher in the 3 years we could measure it than in 1987, whereas adult body mass was similar. The available data thus suggest that conditions for breeding murres have remained very good, although occasional years with lower breeding success (but still within the 'normal' range) occur.

Table 5.1. Comparison of aspects of murre breeding and feeding biology in the 1980s vs this study. *Only plots without egg collection included.

	1987 Kippaku	1987 Apparsuit	1988 Kippaku	2008-2013 Kippaku
Mean hatching*	25-26 July	28-30 July	19-24 July	5-24 July
Hatching success	81%	93%		60-81%
Fledging success	91%	88%		89-95%
Breeding success	0.73	0.82	'High'	0.53-0.77
Feeds/chick/day	4.5		5.5-6.0	2.8-5.8
Main prey	Polar cod		Polar cod	Polar cod
Fledging mass	231 g			243-274 g
Adult mass	942 g			955 g
Source	Evans (1987)	Evans (1987)	Kampp & Lyngs (1989)	This study

5.3 Future studies and need for monitoring

The fieldwork carried out in 2008-2013 has provided a detailed and very useful ecological baseline for some of the most important seabird populations in Baffin Bay. Many of the data collected have not been fully analysed within the scope of this project, and if resources are available, there is thus potential for improving the picture further, including a better assessment of natural year-to-year variation in foraging conditions.

Arctic marine organisms and ecosystems are potentially affected by many different pressures deriving from human activities, including fisheries, hunting, climate change, long-distance transported contaminants as well as hydrocarbon exploration and extraction. Explaining observed changes in terms of these underlying pressures requires a carefully designed monitoring programme. For seabirds, such a monitoring programme should include regular (preferably annual) collection of data on population size, demographic parameters and time budgets at suitable sites. We suggest that Kippaku is a highly suitable site for long-term seabird monitoring in Baffin Bay. Our fieldwork over the last six years has shown that it is logistically feasible to collect a wide range of high-quality data, and many of the existing data could form the start of more extensive time series, with standardized use of camera monitoring and data loggers. Further methodological developments in data processing are necessary to realise the full potential of these semi-automated data collection protocols.

Given the contrasting population development at Kippaku and Apparsuit, a long-term study program at Kippaku should include an Apparsuit component, which should explore additional fieldwork opportunities at this important and logistically challenging colony.

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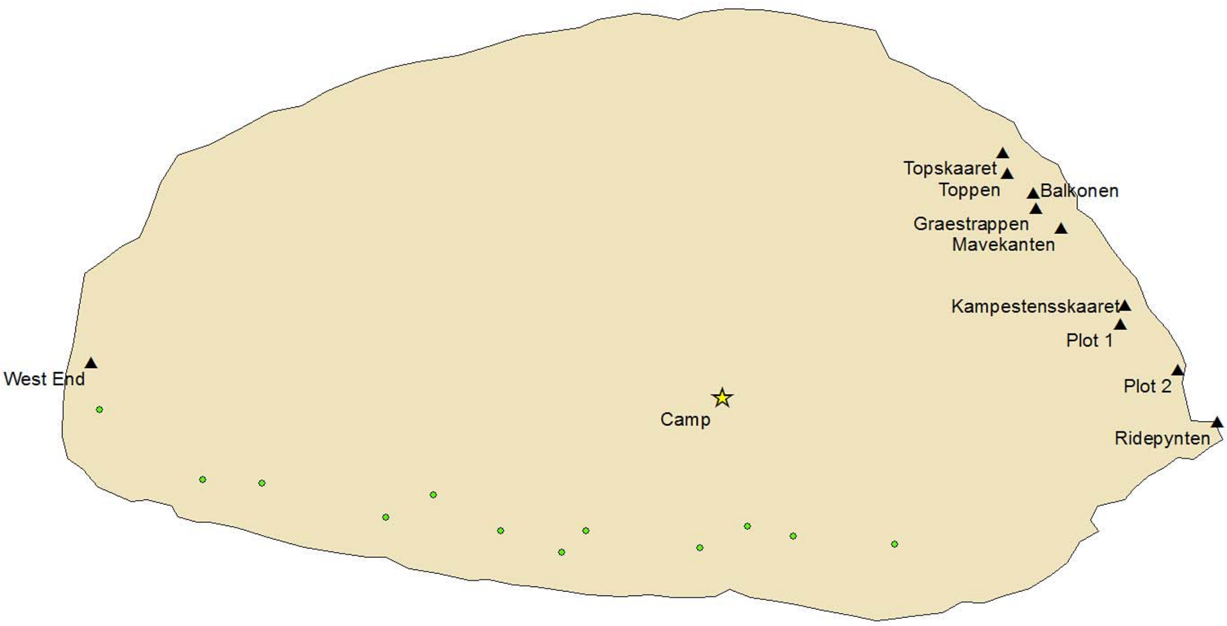
Appendix 1. Description of sites used for capture and observation of thick-billed murres and kittiwakes at Kippaku and Apparsuit

Kippaku

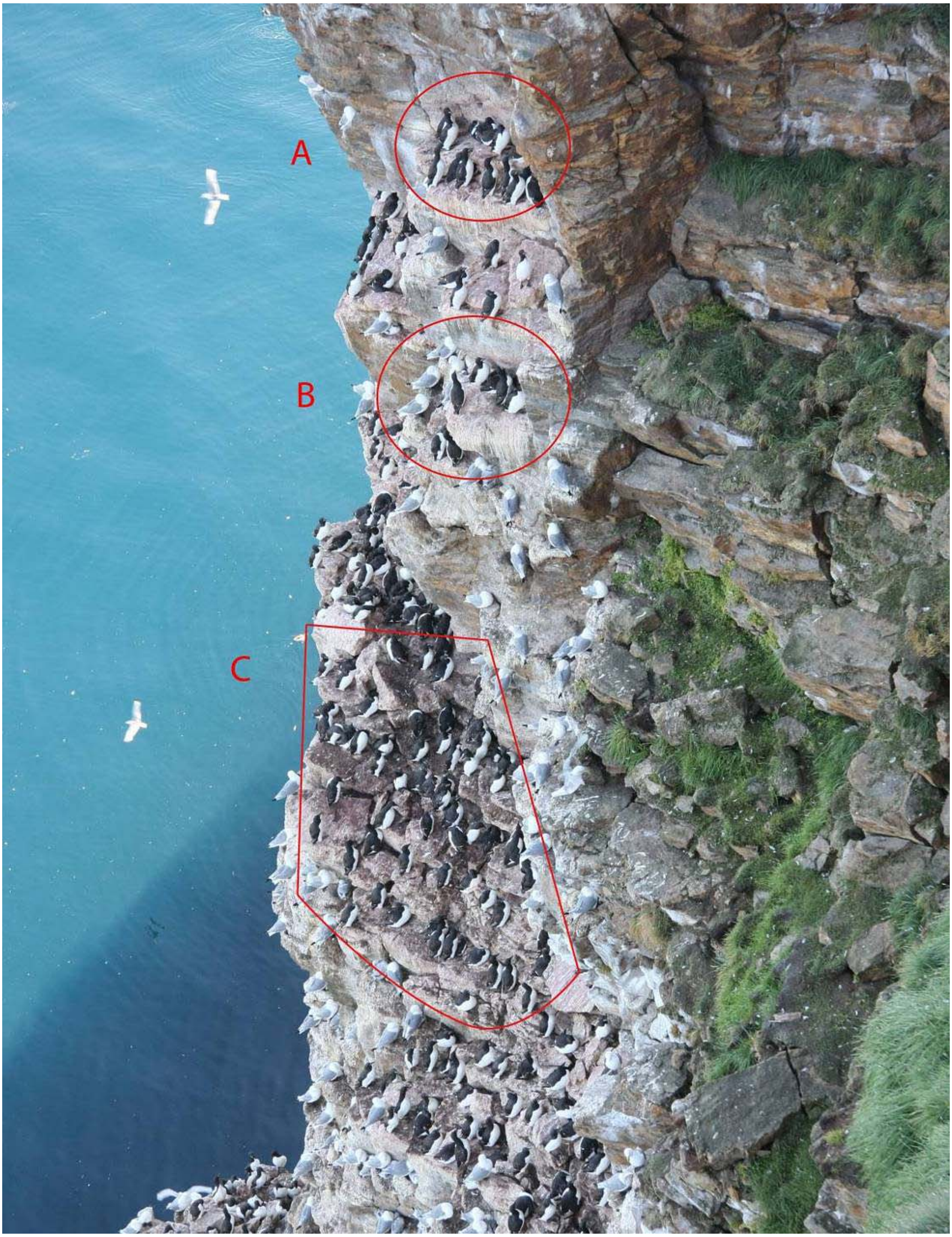


Map of Kippaku showing the location of the camp, capture and observation sites for murres and kittiwakes (black triangles) and black guillemot nests used for capture (green dots).

Ridepynten (GPS N73 43.112 W56 37.293, altitude 14 m)

Main site for logger deployment on kittiwakes.

Plot 2 (GPS N73 43.121 W56 37.329, altitude 39 m)

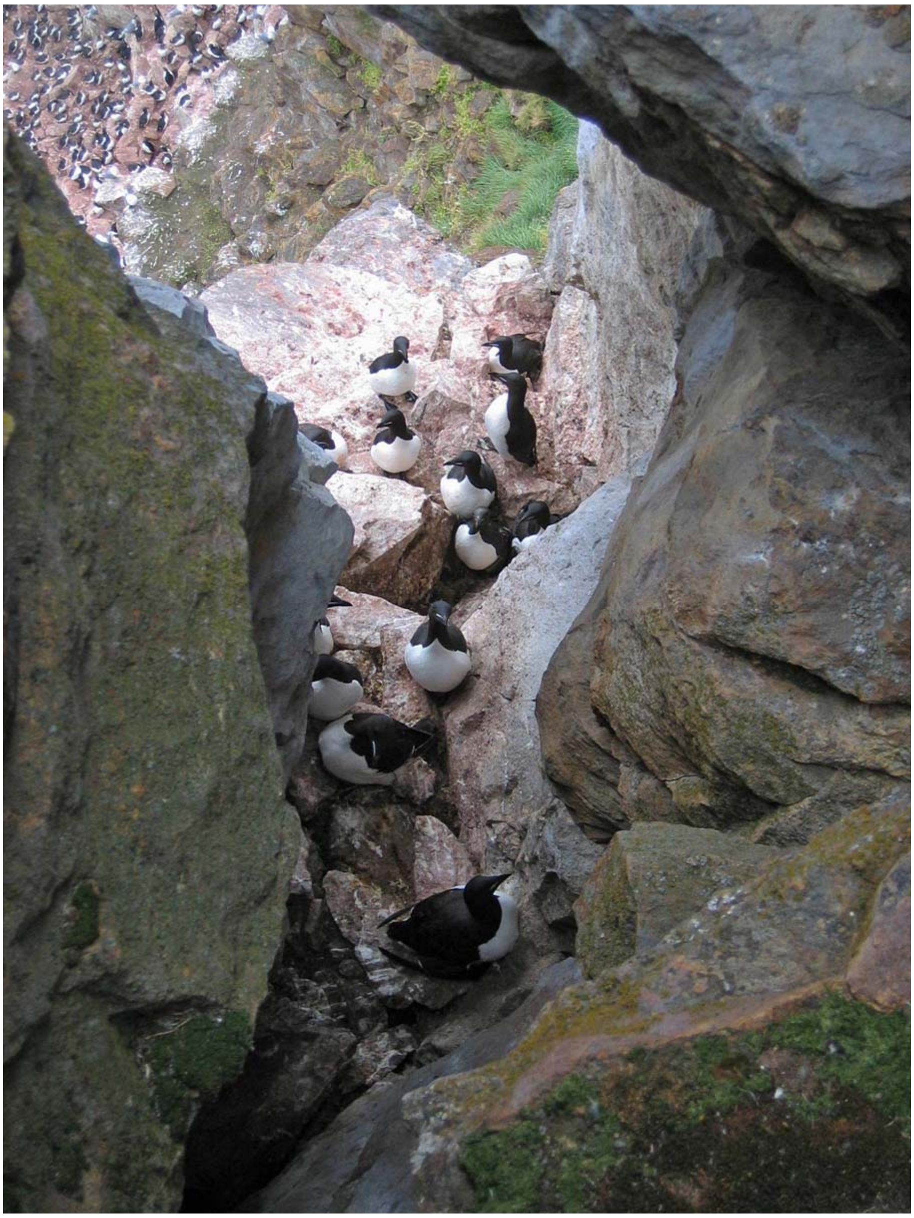


Main plot for colour-ringing, feeding watches and time-lapse photography of murres. Colour rings used in sub-plots A, B and C. Observations mainly made in sub-plot C.

Plot 1 (GPS N73 43.128 W56 37.377, altitude 52 m)

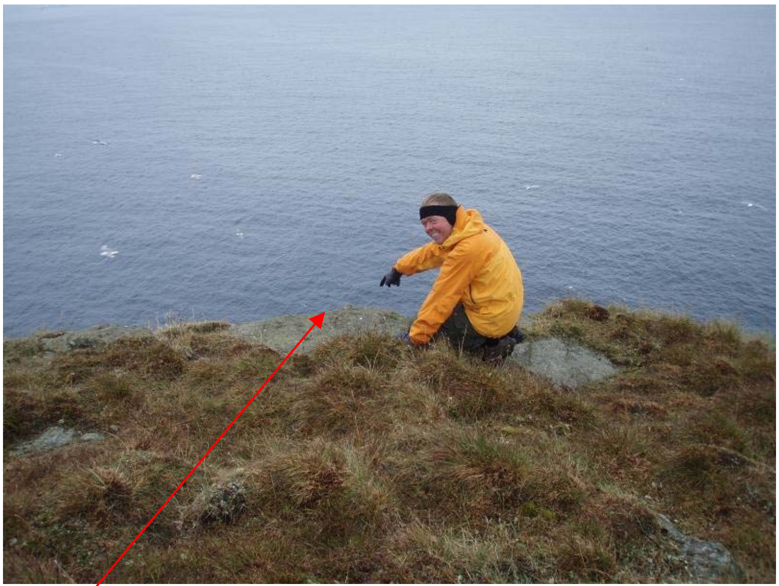
Only used in 2008. Access route (abseiling) marked.

Kampestensskåret (GPS N73 43.132 W56 37.376, altitude 56 m)



Deployment of loggers on murres. Poor site for recapture.

Mavekanten (GPS N73 43.145 W56 37.433, altitude 67 m)



Capture site.

Only used for loggers in 2008. Chick weighing in some years.

6.1.1 Græstrappen (GPS N73 43.148 W56 37.454, altitude 65 m)

Descent point (simple abseiling)

Area enlarged below

Logger deployment on murres. Best capture site 3-4 m below cliff edge.


Logger deployment on kittiwakes, to the right of capture site.

Balkonen (GPS N73 43.151 W56 37.458, altitude 74 m)

Capture site

Very good site for logger deployment on murres. Also a few kittiwakes immediately below capture site.

Balkonen mf (2 m left of Balkonen).

Very good plot for logger deployment on murres – only few pairs.

Balkonen tv (3 m left of Balkonen).

Deployment of loggers on murres.

Toppen (GPS N73 43.154 W56 37.480, altitude 72 m)

Normally, best capture site is from the cliff edge, left or right of indicated position.

Deployment of loggers on murres, and on kittiwakes immediately to the right.

Topskåret (GPS N73 43.158 W56 37.486, altitude 72 m)


Deployment of loggers on murres. Poor site for recapture. Top ledge.


Bottom ledge.

West end (GPS N73 43.079 W56 38.114, altitude 12 m)

Deployment of loggers on murres – poor site for recapture. In addition, four murres were colour-ringed here in 2010.

Apparsuit

Plot B-East (GPS N73.78659 W56.6508)

The landing point for Plot B-East is outside the frame of the picture, on the right. The ledges where birds were caught are below the anchor site, see next pictures.

Appendix 2. Possible effects of egg collection

The area below Plot 1 was densely occupied by breeding murres in 2008 (left picture, red circle). However, in later years many fewer birds were present in this area, and in 2013 no murres appeared to breed (right picture, red circle). Other evidence indicates that egg collection may have been responsible (delayed breeding already in 2008, obstruction of cameras covering potential access route). A small landslide (yellow circle) in spring 2010 directly above the area may also have caused some birds to move to other ledges.

SEABIRD BASELINE STUDIES IN BAFFIN BAY 2008-2013

Colony-based fieldwork at Kippaku and Apparsuit, NW Greenland

As part of the environmental studies in connection with oil exploration in Baffin Bay, baseline studies of seabird ecology were carried out at colonies north of Upernavik during the summers of 2008-13. The main study species were thick-billed murre and black-legged kittiwake. GPS tracking of both species showed that important foraging areas during the breeding season (July) included fiords and archipelagoes as well as the open Baffin Bay up to 40 km offshore. These areas overlapped with existing exploration licenses. Conditions for breeding murres and kittiwakes in the study area were very good in 2008-13. This indicates that the availability of high-quality food in the area was good.

The results of the baseline studies provide a benchmark, which will allow the evaluation of impacts of future oil activities or other environmental changes.

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