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Front page illustration: A Brünnich's guillemot is released after being equipped with a GLS tag at Ossian Sars in Kongsfjorden, Spitsbergen. Photo: Hanne Pilskog.

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Preface

In millions, seabirds roam the world's oceans in search for food, often very far from where they mate and fulfill their purpose in life. Being independent of land, they are only limited in their movements in that they have to return to the breeding grounds once a year to breed. Common and Brunnich's guillemots are no exception, being adapted to a life in the arctic seas. With oil exploration and new shipping routes increasing in the North, there is also an increasing probability of unwanted oil spills with possible devastating damage to the seabirds when at sea. To minimize the potential for conflict between the future oil explorations and the guillemots in the arctic seas, the TOTAL Foundation initiated the project "Winter Ecology of Marine Birds in the Barents Sea" to map the areas of conflict. The results presented in this report are very promising, and they have with great certainty revealed the whereabouts of Brunnich's and common guillemots during the arctic winter.

We thank TOTAL E&P Norge and the TOTAL Foundation for providing funding for this project. Thanks to all members of the project team, to Alexander Koryakin and especially to Gregoire Kuntz for contributing with veterinary expertise. We would also like to thank all fieldworkers involved for the time and effort they have spent on capturing, sampling, instrumenting and recapturing birds: Kjetil Letto, Geir Kristiansen, Finn Eirik B. Olsen, Sigrid Engen, Magnus Irgens, Harald Engan, Josefin Johansson, Robert T. Barrett and Norman Ratcliffe. Finally, we are very thankful to Anders Skoglund and Bernt Bye at the Norwegian Polar Institute for guidance and help with GIS handling and analyses and to Audun Igesund for helping us with the layout for the report. Robert T. Barrett also did a great job with proofreading.

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Tromsø August 2013

Summary

Exploration in the Barents Sea has revealed large reserves of gas and oil. Increased shipping and drilling activity will be demanded in order to extract these resources, which in turn will lead to an increased probability of a major oil spill. In addition to gas and oil, the Barents Sea contains large fish resources and, consequently, abundant marine mammal and seabird life. Brünnich's and common guillemots (*Uria lomvia* and *U. aalge*) make up a large proportion of the seabirds in the region, and they are especially vulnerable to oil spills since they spend almost all their time at sea. Both species are protected and included in the Norwegian Red List. The common guillemot is listed as Critically Endangered on mainland Norway, and any loss of birds would be serious. The Brünnich's guillemot is listed as Vulnerable. Common guillemots on Bjørnøya are currently increasing in numbers after a collapse in the 1980s, whereas Brünnich's guillemots are in steady decline in the western Barents Sea region.

An oil spill may affect and harm numerous birds, and in case of such an event, it is essential to know which breeding colony any affected birds belong to. If they are from a large and otherwise healthy colony, an oil spill may have minor effects, but if the colony is small and declining, the effect might be detrimental. A loss of adult birds will have more serious consequences than loss of young birds. Knowledge about the specific migration patterns and wintering areas of a colony is therefore needed to assess the ecological impacts of oil spills.

The aim of this project was to map the wintering areas and migration patterns of Brünnich's and common guillemots breeding on Spitsbergen, Bjørnøya, Hornøya (Norway) and Kharlov Island (Russia) in order to increase the general knowledge about the species and to strengthen the ability to make qualified environmental risk assessments before starting oil exploration in the Barents Sea region. The project was a Norwegian-French-Russian cooperation organized as an add-on to the Norwegian SEAPOP program. Between 2007 and 2010, a total of 408 Global Location Sensor (GLS) loggers (a light-based geolocation system) were attached to common and Brünnich's guillemots to collect data on their movements between August and April. In this report we will present Kernel density plots for Brünnich's and common guillemots in different months based on aggregated daily position calculations from all three study years. Time-Depth Recorders (TDR) implanted into the abdominal cavity of some of the birds were also used to record behavioural data the first year, but due to technical failures no data could be collected from these devices.

Our study shows that migration patterns differed both between the two focal species and between colonies. Brünnich's guillemots breeding on Spitsbergen migrated all the way to Greenland and Newfoundland. Brünnich's guillemots from Bjørnøya migrated to Iceland, whereas Brünnich's guillemots breeding on Hornøya stayed in the Barents Sea during winter. The Brünnich's guillemots from Spitsbergen were absent from the Barents Sea between November and March, while the Bjørnøya breeding birds were absent from the Barents Sea in December and for the most part also in November and January. The birds breeding on Hornøya spent the whole year east of 20°E. Operations in the Barents Sea in November through January will therefore have limited impact on Brünnich's guillemots breeding on Bjørnøya and Spitsbergen, while Brünnich's guillemots breeding on the mainland (Hornøya) would be at risk in the event of an oil spill in the eastern Barents Sea. Oil spills in any of the other months may pose a threat to birds from all colonies in the Barents Sea area.

Common guillemots breeding on Bjørnøya moved into the southeastern parts of the Barents Sea during the autumn and returned westward in January and February. During this period the birds were rather dispersed. From March and onwards the birds concentrated around Bjørnøya and the shallow areas to the northeast. Therefore, any oil spill in the central or eastern Barents Sea at any time of the year may affect common guillemots breeding on Bjørnøya.

Due to lack of recaptures we have no data from the Kharlov Island colony. Having data only from the previously mentioned colonies, we cannot infer where guillemots from other parts of the Barents Sea region migrate, but common and Brünnich's guillemots from the Russian coast are believed to show a migration pattern similar to that of the Hornøya birds. Ship traffic between Svalbard and Norway will pose the least threat to common and Brünnich's guillemots when restricted to the zone between 0 and 15°E in December and January, but this zone is an important transit area for Brünnich's guillemots in September–November and February–March. The waters around Bjørnøya, the Svalbard archipelago and the Finnmark coast will have high densities of guillemots from February through October.

The data collected in this project will be used in future studies of the migration strategies of Brünnich's and common guillemots from the Barents Sea region.

Contents

Introduction

The marine ecosystem of the Barents Sea is of key biological interest because it holds one of the world's largest concentrations of seabirds (Anker-Nilssen et al., 2000) and sustains one of the world's leading fisheries. About 20 million seabirds harvest approximately 1.2 million tonnes of biomass annually from the area (Barrett et al., 2002). Many of the seabird populations in the Barents Sea area are of international importance and considered to be sensitive ecosystem components (Anker-Nilssen et al., 2000).

The seabirds utilize the high primary production and large stocks of pelagic fish species such as capelin *Mallotus villosus*, herring *Clupea harengus* and polar cod *Boreogadus saida*. The Barents Sea area represents an ecotone from a North Atlantic ecosystem in the south via the Polar front to an Arctic ecosystem in the north. In the north and east, the marginal ice-zone is an important feeding habitat where seabirds forage on migrating capelin, polar cod and zooplankton (Mehlum and Gabrielsen, 1993, Mehlum et al., 1998a, Mehlum et al., 1998b). The seabird communities in south and west depend on juvenile gadoids, juvenile herring, sandeels (*Ammodytes* sp.) and capelin (e.g. Anker-Nilssen, 1992, Barrett and Krasnov, 1996, Barrett et al., 1997, Fauchald and Erikstad, 2002). Atlantic puffins *Fratercula arctica*, black-legged kittiwakes *Rissa tridactyla* and common guillemots *Uria aalge* dominate the seabird communities south of the Polar front while more arctic species such as Brünnich's guillemots *U. lomvia* and little auks *Alle alle* dominate the north (Strøm et al., 2009).

Climate change, fisheries, oil pollution and, for some seabird populations, contaminants are considered to be among the greatest threats to seabirds in the Barents Sea today (Anker-Nilssen et al., 2000). Several assessments of the vulnerability of the environment, including seabirds, to oil pollution have been made for the region and all concluded that, in whatever area or season, many seabird populations of international conservation value will be in danger of being seriously affected in the event of an oil spill (Huntington, 2007). Because auks spend most of their life at sea, are surface-divers and tend to spend most of their time in dense flocks on the sea surface, they are among the seabirds most vulnerable to long-term effects of oil pollution at the population level (e.g. Camphuysen et al., 1999). In Norway, common and Brünnich's guillemots are among the most conspicuous casualties of oil spills (Barrett et al., 2008).

The common guillemot populations have declined dramatically over the last 40 years, especially in the western Barents Sea region (Barrett and Golovkin, 2000). It is therefore feared that local populations of the common guillemot west of Nordkapp will soon become extinct (Erikstad et al., 2007, Lorentsen and Christensen-Dalsgaard, 2009). The common guillemots on Bjørnøya (Bear Island) and Hornøya are now increasing in numbers, while the Brünnich's guillemot population is declining in Svalbard as well as in mainland Norway (Strøm, 2011, Erikstad et al., 2007). Due to their population status, the common guillemot is classified as Critically Endangered on the Norwegian mainland and Vulnerable in Svalbard, whereas the Brünnich's guillemot is classified as Vulnerable and Near Threatened, respectively, in the National Red List (Kålås et al., 2010). Both species are two of the main study species of the SEAPOP program (Anker-Nilssen et al., 2005), which is funded by the Norwegian government and the Norwegian oil industry.

With the present focus on oil and gas exploration, production and transport from the Barents Sea, the possibility of the populations of guillemots being directly affected by an oil spill is increasing. Furthermore, seabirds are constantly under direct and indirect pressure by fishing activity in the region, thus the possibility of a mass mortality incident is always present. Since at least the common guillemot population in the Barents Sea is already seriously threatened, there is a need to be able to identify the origin of birds killed in oil incidents in order to document effects at the population level and identify any mitigating post-event management actions (Barrett et al., 2008).

Both guillemot species breed along the coasts of many North Atlantic seaboard countries and are very faithful to their breeding site (*philopatric*). Outside the breeding season, however, birds from many regions may gather at sea in large flocks, so that any 'incident' may involve birds from several breeding populations simultaneously (Bakken et al., 2003, Cadiou et al., 2004, Strann et al., 1991). In these cases, being able to assess the scale of the impact through the identification of the source populations is of utmost importance for the management of those populations (Barrett et al., 2008).

Recoveries of ringed birds indicate that the common guillemots breeding on Bjørnøya and the Kola Peninsula probably winter in the southern parts of the Barents Sea and in coastal waters off Northern Norway, whereas Brünnich's guillemots breeding on the Kola Peninsula, Bjørnøya and Spitsbergen spend the winter in the seas around Iceland, Greenland and Newfoundland (Nikolaeva et al., 1996, Bakken et al., 2003, Bakken and Mehlum, 2005). However, ring recovery reports are notoriously biased because far more birds are recovered in areas where they are being hunted, such as Greenland and Newfoundland.

By use of miniaturized electronic tags it is now possible to collect unbiased information on the migration routes, the wintering areas, and the wintering ecology of common and Brünnich's guillemots breeding in the Greenland and Barents Seas.

Our objectives were:

Principle objective: To study seasonal movement patterns and winter biology of adult common and Brünnich's guillemots in the Barents Sea ecosystem using geolocators and time-depth recorders.

Subgoals:

- To assess the vulnerability of common and Brünnich's guillemots to human activity such as oil exploration and ship traffic with special emphasis on post-breeding migration to wintering areas.
- To map migration routes and wintering areas of common and Brünnich's guillemots breeding on Spitsbergen, Bjørnøya, and Kola Peninsula (Russia).
- To explore the three-dimensional movements and behaviour of adult common and Brünnich's guillemots during the winter months.

Guillemot biology

Migration routes, wintering areas and winter behaviour are very poorly known in seabirds from the Barents Sea (e.g. Anker-Nilssen et al., 2000, Anker-Nilssen et al., 2005). This is problematic since information on spatial and temporal distribution of seabirds all year round is essential to define the drivers of winter mortality, pinpoint conflict areas with human activities and anticipate the impact of potential incidents such as oil spills.

Based on an estimate of more than three million individuals (Anker-Nilssen et al., 2000), common guillemots and Brünnich's guillemots are the two dominating seabird species in the Barents Sea, both in terms of numbers and biomass. They are found all year round in this area (Bakken and Pokrovskaya, 2000, Barrett and Golovkin, 2000). The two species are similar in morphology and ecology, and they are often considered to be high- and low-arctic ecological counterparts (Birkhead, 1985). The common guillemot breeds on Bjørnøya, mainland Norway and in Russia, whereas the Brünnich's guillemot breeds in colonies on Spitsbergen, Bjørnøya and in a few small colonies on the Norwegian and Russian mainland (Strøm, 2006). Both species lay one egg directly on the ledge where they breed. Egg laying occurs in May and early June in the southern parts of their distribution range and a bit later further north. Both parents participate in the brooding and chick rearing. The chicks may fledge after 16 days, but normally they fledge 21 days after hatching. The flightless chicks jump off their ledge and glide towards the sea. The parents guard the chicks from aerial predators, e.g. great black-backed gull *Laurus marinus* and glaucous gull *L. hyperboreus* during their passage to the sea. Once at sea, the male escorts the chick out to sea to forage and grow into an adult bird. The juvenile becomes independent of the parents 6–12 weeks after fledging, and the age of first breeding is normally five years for both species.

Like many other seabirds, the Brünnich's and common guillemot are relatively long-lived, and each pair invests in only one offspring annually (Gaston and Jones, 1998). Mortality is highest in young birds, but once they attain sexual maturity, the birds may have many chances of reproducing (Hamer et al., 2002). Any incident reducing the number of adult Brünnich's and common guillemots can therefore be expected to induce more damage to the population as such, compared to loss of young individuals. One year of low reproduction can be compensated for in the coming years, but for the colonies to survive, a steady basis of adult birds have to return year after year to breed.

Project organization

This project was a co-operation between the Norwegian Polar Institute (NPI), Centre for Functional and Evolutionary Ecology (CEFE) in France, Tromsø University Museum and Kandalaksha State Nature Reserve. Being an add-on to the SEAPOP program, the project piggybacked on this and other already existing projects (NPI monitoring programs) based at NPI's research facilities on Bjørnøya, in Ny-Ålesund, Longyearbyen and on Hornøya. In Russia, the project collaborated with ongoing monitoring activities at Kharlov Island, Seven Islands, Kola Peninsula. Using the already existing field sites and logistics, we cut costs and assured that the project had access to appropriate individuals of the right sex and breeding status.

In addition to Global Location Sensors (GLS), we deployed time-depth recorders (TDR) to investigate winter behaviour. The TDRs were implanted into the abdominal cavity of the adult birds by our veterinary team, which has extensive experience in these deployments in seabirds. The permit for this work was given by the Norwegian Animal Research Authority, NARA. However, due to technical failures in the TDRs, no data could be collected, thus precluding the presentation of any results.

Material and methods

Global Location Sensor (GLS) tags (Fig. 1) were used to collect position data for adult Brünnich's and common guillemots breeding at six different locations in the Barents Sea region from June 2007 to June 2010. The GLS tags, produced by Lotek Wireless Inc. in Newfoundland, Canada, are designed to record time, light intensity, pressure (± 1 % accuracy), temperature (< 0.2°C accuracy) and wet/dry state. Each tag uses time and recorded light intensity to estimate latitude and longitude once per day. A study on albatrosses using both satellite tags and GLS simultaneously on the same birds showed that, on average, the GLS positions differ from the satellite tag positions with 186 SD ±114 km in any direction (Phillips et al., 2004). This translates to about 100 nautical miles. At high latitudes, the GLS-based localization is more accurate when calculating longitude than latitude. This means that we are more certain of east-west movements than we are of north-south movements. In early August and late April this difference is exaggerated and we can trust the latitudinal positioning even less. These factors are important to keep in mind when studying the results. We are nonetheless confident that we give a correct presentation of the main pattern of temporal and spatial winter distribution of the guillemots from the breeding locations.

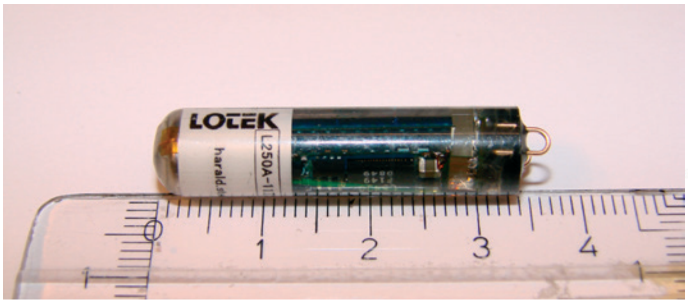

Figure 1. Global Location Sensor (GLS) tag, (Lotek Wireless Inc.)

A total of 408 GLS tags were used in this study. Each tag weighed approx. 3.6 grams and was attached with cable ties and glue to a plastic ring sitting around the bird's left leg. The birds were captured and tagged while breeding in the colonies between 13th June and 27th July in 2007, 2008 and 2009. As many tags as possible were retrieved by recapturing the birds in 2008, 2009 and 2010. A map with the sampling locations is given in Figure 2. On Bjørnøya, common and Brünnich's guillemots were tagged in Revdalen on the southern tip of the island (74°20'N, 19°5'E) all three years.

On Spitsbergen, where only Brünnich's guillemots were tagged, we used the colony at Ossian Sarsfjellet (78°56'N, 12°27'E, Fig. 3) in Kongsfjorden in 2007. In 2008, the effort was divided between the colony in Amfifjel-

Figure 2. Tagging and recapture locations (red dots) for Brünnich's (*Uria lomvia*) and common guillemots (*Uria aalge*). (Norwegian Polar Institute)

The GLS tags collected pressure data every two seconds for periods of varying lengths (3–55 days) during the winter months. With these data we were able to tell how deep the individual birds dove and investigate the dive trajectories. Temperature and wet/dry state were measured every five minutes over a period of five to ten months. All these data were intended to complement the TDR data in our exploration of the three-dimensional movements and behavior of common and Brünnich's guillemots. The data are still being processed by our project partners in France, and no results are currently ready for presentation.

GLS tags do not communicate the collected data wirelessly. The data are stored in the tag, so the tagged birds had to be recaptured for the data to be downloaded. We captured the birds using a noose attached to the end of a 5–6 meter long pole.

let (79°10'N, 11°52'E) in Krossfjorden and the colony at Diabasodden (78°21'N, 16°08'E) in Isfjorden. We tagged Brünnich's guillemots in all three colonies in 2009. Throughout the rest of this report, these three Spitsbergen colonies will be referred to as one sampling location (Spitsbergen).

GLS tags were also deployed on Brünnich's and common guillemots on Kharlov Island (68°49'N, 37°19'E) in the Seven Island archipelago on the Murman Coast in Russia in 2008 and 2009. However, none of the birds tagged on Kharlov Island were observed in the colonies the year after deployment, and therefore no recapture was possible. Despite meetings between Norwegian and Russian representatives in which the instrumentation process was clarified, the GLS loggers used on Kharlov Island were attached to the birds in a manner different to that intended. This might have affected the recapture rate negatively. In addi-

tion, the Russian guillemot populations have been declining strongly in recent years, which also might have reduced the return rate of the birds. Attempts to recapture the birds tagged on Kharlov Island will be made if they are observed in the colony. To compensate for the lack of data from Kharlov, sixteen Brünnich's guillemots were tagged in 2009 on Hornøya (70°23'N, 31°09'E) on the coast of Finnmark, Norway. Tables 1 and 2 present the number of GLS tags deployed and retrieved from Brünnich's and common guillemots, respectively, in the different colonies during the three-year study period.

In total, 218 (54 %) of the GLS loggers that were attached to Brünnich's and common guillemots were retrieved, most of them during the summer of 2010. There are three main reasons for a logger not to be retrieved: 1) the tagged bird did not return to the colony in any of the years after it was tagged, 2) the bird returned, but it had lost its GLS logger, or 3) the bird returned with the logger but could not be caught, either because it had moved to a nest site that was out of reach or because it was simply too nervous and jumpy to be caught. The latter seemed to be the case more often for Brünnich's guillemots than for common guillemots. Tag loss was mainly seen during the first winter (2007–2008). Applying glue to secure the tags on the plastic bands in the following years almost eliminated this problem. We have no reason to suspect that attaching GLS tags affected the guillemots' survival or return rate.

Overall, the retrieval rate was somewhat higher at Bjørnøya than at the other tagging locations.

The manufacturer of the GLS tags, Lotek Wireless Inc. (Newmarket, Ontario, Canada), supplied us with the neces-

Figure 3.
Above: Brünnich's guillemots (*Uria Lomvia*) on a breeding ledge in the colony at Ossian Sarsfjellet, Kongsfjorden, Spitsbergen. Below: GLS (Geolocation Sensor) tag attached to a plastic ring on the leg of a Brünnich's guillemot. (Photos: Erlend Lorentzen, Norwegian Polar Institute)

Table 1. Number of GLS tags deployed on and retrieved from Brünnich's guillemots (*Uria lomvia*) on Bjørnøya (BI), Spitsbergen (SP), Kharlov Island (KI) and Hornøya (HO) between 2007 and 2010. Retrieval rate refers to the number of tags retrieved divided by the number deployed. Success rate represents the number of tags from which good quality data could be downloaded divided by the number of tags deployed.

GLS tags on Brünnich's guillemots			Year of deployment									
			2007		2008			2009				Grand Total
Year of retrieval		Deployed	BI	SP	BI	SP	KI	BI	SP	KI	HO	All
	Retrieved		15	15	40	44	20	40	45	19	16	254
2008	Bjørnøya (BI)	Good quality	3									3
		Poor/unreadable	2									2
	Spitsbergen (SP)	Good quality		6								6
		Poor/unreadable		1								1
	2008 Total retrieved		5	7								12
2009	Bjørnøya (BI)	Good quality			19							19
		Poor/unreadable			9							9
	Spitsbergen (SP)	Good quality				14						14
		Poor/unreadable				1						1
	Kharlov Island (KI)						0					0
	2009 Total retrieved				28	15	0					43
2010	Bjørnøya (BI)	Good quality			0			17				17
		Poor/unreadable			7			14				21
	Spitsbergen (SP)	Good quality				7			18			25
		Poor/unreadable				1			5			6
	Kharlov Island (KI)						0			0		0
	Hornøya (HO)	Good quality									5	5
		Poor/unreadable									9	9
	2010 Total retrieved				7	8	0	31	23	0	14	83
Grand Total retrieved			5	7	35	23	0	31	23	0	14	138
Retrieval rate			0.33	0.47	0.88	0.52	0.00	0.78	0.51	0.00	0.88	0,54
Grand Total with good quality data			3	6	19	21	0	17	18	0	5	89
Success rate			0.20	0.40	0.48	0.48	0.00	0.43	0.40	0.00	0.31	0,35

sary equipment to download data from the tags ourselves. However, it turned out that a large number of the retrieved tags needed to be sent to Lotek for downloading (43 % in 2008, 100 % in 2009 and 41 % in 2010). The main reason for this was battery failure. Due to the downloading cost per tag, we decided not to send 20 of the tags retrieved in 2010 to Lotek. We prioritized the tags that would balance the data with respect to colony and sex of the birds being tagged. We expect to retrieve more of our GLS loggers from guillemots in the years to come, so the retrieval rates and success rates in tables 1 and 2 will change over time.

All birds instrumented in this project, except for those captured on Hornøya, were sexed molecularly using DNA from blood samples following a modified protocol of Griffiths et al. (1998).

Table 2. Number of GLS tags deployed on and retrieved from common guillemots (*Uria aalge*) on Bjørnøya (BI) and Kharlov Island (KI) from 2007 to 2010. Retrieval rate refers to the number of tags retrieved divided by the number deployed. Success rate represents the number of tags from which good quality data could be downloaded divided by the number of tags deployed.

GLS tags on common guillemots			Year of deployment					
			2007	2008		2009		Grand Total
Year of retrieval		Deployed	BI	BI	KI	BI	KI	All
	Retrieved		10	44	25	44	27	150
2008	Bjørnøya (BI)	Good quality	5					5
		Poor/unreadable	4					4
	2008 Total retrieved		9					9
2009	Bjørnøya (BI)	Good quality		15				15
		Poor/unreadable		15				15
	Kharlov Island (KI)				0			0
	2009 Total retrieved			30	0			30
2010	Bjørnøya (BI)	Good quality		2		25		27
		Poor/unreadable		3		11		14
	Kharlov Island (KI)						0	0
	2010 Total retrieved			5		36	0	41
Grand Total			9	35	0	36	0	80
Retrieval rate			0.90	0.80	0.00	0.82	0.00	0.53
Grand Total with good quality data			5	17	0	25	0	47
Success rate			0.50	0.39	0.00	0.57	0.00	0.31

Geolocation

One hundred and thirty six tags (89 from Brünnich's guillemots and 47 from common guillemots) of the 218 retrieved tags held position data that were of sufficient quality to be analyzed further. The remaining tags either stopped operating too early because of battery failure, contained data series with obvious miscalculations or did not successfully download data. The usable data were downloaded to and analyzed in LAT Viewer Studio® ver. 2.9.30 (©Lotek Wireless, Inc.). Latitude data from GLS tags are known to be skewed in the periods prior to and after equinoxes (Ekstrom, 2004). In addition, the longitude estimate is not reliable at latitudes where, and in periods when, the sun does not rise and set, i.e. during periods of midday darkness and midnight sun.

In the analysis, we therefore refined the position data by comparing each tag's temperature record with sea surface temperature (SST) data collected by satellites. The SST data originated from the MODIS instruments aboard NASA's Aqua and Terra satellites and the AVHRR instrument aboard two polar-orbiting TIROS satellites. The MODIS instruments provide daily SST data with a resolution of 1-36 km and accuracy goals of 0.3 – 0.5°C (GSFC, 2010, http://aqua.nasa.gov/about/instrument_modis_dp.php) (data can be accessed online at http://oceancolor.gsfc.nasa.

gov/cgi/l3). The AVHRR instrument produces medium wavelength infrared SST data with a 4 km resolution at a daily basis (NODC, 2010, http://www.nodc.noaa.gov/SatelliteData/pathfinder4km). All SST data were organized in Matlab files by the Hopkins Marine Station at Stanford University in California, USA. A data filtering was performed in order to remove obviously miscalculated position data from the dataset. The filter removed position estimates that were

- outside the latitude range between 35°N and 85°N,
- outside the longitude range between 65°W and 75°E,
- too far away from the previous estimate according to a defined maximum move distance of 3.3° (approx. 360 km) in the latitudinal and 8° in the longitudinal direction per day,
- at locations for which bathymetry data indicate a water depth that is less than the maximum depth recorded by the tag on the actual day.

The remaining position estimates from all the years were exported to ESRI® ArcMap™ 9.3 and used to create distribution maps presenting the observed aggregations of common and Brünnich's guillemots in the months from August to April. Depending on oceanographic conditions, guillemots may migrate to different areas in different years. By not distinguishing between years in the presentation we incorporate the climatic variation in wintering areas. We consider this the appropriate way to present the information.

Based on the position estimates, we generated Kernel density maps using ArcMap's™ Spatial Analyst tool. Search radius was kept at 150 km in the Kernel density analyses for the Brünnich's guillemots, whereas for the common guillemots we used a 100 km search radius. To the keep the resolution of the contour plots as high as possible, we varied the cell sizes depending on the spread of the individual points (table 3). For a detailed description of Kernel density estimation, see Worton (1989).

Bearing in mind the low accuracy of the GLS localization, it is important to stress that no inference should be made from our data regarding detailed migration trajectories of the guillemots, even after refining the position data using SST. We feel confident that our large-scale presentation of the results is both valid and reliable.

Table 3. Cell size and search radius used in monthly Kernel density analyses for Brünnich's (*Uria lomvia*) and common guillemots (*U. aalge*) breeding at three different study sites.

	Brünnich's guillemots				Common guillemots	
	Spitsbergen & Bjørnøya		Hornøya		Bjørnøya	
Month	**Cell Size (km)**	**Search Radius (km)**	**Cell Size (km)**	**Search Radius (km)**	**Cell Size (km)**	**Search Radius (km)**
Aug	5.0	150	4.0	150	4.0	100
Sep	7.5	150	4.0	150	4.0	100
Okt	10.0	150	4.0	150	5.0	100
Nov	10.5	150	5.0	150	6.0	100
Des	10.5	150	5.0	150	6.0	100
Jan	12.0	150	5.0	150	6.0	100
Feb	12.0	150	5.0	150	6.0	100
Mar	11.0	150	3.0	150	5.0	100
Apr	8.0	150	3.4	150	5.0	100

Results

Guillemots breeding in the Barents Sea region arrive at the colonies in the period from March throughout May and depart as soon as their chicks fledge, normally in the end of July or first half of August (Bakken and Pokrovskaya, 2000, Barrett and Golovkin, 2000). All the birds gathering position data in this study were tagged while breeding in colonies located between 70º and 80°N. At the northernmost of our study sites, the period of midnight sun lasts from mid-April to the end of August. Since GLS tags cannot calculate positions exposed to midnight sun, we present position data for the period from late August to mid-April. Brünnich's and common guillemots will be considered separately in this section, and we will give an overview of their general distribution in different months. The distribution maps presented here show monthly contour plots of Kernel density estimates based on all the daily individual positions that were not removed during filtering. The gradient from the outermost to the innermost boundary of the contour plot represents the increase in density of registered GLS positions (points). E.g. the 10 densest percent of the point distribution are within the 10 percent contour. In the underlying dataset, some individual birds are represented with more positions than others. In theory, any bird can be represented with a maximum of 31 positions (one per day of the month). We refer to Appendices 1 and 3 for maps showing individual positions for birds from the different colonies.

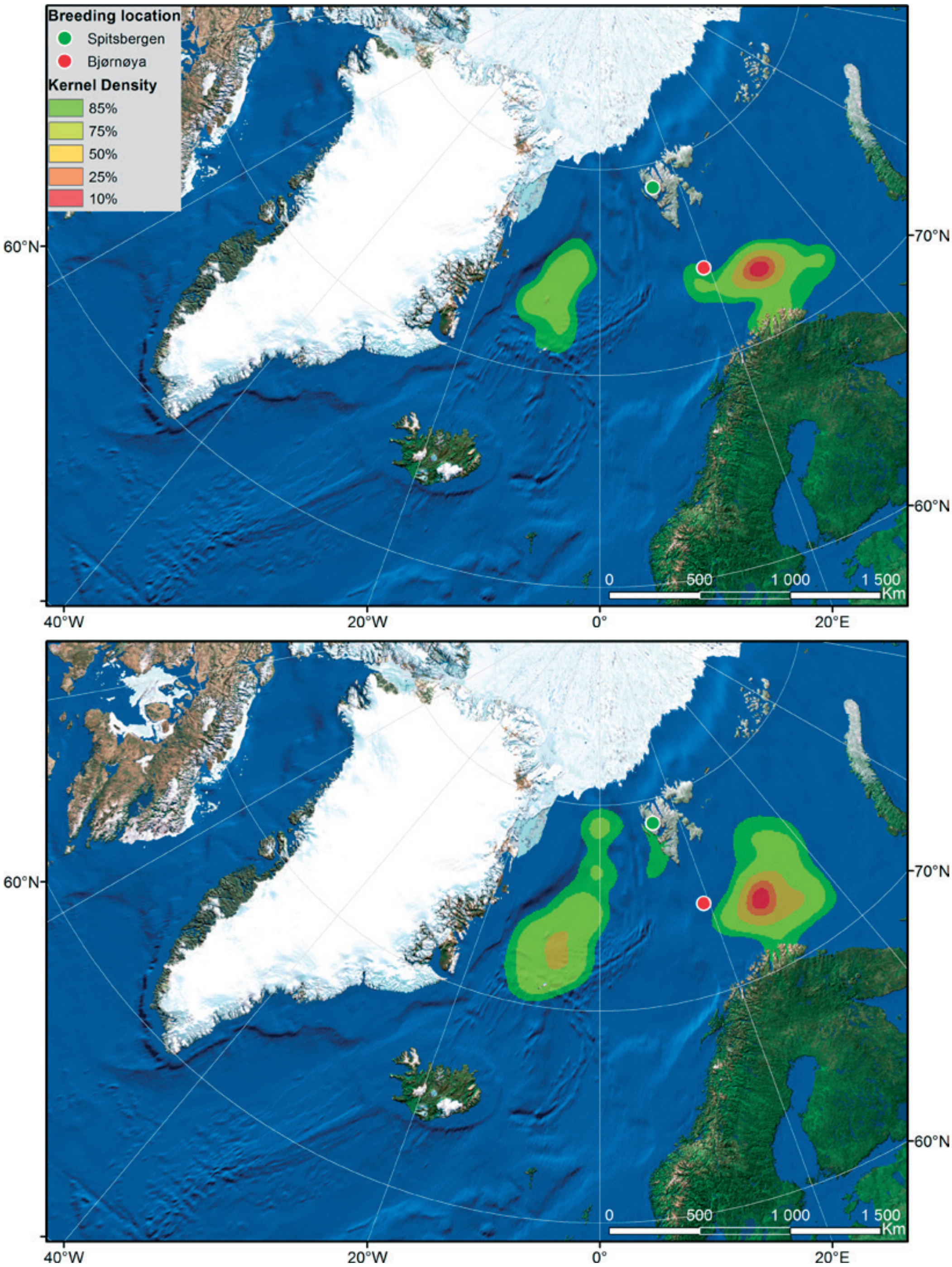

Figure 4. Kernel density distribution of Brünnich's guillemots from Spitsbergen and Bjørnøya in August (upper panel) and September (lower panel). (Norwegian Polar Institute)

Brünnich's guillemots

Brünnich's guillemots from Spitsbergen migrated southwestward towards Iceland after leaving the colonies in August (N=24; 89 positions; Fig. 4). At the end of the month they were distributed between Spitsbergen and Jan Mayen. The birds from Bjørnøya (N=21; 147 positions) were mainly located southeast of their colony, and some went south to the coast of Finnmark. Due to the difficulty of calculating positions in midnight sun periods, the amount of data is small for August, and the positions we have are from the end of the month. The reader should be aware that the distribution presented in the map for August might therefore be somewhat skewed in a southerly direction.

The September distribution shows that the Brünnich's guillemots from Spitsbergen (N=38; 1192 positions) were spread between Spitsbergen and Iceland, and the bulk could be found around Jan Mayen (Fig. 4). A few individuals went south and eastwards to the central Barents Sea. The Bjørnøya birds (N=57; 1095 positions) were mainly east of Bjørnøya.

In October, the Spitsbergen birds underwent a large movement (N=38; 1176 positions, Fig. 5). They continued southwest along the east coast of Greenland, and most of them had passed Jan Mayen by the end of the month. Some birds also rounded Cape Farewell on the southern tip of Greenland and continued northward along the west coast. The Brünnich's guillemots from Bjørnøya (N=53; 1068 positions) were still in the central Barents Sea in October, but a few had joined the Spitsbergen birds and moved towards Iceland.

The Brünnich's guillemots from Spitsbergen were located all around the southern half of Greenland in November (N=38; 1158 positions; Fig. 5). Two main aggregations appeared: one northwest of Iceland, and the other on the southwest coast of Greenland. A few individuals had moved south along the coast of Labrador and Newfoundland. During this month, the Bjørnøya birds (N=45; 866 positions) moved southwest, and most reached the area between Iceland and Jan Mayen, although some remained in the Barents Sea.

The distribution of the Spitsbergen birds did not change much in December, and they remained south of 70°N (N=38; 1180 positions; Fig. 6). The Brünnich's guillemots from Bjørnøya (N=30; 793 positions) also seemed to have

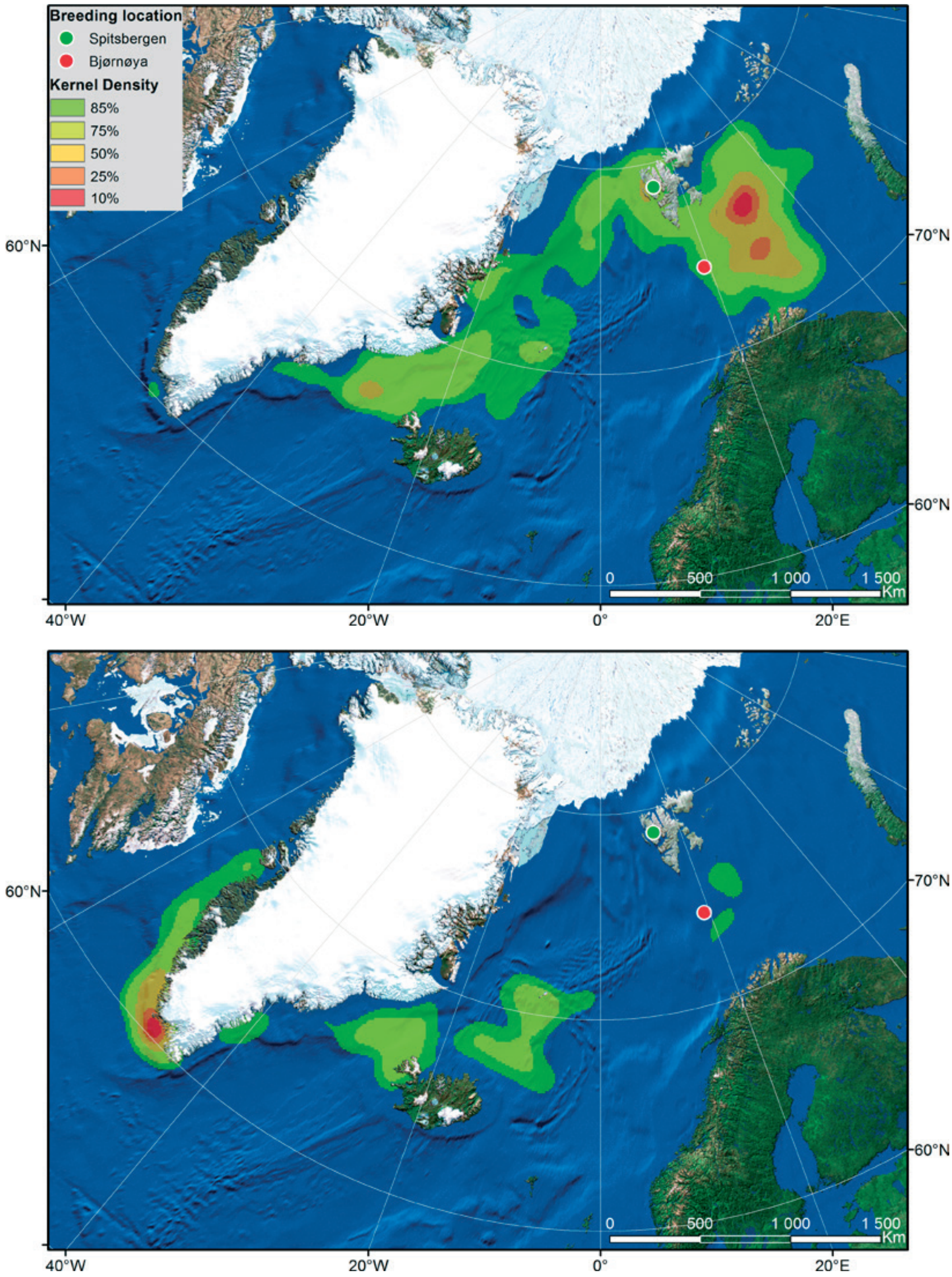

Figure 5. Kernel density distribution of Brünnich's guillemots from Spitsbergen and Bjørnøya in October (upper panel) and November (lower panel). (Norwegian Polar Institute)

reached the southernmost boundary of their migration route this month. The individuals travelling the furthest southwest almost reached Cape Farewell on Greenland, but the abundance of Bjørnøya birds was highest north of Iceland and between Shetland and Jan Mayen. The easternmost contour plot in Figure 6 is therefore a mix of Spitsbergen and Bjørnøya breeders in which the Bjørnøya birds are clearly most abundant east of 20°W (see Appendix 1). Only birds from Spitsbergen were on the west coast of Greenland.

The only noticeable movement occurring in January was that the Bjørnøya birds (N=42; 797 positions) started their return towards Svalbard (Fig. 6). Also, the number of Spitsbergen birds present in the Labrador Sea was at its peak this month. The birds breeding on Spitsbergen started their return northeast in February (N=35; 955 positions), but the highest densities could still be found on both sides of Greenland and around Iceland, and the estimated positions were widely spread in this period (Fig. 7). Most of the Bjørnøya birds (N=50; 916 positions) returned to the areas south of Spitsbergen, although a few still remained as far south as Iceland in the end of February.

In March, the Spitsbergen birds that had wintered on the west side of Greenland started the first stage of their journey back towards their colonies, and by end of the month, all of them had reached Iceland, where the main bulk of the positions were registered (N=33; 872 positions; Fig. 7). A few positions were also registered north and west of Spitsbergen (see Appendix 1), but they were too few and too scattered to come within the 85 % contour of the Kernel density plot. A distinct separation of the Spitsbergen and Bjørnøya populations was evident in March, as all the birds from Bjørnøya (N=53; 752 positions) gathered close to the Svalbard archipelago. We strongly doubt that they were actually as far north as the map for March displays, since the area north of Spitsbergen is normally covered by ice in the end of March. During our study period, 2008 was the year with the least ice extent. Figure 8 presents the ice cover on the 31st March 2008 when there is a relatively small area north of Spitsbergen where the ice cover varied from 20 to 80 %. Brünnich's guillemots are

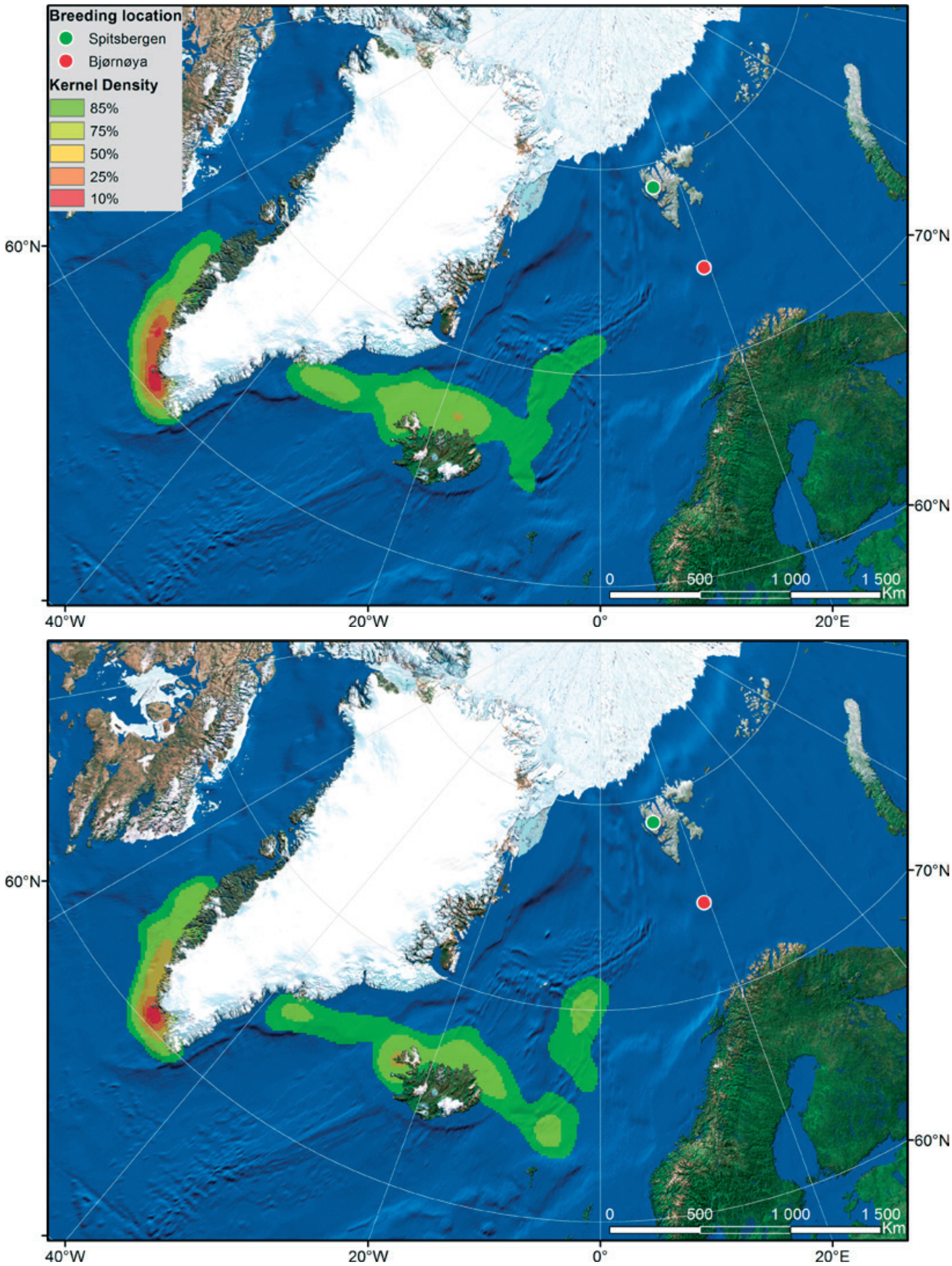

Figure 6. Kernel density distribution of Brünnich's guillemots from Spitsbergen and Bjørnøya in December (upper panel) and January (lower panel). (Norwegian Polar Institute)

known to feed close to the ice-edge (Bradstreet and Brown, 1985), and large flocks of guillemots can also gather in open leads in the ice more than 100 km from the marginal ice zone (Bakken, 1990). However, our distribution map for March places the birds' positions far into the fast ice where there were few or no open leads even in April 2008. Spring equinox is approximately 20th March, and therefore the GLS tags were not able to produce reliable calculations of latitude for much of this month. We have applied SST data to correct for this error, but the presented distribution of Brünnich's guillemots in March is an example that this does not completely remove the uncertainty related to the position data. We believe that the Brünnich's guillemots breeding on Bjørnøya were mainly located in, or close to, the marginal ice zone in the waters around Svalbard in this period.

The few positions we have for April are from the beginning of the month, but it is apparent that the Brünnich's guillemots breeding on Spitsbergen (N=23; 137 positions) were heading toward their colonies, as they were distributed in the area between Iceland and the northern part of Spitsber-

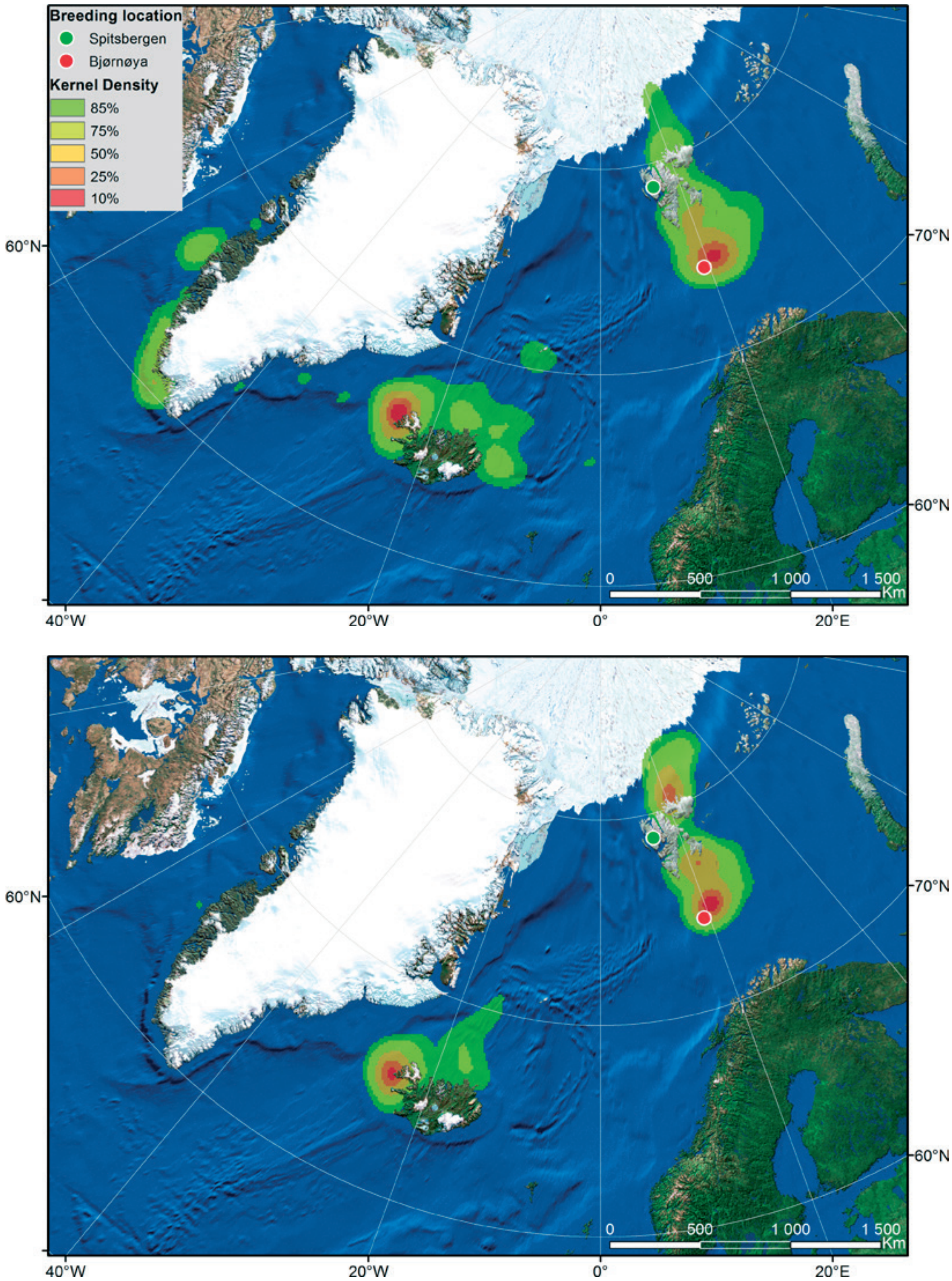

Figure 7. Kernel density distribution of Brünnich's guillemots from Spitsbergen and Bjørnøya in February (upper panel) and March (lower panel). (Norwegian Polar Institute)

gen in this period. Due to the low number of observations, and their wide distribution, the location of the Spitsbergen birds does not show in the Kernel density plot for April. Figure 9 therefore mainly represents the Bjørnøya birds (N=35; 254 positions), which remained in the areas between Spitsbergen and Bjørnøya.

After leaving the breeding grounds, the Brünnich's guillemots breeding at Hornøya went eastward, and by the end of August they were in the southeastern Barents Sea (N=5; 64 positions; Fig. 10). Throughout September, they stayed in the area southwest of Novaya Zemlya and north of the coast of Nenets Okrug

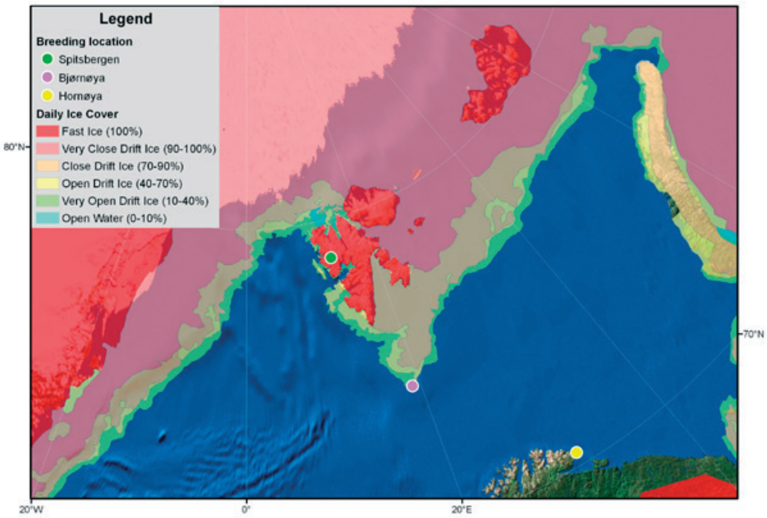

Figure 8. Ice cover in the western Barents Sea on 31st March 2008 by gradient from 0-10 % (open water) to 100 % (fast ice). Source: Norwegian Meteorological Institute.

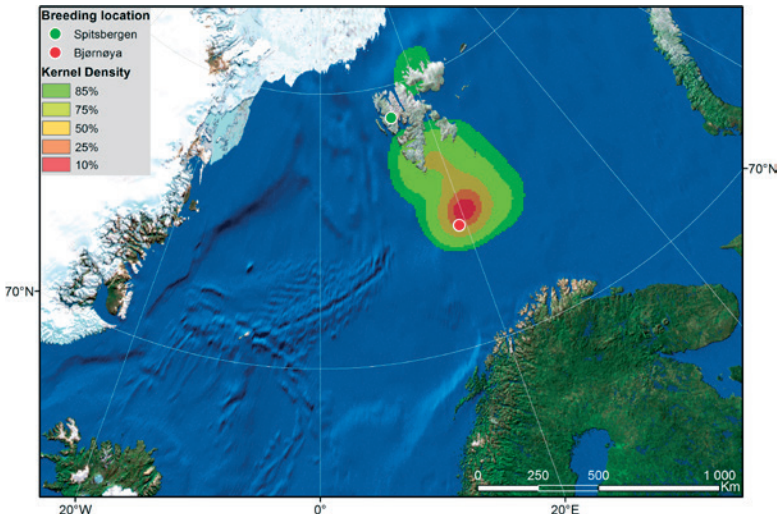

Figure 9. Kernel density distribution of Brünnich's guillemots from Spitsbergen and Bjørnøya in April. (Norwegian Polar Institute)

in Russia (N=5; 150 positions; Fig. 10). In October, the Hornøya birds moved slightly westward (N=5; 150 positions), and throughout January they stayed in the open waters between Hornøya and Novaya Zemlya (Fig. 10 and 11). It is interesting to notice that one Brünnich's guillemot from Hornøya joined the birds migrating from Bjørnøya and appeared in the area northeast of Iceland in the winter months (see Appendix 1).

In February, the Hornøya birds moved a little more westward, and the highest densities of positions were recorded along the north coast of the Kola Peninsula (N=4; 106 positions; Fig. 11). The rest were located further north, and by March all the birds seemed to be relatively tightly aggregated in the central Barents Sea (N=4; 110 positions; Fig. 11). This gathering coincided with the return of the Brünnich's guillemots from Bjørnøya to the same area, but the Hornøya breeders kept a little further east than the Bjørnøya birds. The movement back towards their colony on Hornøya started in April (N=3; 67 positions).

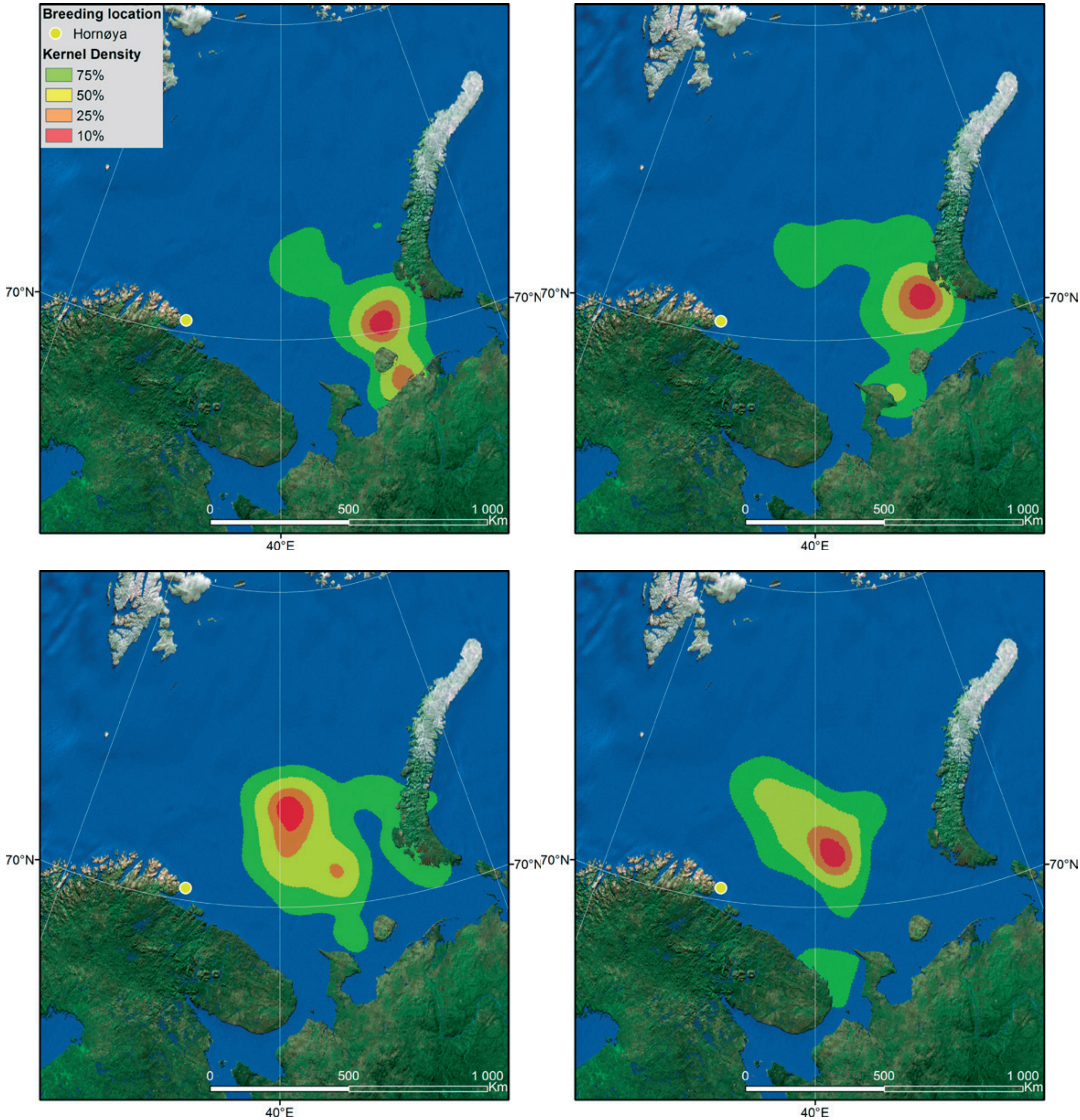

Figure 10. Kernel density distribution of Brünnich's guillemots from Hornøya in August (upper left panel), September (upper right panel), October (lower left panel) and November (lower right panel). (Norwegian Polar Institute)

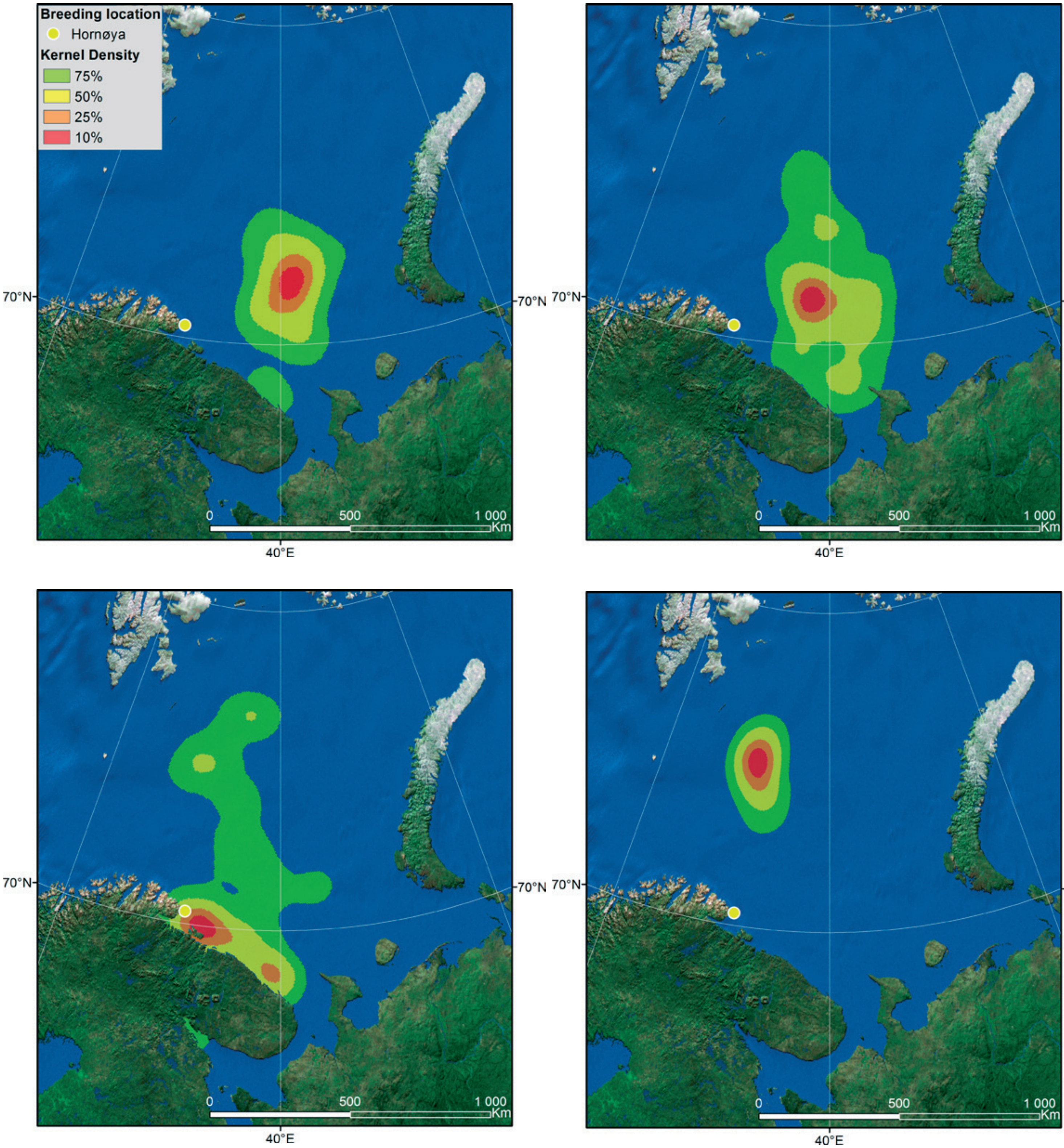

Figure 11. Kernel density distribution of Brünnich's guillemots from Hornøya in December (upper left panel), January (upper right panel), February (lower left panel) and March (lower right panel). (Norwegian Polar Institute)

Common guillemots

All the data on common guillemot movement and distribution are from Bjørnøya. After leaving their colony in August, these birds migrated southeast and were distributed in the waters between 74°N and the Finnmark/Murman Coast in September (N=37; 1348 positions; Fig. 12).

Throughout the winter, the birds stayed in the central Barents Sea. In October (N=37; 1377 positions) and November (N=36; 1095 positions), their distribution expanded a little in all directions, but the birds mainly kept east of Bjørnøya and west of Kolguyev Island off the coast of Nenets (Fig. 12). Some migration into the White Sea was also noticeable. The common guillemots moved little during December (N=30; 492 positions) and January (N=33; 655 positions). They were still mainly distributed both close to land and on the open sea north of the Finnmark and Murman coasts (Fig. 13).

A model developed at CEFE presenting the likelihood of presence of birds indicates that the probability of encountering common guillemots from Bjørnøya along the Murman Coast is much higher than in the open sea in January, and that the birds are very likely to be found in the White Sea. In this modeling process, an SST data set from NOAA with a relatively high resolution (0.1 degree) was used. After examining ice charts for the Barents Sea we found reason to doubt this scenario, as most of the White Sea is more or less covered with ice in January.

In February, it seems that the main bulk of the common guillemots were gathered in the areas just east of Bjørnøya (N=32; 1025 positions), and by March this aggregation was even denser (N=29; 821 positions; Fig. 13). Only a few positions were recorded along the Norwegian coast this month, and this situation remained throughout April.

Studying the Kernel density maps in combination, we see that the density of guillemots around Spitsbergen and Bjørnøya is lowest in December and January. In general, the maps give the impression that the guillemots are least abundant in the maritime zone stretching north from mainland Norway to approx. 77°N between 0º and 15°E. However, we must take into account that migrating Brünnich's guillemots cross this "corridor" twice a year: first on their way southwest in September-November, and later on their way back towards the colonies in February-April. Their individual track points show that in September, Brünnich's guillemots from Spitsbergen passed through this zone as far south as 72°N. There was a mix of individuals from Spitsbergen and Bjørnøya crossing in October, whereas in November, we have only recorded Brünnich's guillemots from Bjørnøya in the area. They passed through the zone between 0 and 10°E as far south as 68°N.

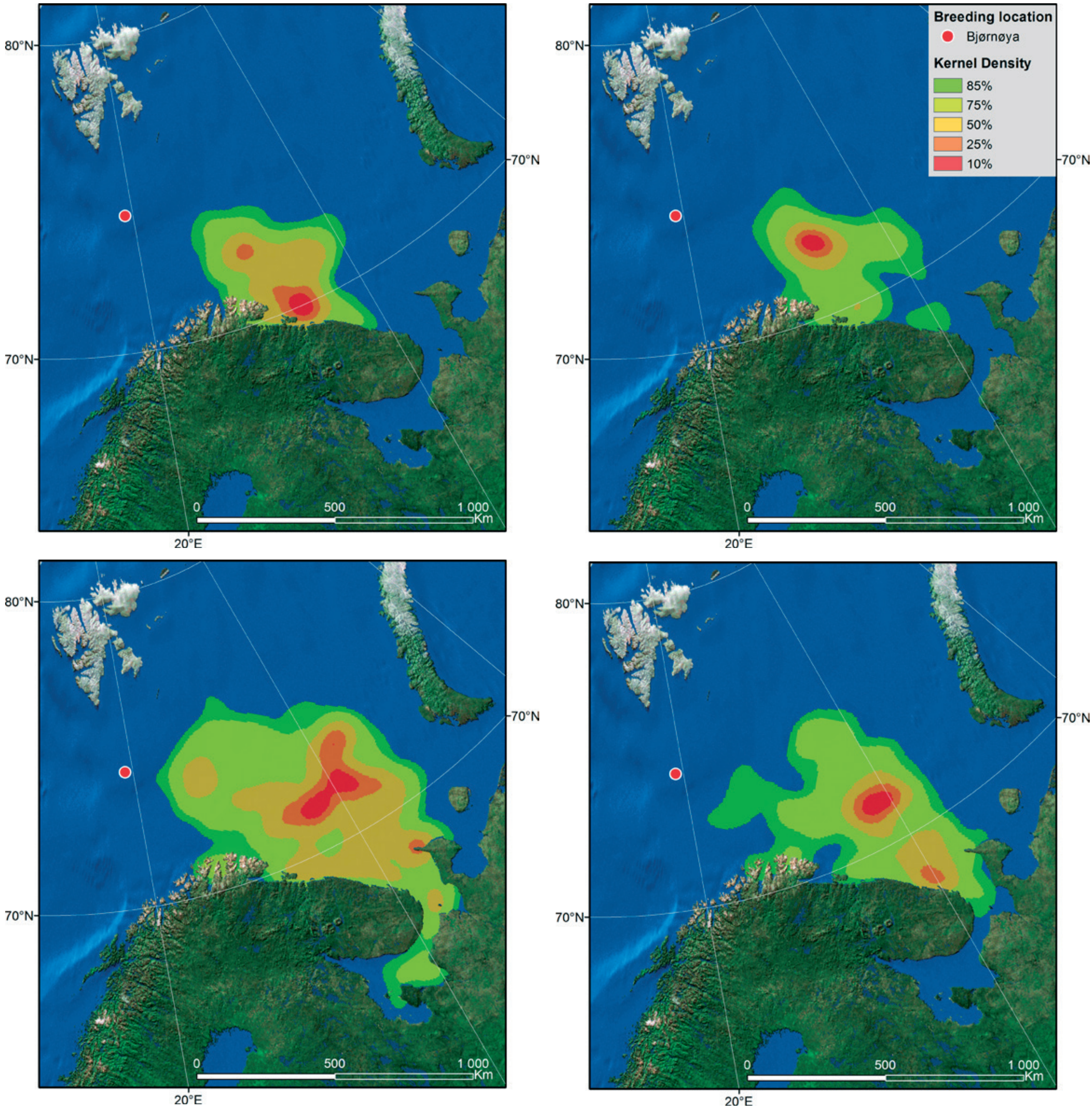

Figure 12. Kernel density distribution of common guillemots from Bjørnøya in August (upper left panel), September (upper right panel), October (lower left panel) and November (lower right panel). (Norwegian Polar Institute)

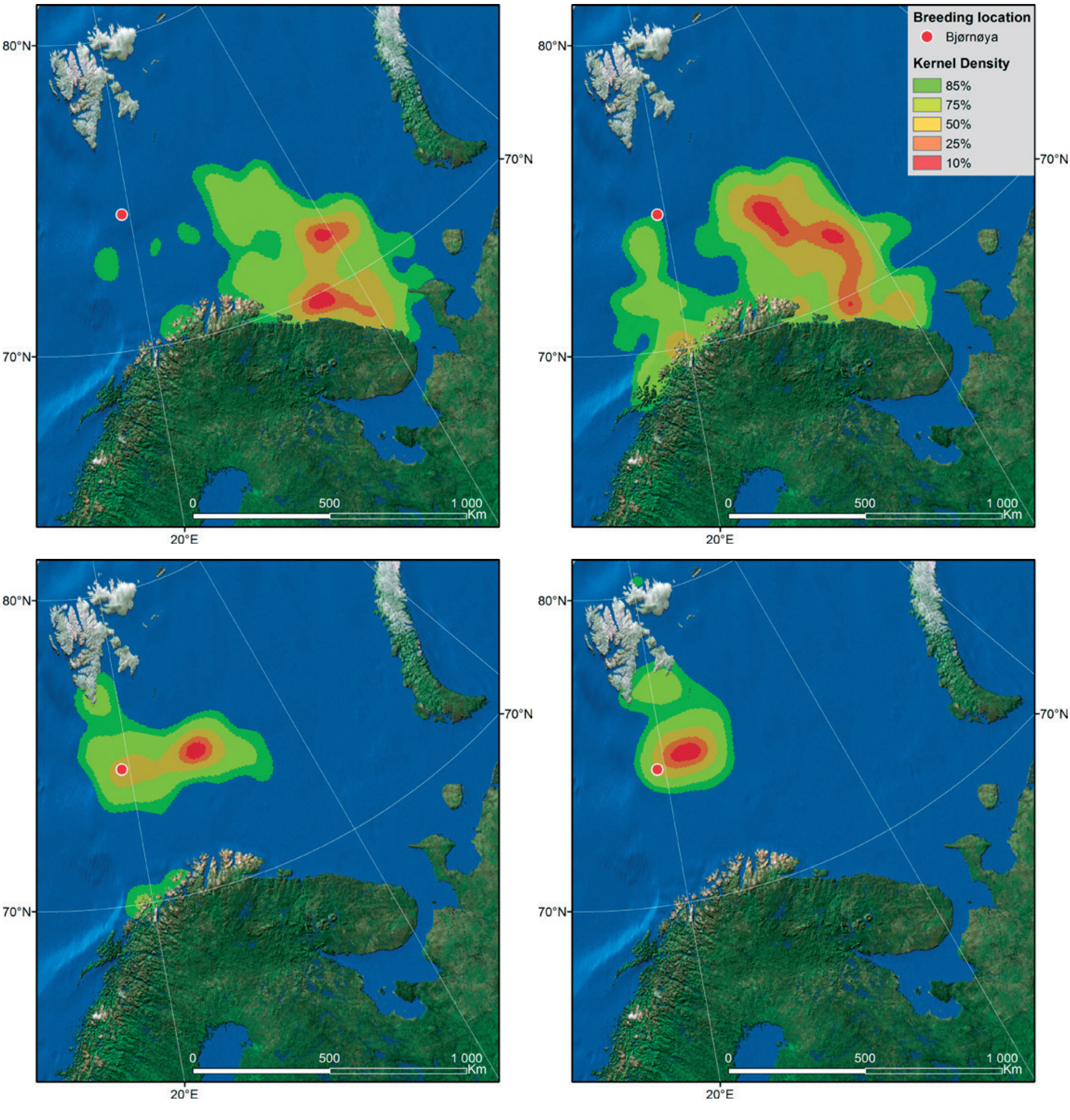

Figure 13. Kernel density distribution of common guillemots from Bjørnøya in December (upper left panel), January (upper right panel), February (lower left panel) and March (lower right panel). (Norwegian Polar Institute)

Discussion

The Brünnich's guillemots breeding on Hornøya, eastern Finnmark, stayed east of 20°E in the southern part of the Barents Sea during the whole winter, whereas birds from Bjørnøya and Spitsbergen left the Barents Sea and their breeding areas by November. The Brünnich's guillemots from Bjørnøya returned to the central and western part of the Barents Sea by the end of February. The Spitsbergen birds returned somewhat later in March. Brünnich's guillemots breeding on Spitsbergen overwintered northwest of Iceland and on the west coast of Greenland while the Brünnich's guillemots breeding on Bjørnøya spent the winter around Iceland, Jan Mayen and some as far south as Shetland. During the three-year course of our study, the birds from Bjørnøya never rounded the southern tip of Greenland. Common guillemots breeding on Bjørnøya stayed in the southeastern part of the Barents Sea during the autumn and moved west towards Bjørnøya in early spring. Although the GLS localizations are not accurate, we feel certain that the general movements we have presented are correct. The GLS loggers use light to determine position. Therefore, the position of any bird staying in areas where light levels are too low to be detected during the polar night will be an erroneous position that will be removed by the filtering procedure. This will introduce a southward bias in the results, since the length of the polar night increases with latitude.

Several assessments of the vulnerability of the environment, including seabirds, to oil pollution have been made for the Barents Sea. All concluded that, in whatever area or season, many seabird populations of international conservation value will be in danger of being seriously affected in the event of an oil spill (Huntington, 2007). The results from our study support this conclusion and add important information on colony affiliation.

Among the guillemot colonies in the Barents Sea region there seems to be a gradient from south (and east) to north with regard to the length of the migration: birds from Hornøya in the southeast stay resident, while the Spitsbergen birds in the northwest migrate to the Labrador Sea and Davis Strait. Based on this, it is reasonable to believe that the large populations of Brünnich's guillemots breeding in the Russian part of the Barents Sea (Novaya Zemlya and Franz Josef Land) spend the winter in the ice-free areas of the southern and central Barents Sea. The theory suggesting that Svalbard birds are replaced by birds breeding in Russia during winter is supported by the fact that most of the ringed birds recovered in Greenland and Canada were ringed on Bjørnøya and Spitsbergen, while very few of them have been ringed in Novaya Zemlya (Bakken et al., 2003).

Data from surveys of birds at sea (referred to as "at-sea surveys") also support the theory of replacement of birds, since the numbers of both common and Brünnich's guillemots in the Barents Sea remain high throughout the winter (Fauchald et al., 2011). However, the estimated densities based on at-sea surveys vary between years. For example, the estimated abundance of Brünnich's guillemots in the western Barents Sea during the September surveys varied between 1.5 million individuals in 2003 and 100 000 individuals in 2007, and in the ice-free part of the Barents Sea during the winter survey, the abundance of Brünnich's guillemots varied between 600 000 in 1987 and 6 million in 1991. Similar variation was found for the other common species (Fauchald et al., 2011). The large year-to-year variation cannot be explained entirely by changes in population size, but is probably related to year-to-year changes in the profitability of the Barents Sea as a habitat, and thus also to species-specific migration patterns in and out of the area. There is accordingly a close positive relationship between the winter abundance of seabirds and the abundance of capelin, suggesting that the abundance of capelin is an important factor during winter (Fauchald et al., 2011). A distribution map for capelin in the Barents Sea produced by the Norwegian Institute of Marine Research shows that the capelin feeds in the northeast parts of the Barents Sea, but move southwards as the sea ice extends its cover from the north (Fig. 14). By the beginning of March, the capelin reach the coasts of Finnmark and the Kola Peninsula to spawn, and these movements coincide very well with the movements of our GLS-tagged Brünnich's guillemots from Hornøya. Polar cod may also be an important resource for the Hornøys birds in the autumn, seeing that the polar cod larvae drift northwards from the area between Novaya Zemlya and Nenets in Russia during late summer and early autumn

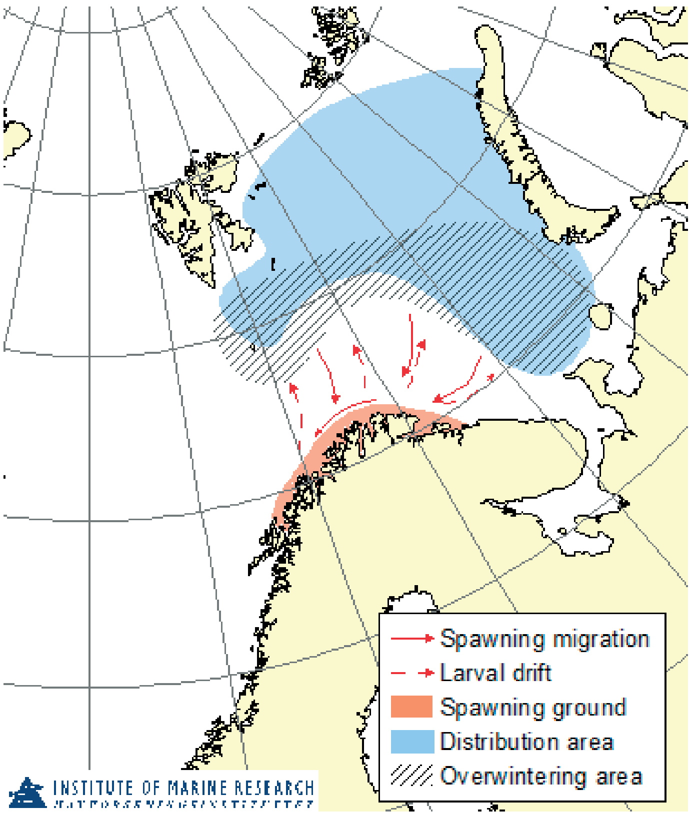

Figure 14. Distribution of capelin (*Mallotus villosus*) in the Barents Sea (with permission of the Norwegian Institute of Marine Research).

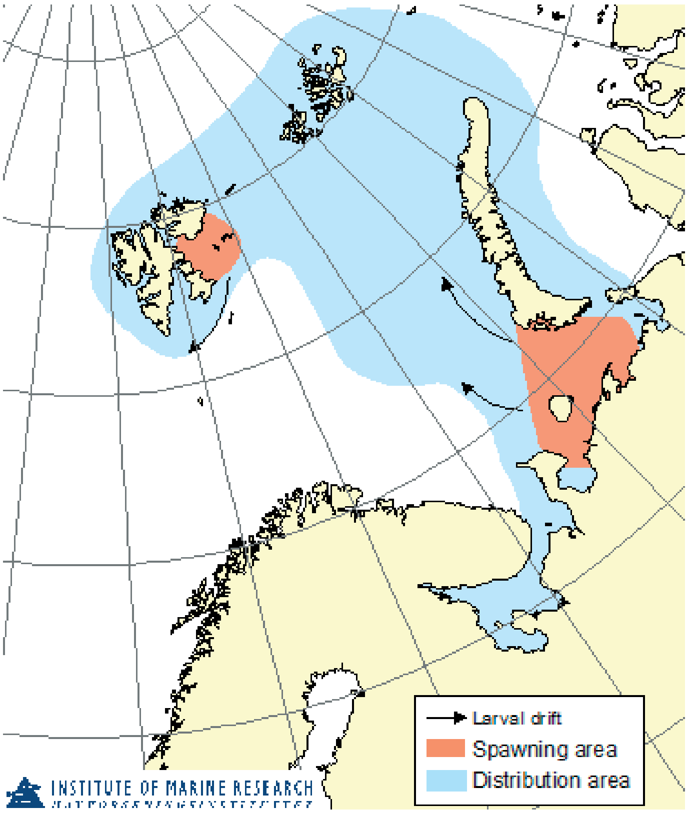

Figure 15. Distribution of polar cod (*Boreogadus saida*) in the Barents Sea (with permission of the Norwegian Institute of Marine Research).

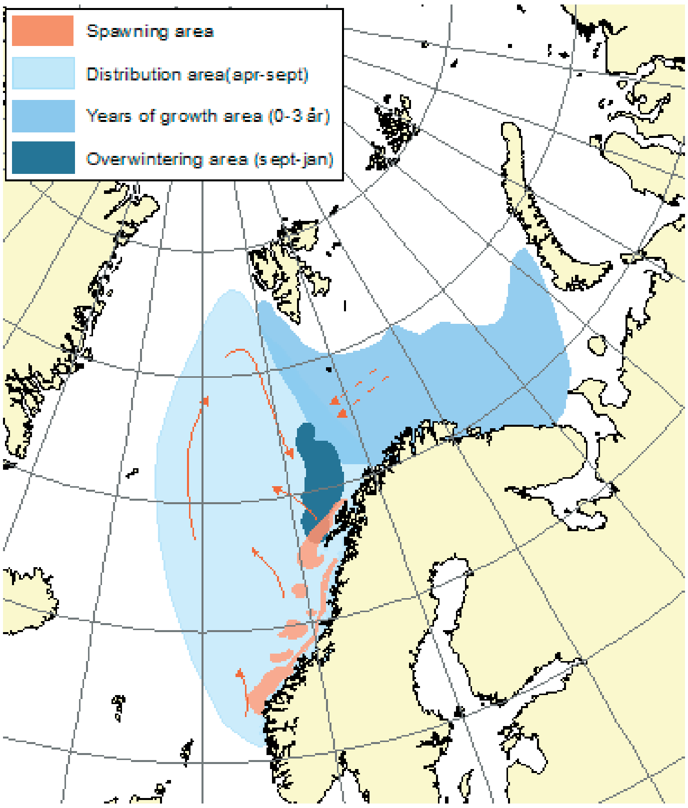

Figure 16. Distribution of Norwegian spring-spawning herring (*Clupea harengus L.*) in the Barents Sea (with permission of the Norwegian Institute of Marine Research).

(Fig. 15). These larvae are probably important food that is easy to catch for the young guillemots in the first period after leaving the colonies. Guillemots from Bjørnøya and the coastal areas of Norway and Finnmark probably also benefit highly from the Norwegian spring-spawning herring (*Clupea harengus L.*). The nursery area for this species covers a large part of the Barents Sea (Fig. 16). In our study, the common guillemots from Bjørnøya and Brünnich's guillemots from Hornøya kept within this nursery area almost the whole period from September to April.

For the Brünnich's and common guillemots leaving the Barents Sea in the autumn, the capelin stock in the Iceland – East Greenland – Jan Mayen area is probably of great importance and partly explains the migration pattern we have observed for these birds. In Figure 17 we can see that the feeding and nursery areas of the capelin overlap very nicely with the area that our tagged Brünnich's guillemots used around Iceland from November through March (Fig. 4 and 5). All the fish species we have mentioned here as essential resources for the guillemots feed mainly on zooplankton, which are very abundant along the ice edge. This also underlines the important link between guillemots and sea-ice.

Any oil spill in the Barents Sea, regardless of origin, may harm many guillemots since there are birds present throughout the year. The threatened common guillemot is of major concern since this species occupies the central Barents Sea during winter and breeding period, whilst they are further east in the autumn. At-sea surveys of seabirds prior to this project showed a year-round presence of common guillemots in the Barents Sea, but we previously had no idea of which colony or population they belonged to, and the data coverage during midwinter has been poor. Our results confirm earlier findings and clearly document that common guillemots breeding on Bjørnøya are present all year in the Barents Sea. The Brünnich's guillemots breeding at the Hornøya colony on the Norwegian mainland followed the same general pattern as the common guillemots from Bjørnøya, although they stayed a bit further east. There is an observed tendency of eastern populations to migrate shorter distances than the birds breeding further west. Thus, the birds from the north-eastern colonies in Norway and the Russian coast are probably at risk in the Barents Sea throughout the winter. Brünnich's guillemots breeding Bjørnøya and Spitsbergen are at an equally high risk in this area from February to November.

Brünnich's and common guillemots are in general highly susceptible to pollution at sea because they spend almost all their time and find all their food in the ocean. As we have shown, these two species are found in most parts of the Barents Sea and the North Atlantic. Due to their wide distribution and diverse migratory behaviour, it is therefore difficult to pinpoint where and when they are most vulnerable to human activity. Based on our findings and what is already known about the biology of the common and Brünnich's guillemot, we will attempt to highlight the time periods and areas within the Barents Sea region in

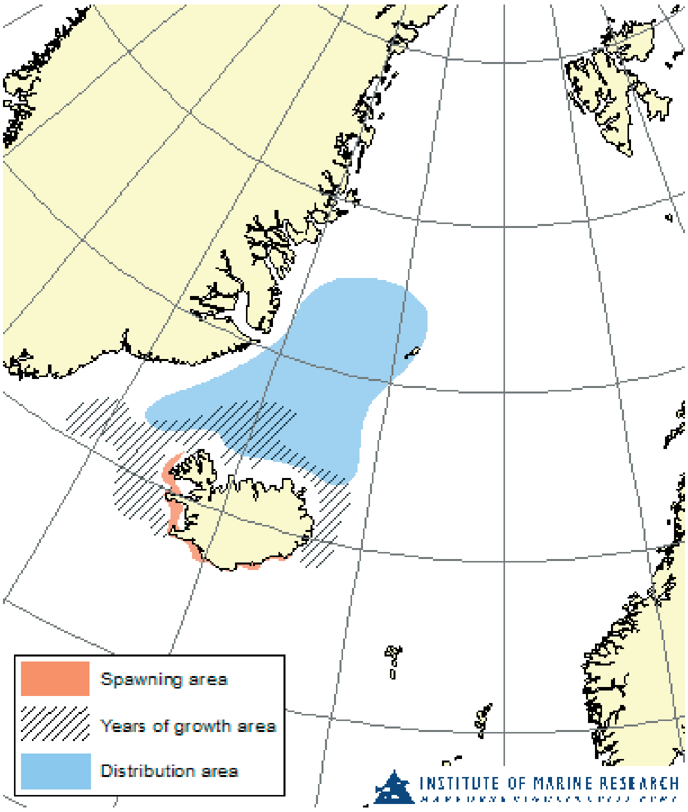

Figure 17. Distribution of capelin (*Mallotus villosus*) between Iceland, Greenland and Jan Mayen (with permission of the Norwegian Institute of Marine Research).

which ship traffic and oil spills would potentially be most harmful to the guillemot populations we have studied in this project. In their analysis of vulnerability and conservation value of seabirds with respect to exploration drilling in the Barents Sea, Fjeld and Bakken (1993) concluded that Brünnich's and common guillemots are highly vulnerable to oil spills throughout the year. In particular, the vulnerability of guillemots was considered highest in spring and autumn. Adult guillemots moult their flight feathers while accompanying their young away from the breeding colonies in August–September (Bédard, 1985, Cramp, 1985). Being flightless in this period, the birds have a severely reduced ability to avoid oil spills. The growth of the flight feathers of the young birds is completed by September–October. Any oil pollution at sea would therefore induce the heaviest damage to the guillemot populations if it occurred in August–October, just after they have left the colonies and started swimming towards the wintering areas. In this regard it is also important to emphasize that we have only studied the movements of **adult** guillemots. Migration routes of young and immature birds remain largely unknown, although results from ringing studies indicate that the wintering areas of the juveniles are generally similar to those of the adults (Nikolaeva et al., 1996).

Our results support the findings of Fjeld and Bakken (1993). We also have indications that Brünnich's guillemots breeding on the west coast of Spitsbergen will be most vulnerable to off-shore operations around and west of Spitsbergen and Bjørnøya from March throughout October. Brünnich's guillemots breeding on Bjørnøya will likely be affected by operations around Bjørnøya and Spitsbergen from February throughout April, after which they will probably keep close to Bjørnøya until August. From August to November they are spread out from Finnmark to Franz Josef Land, and will thus be vulnerable to operations in the central and eastern Barents Sea. Brünnich's guillemots breeding along the Finnmark and Russian coasts will most likely be highly affected by activities in the central and eastern Barents Sea throughout the year. Common guillemots from Bjørnøya are vulnerable to operations in the central and south-eastern Barents Sea all year round. From March through July, they most likely stay closer to the colonies on Bjørnøya, and would therefore be highly susceptible to operations around the island.

Even though the wintering areas for Brünnich's and common guillemots have already been indicated through band recovery studies (Bakken et al., 2003, Bakken and Mehlum, 2005), this project has not only confirmed the previously acquired knowledge, but also provided new and very important information that is valuable from both a management-oriented and a pure biological point of view. Besides knowing which areas the adult birds migrate to, we now also have a very good image of the timing of the migration and which areas are important at different times of the year. No data of this kind have previously been presented for Brünnich's and common guillemots breeding in the Barents Sea region. For the conservation of these red-listed populations, information on temporal and geographical distribution is essential. In combination with knowledge about e.g. food resources, ocean currents and climate we will now be able to study, outline and explain any differences in migration strategies between species, sexes and different colonies. As such, the project will add to future knowledge about Brünnich's and common guillemot biology and enhance our ability to create effective and goal-oriented conservation plans for these species.

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All figures in Appendices made by Norwegian Polar Institute.

Appendix 1. Distribution maps for Brünnich’s guillemots[1]

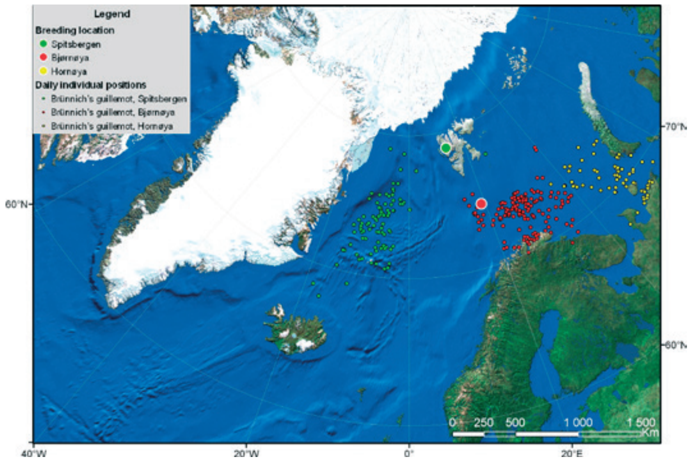

Figure 1. Distribution of Brünnich’s guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in August.

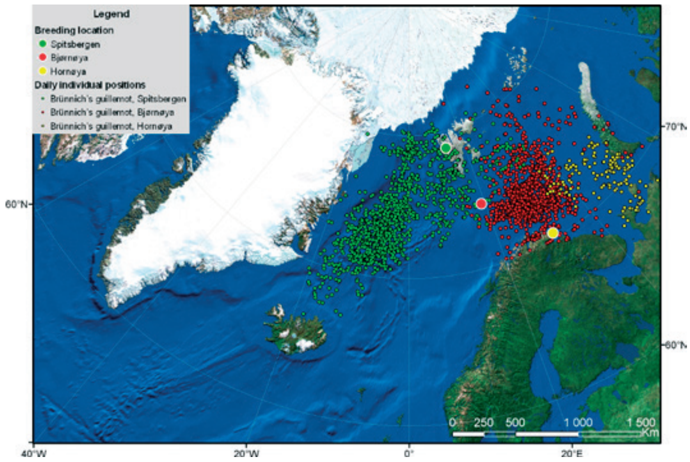

Figure 2. Distribution of Brünnich’s guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in September.

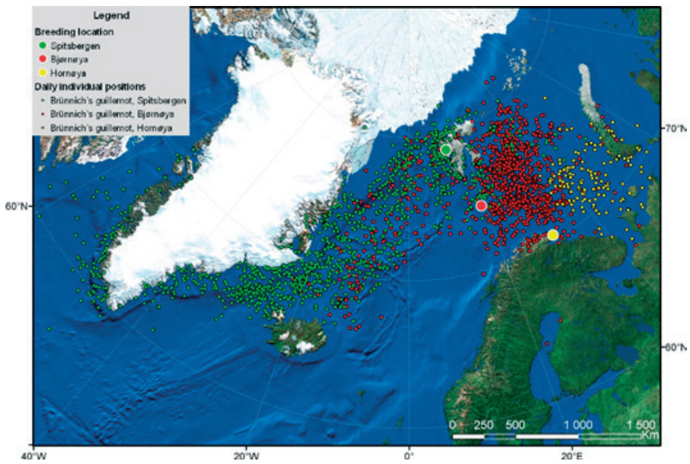

Figure 3. Distribution of Brünnich’s guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in October.

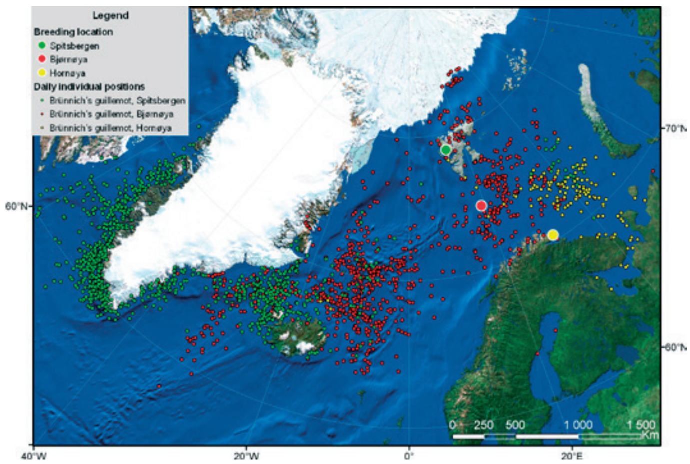

Figure 4. Distribution of Brünnich’s guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in November.

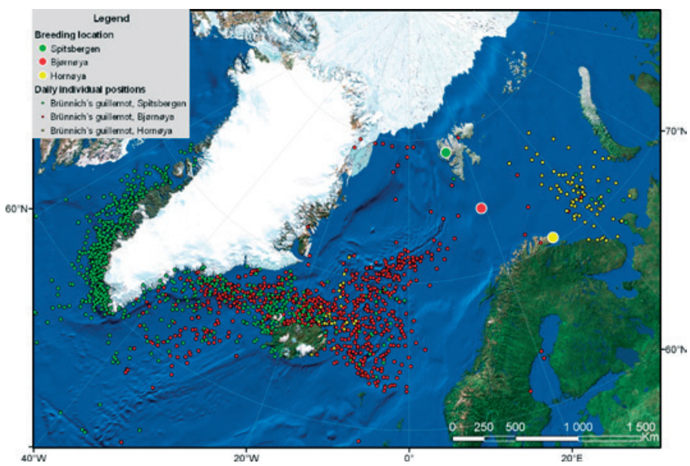

Figure 5. Distribution of Brünnich’s guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in Desember.

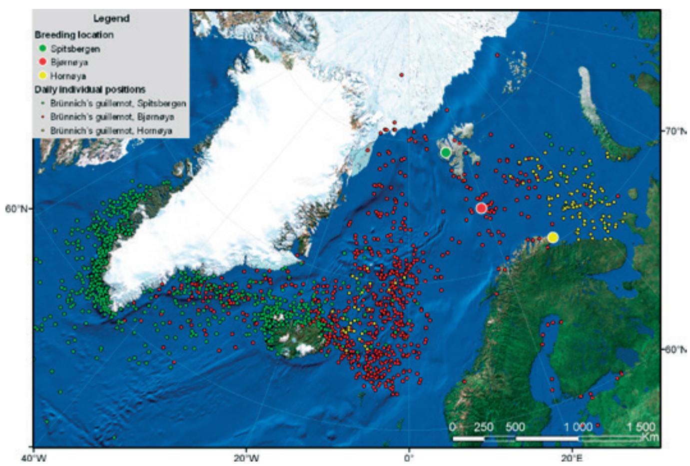

Figure 6. Distribution of Brünnich’s guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in January.

[1] Despite of data filtering, there might still be some individual position estimates that are most likely incorrect in the maps presented in this appendix.

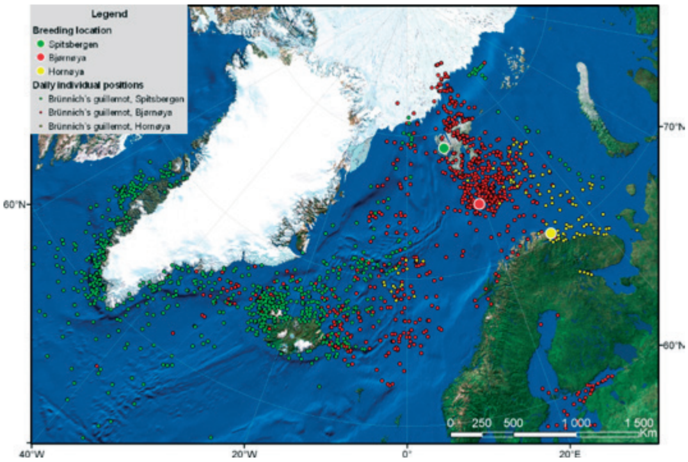

Figure 7. Distribution of Brünnich's guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in February.

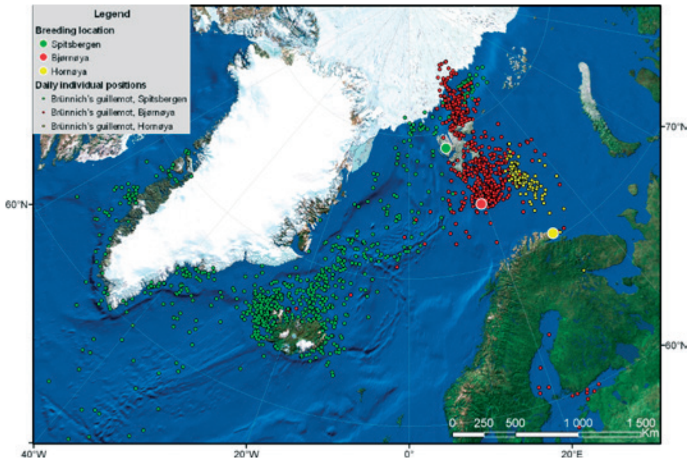

Figure 8. Distribution of Brünnich's guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in March.

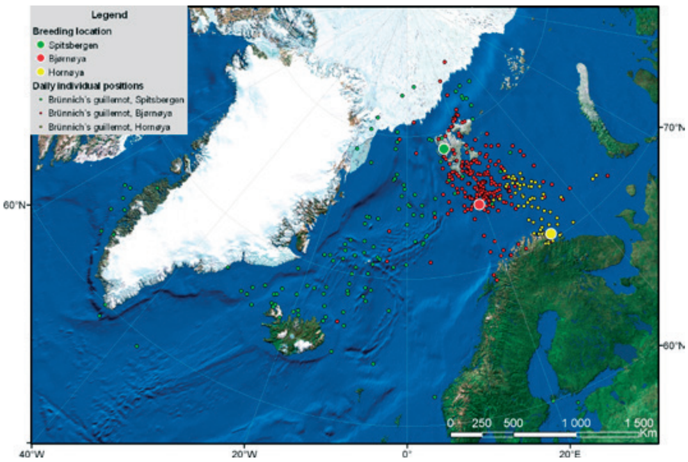

Figure 9. Distribution of Brünnich's guillemots from Spitsbergen, Bjørnøya and Hornøya by daily individual positions in April.

Appendix 2. Kernel density maps for Brünnich's guillemots from Spitsbergen and Bjørnøya

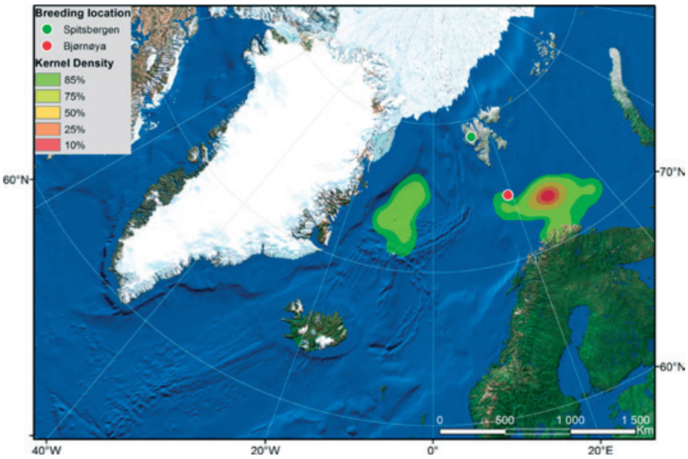

Figure 1. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in August.

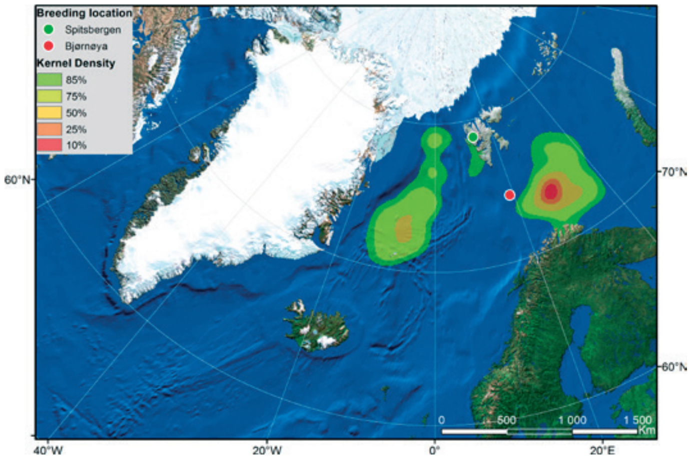

Figure 2. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in September.

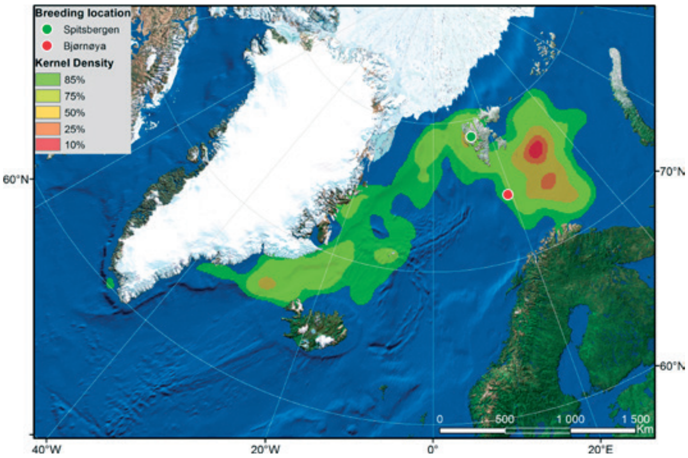

Figure 3. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in October.

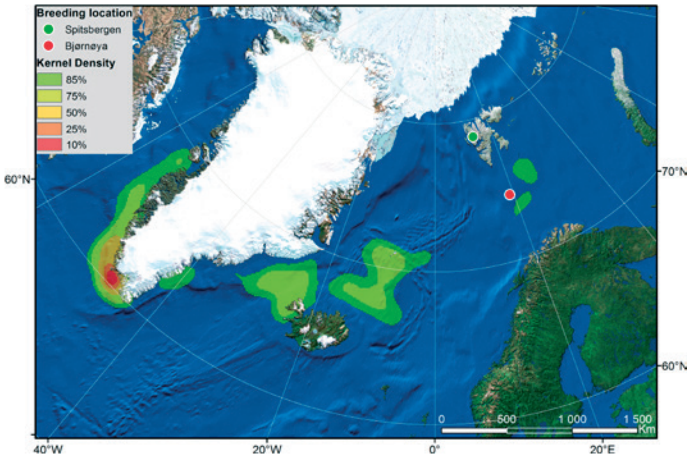

Figure 4. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in November.

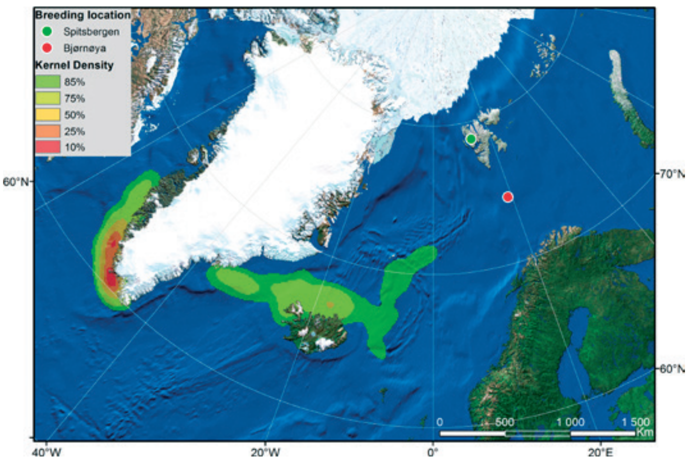

Figure 5. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in Desember.

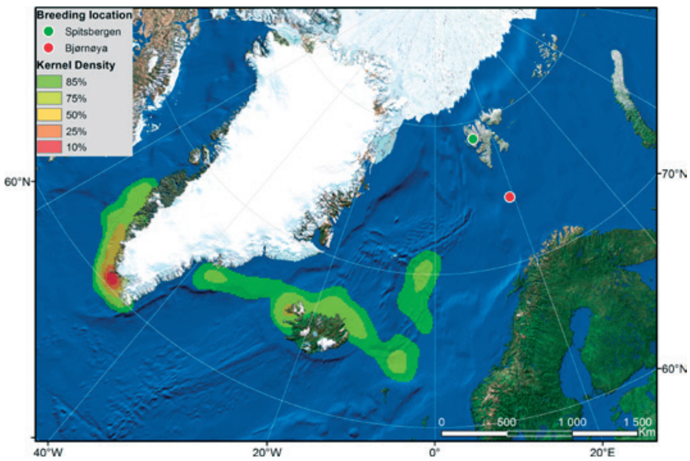

Figure 6. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in January.

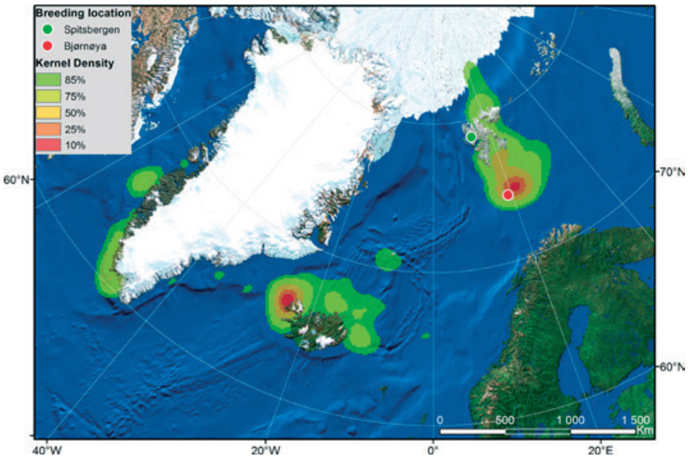

Figure 7. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in February.

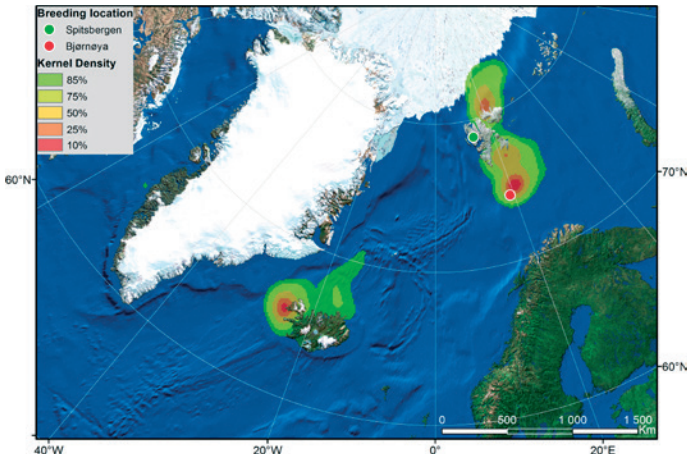

Figure 8. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in March.

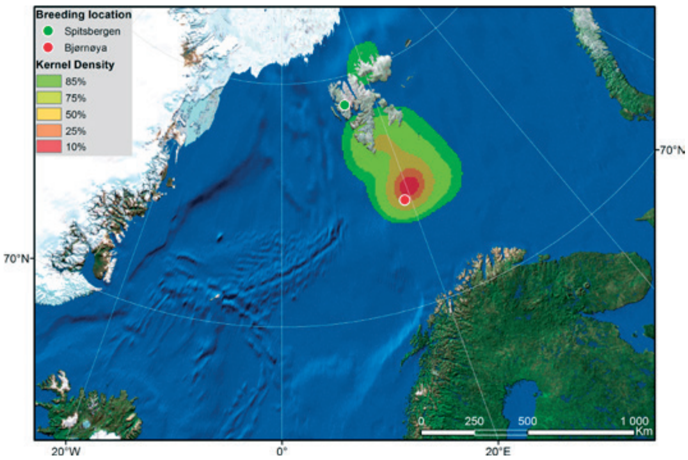

Figure 9. Kernel density estimation of Brünnich's guillemots from Spitsbergen and Bjørnøya in April.

Appendix 3. Distribution maps for common guillemots[1]

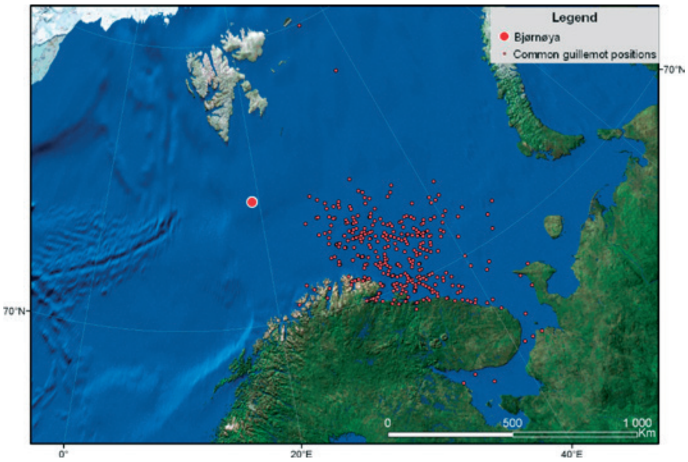

Figure 1. Distribution of common guillemots from Bjørnøya by daily individual positions in August.

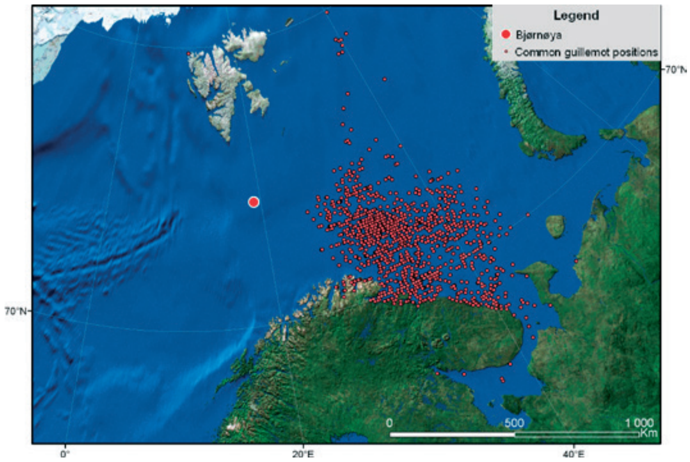

Figure 2. Distribution of common guillemots from Bjørnøya by daily individual positions in September.

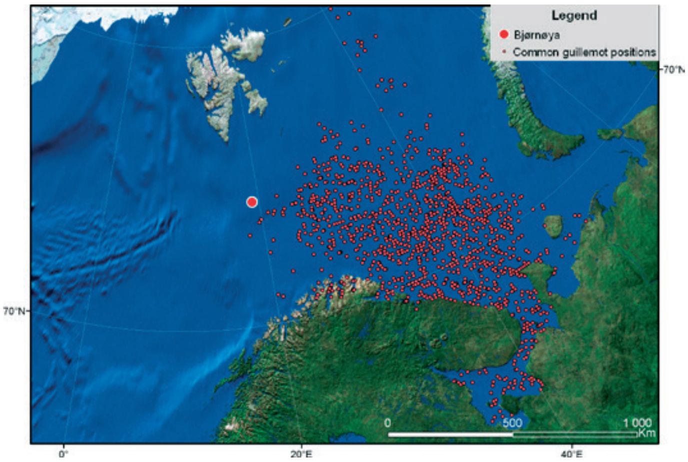

Figure 3. Distribution of common guillemots from Bjørnøya by daily individual positions in October.

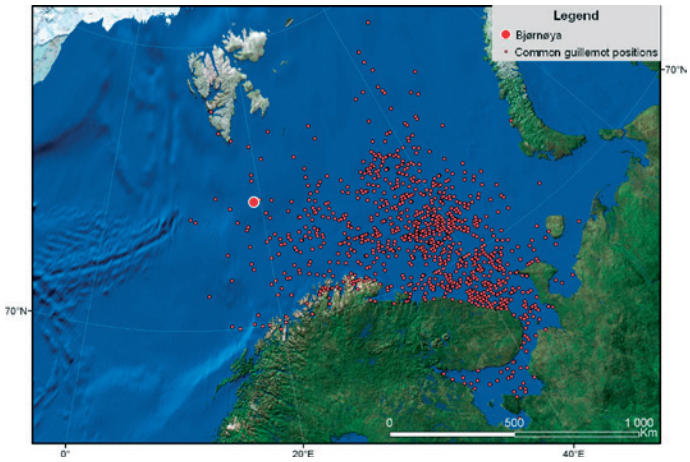

Figure 4. Distribution of common guillemots from Bjørnøya by daily individual positions in November.

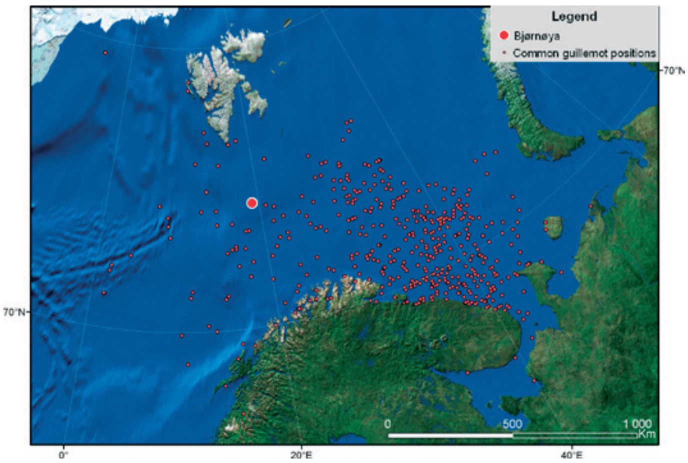

Figure 5. Distribution of common guillemots from Bjørnøya by daily individual positions in Desember.

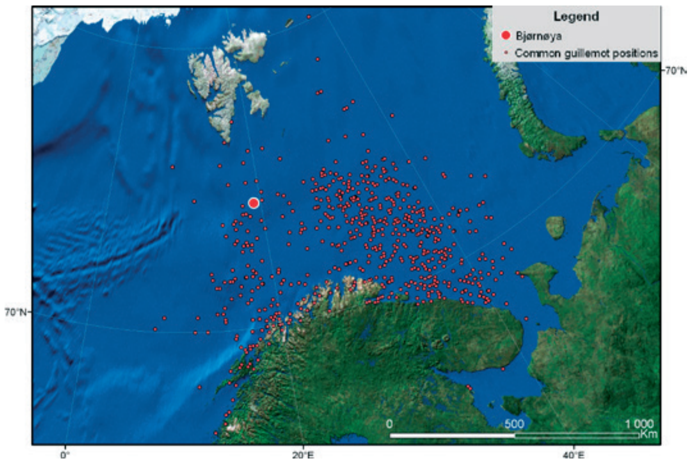

Figure 6. Distribution of common guillemots from Bjørnøya by daily individual positions in January.

[1] Despite of data filtering, there might still be some individual position estimates that are most likely incorrect in the maps presented in this appendix.

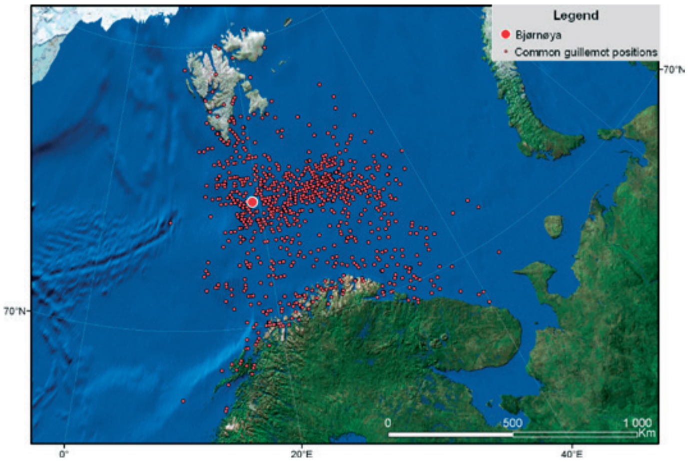

Figure 7. Distribution of common guillemots from Bjørnøya by daily individual positions in February.

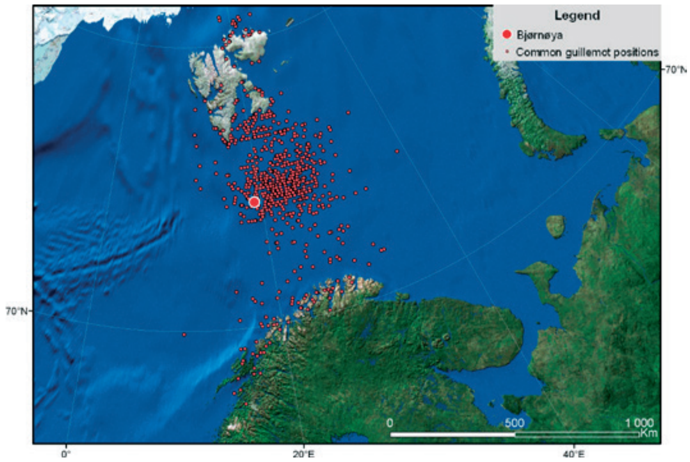

Figure 8. Distribution of common guillemots from Bjørnøya by daily individual positions in March.

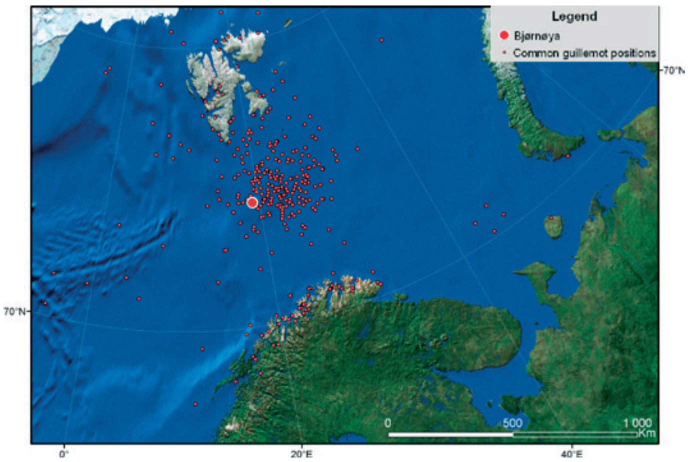

Figure 9. Distribution of common guillemots from Bjørnøya by daily individual positions in April.

Appendix 4. Kernel density maps for common guillemots.

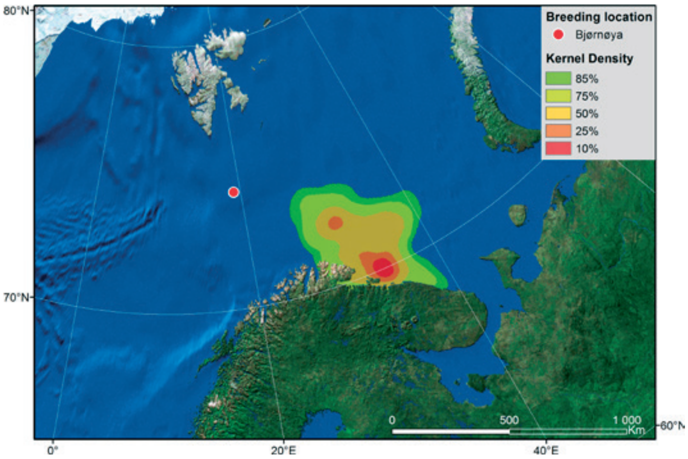

Figure 1. Kernel density estimation of common guillemots from Bjørnøya in August.

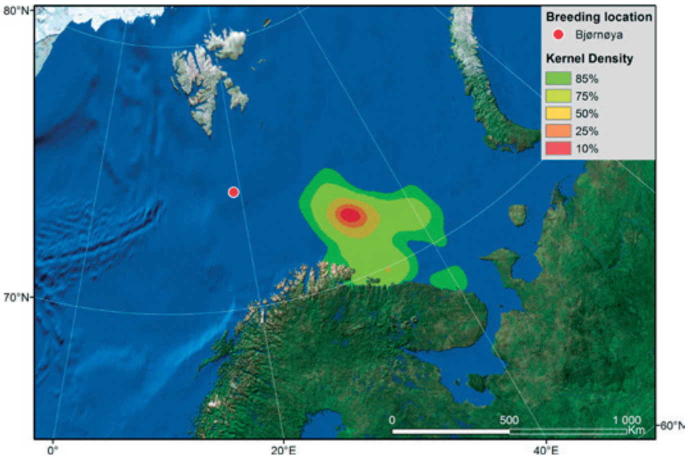

Figure 2. Kernel density estimation of common guillemots from Bjørnøya in September.

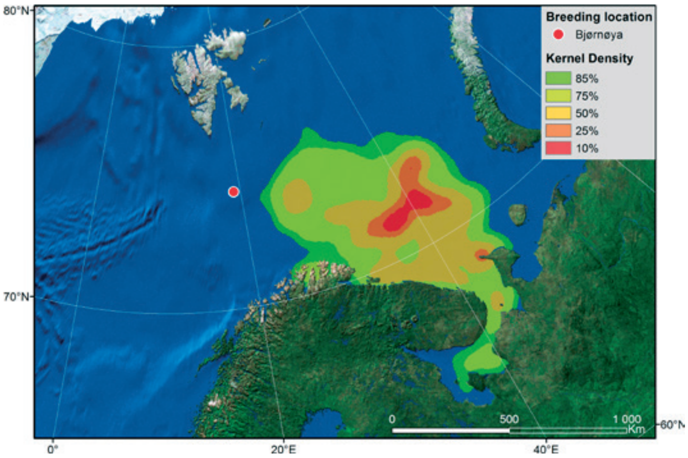

Figure 3. Kernel density estimation of common guillemots from Bjørnøya in October.

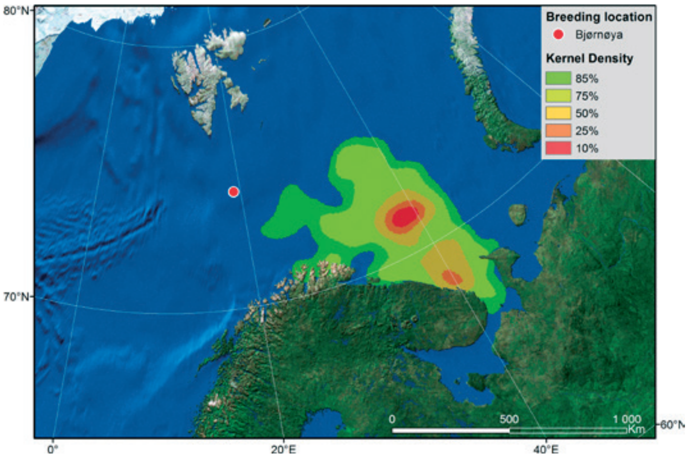

Figure 4. Kernel density estimation of common guillemots from Bjørnøya in November.

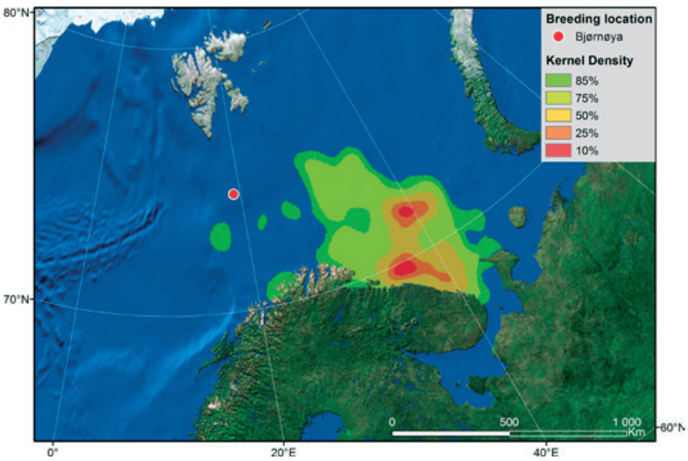

Figure 5. Kernel density estimation of common guillemots from Bjørnøya in Desember.

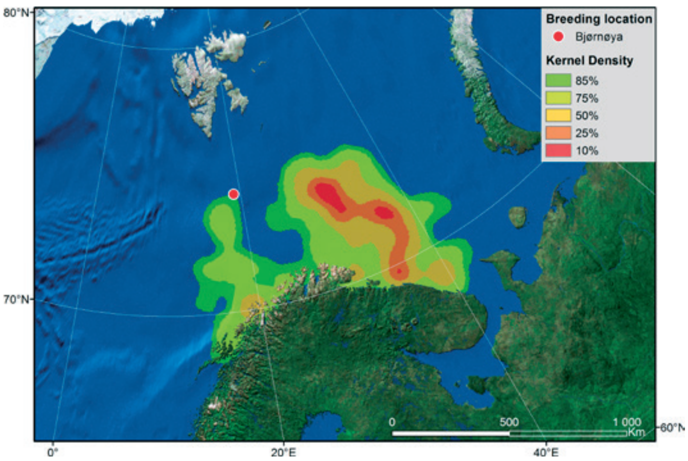

Figure 6. Kernel density estimation of common guillemots from Bjørnøya in January.

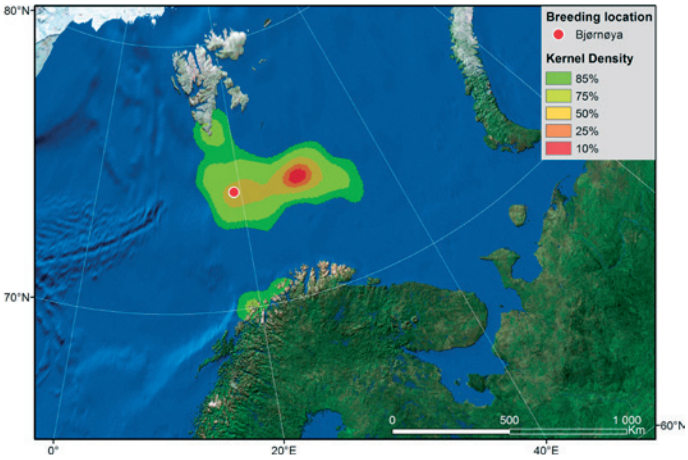

Figure 7. Kernel density estimation of common guillemots from Bjørnøya in February.

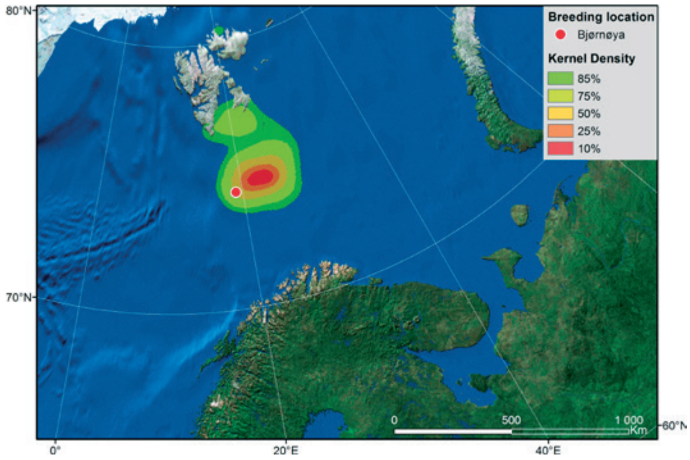

Figure 8. Kernel density estimation of common guillemots from Bjørnøya in March.

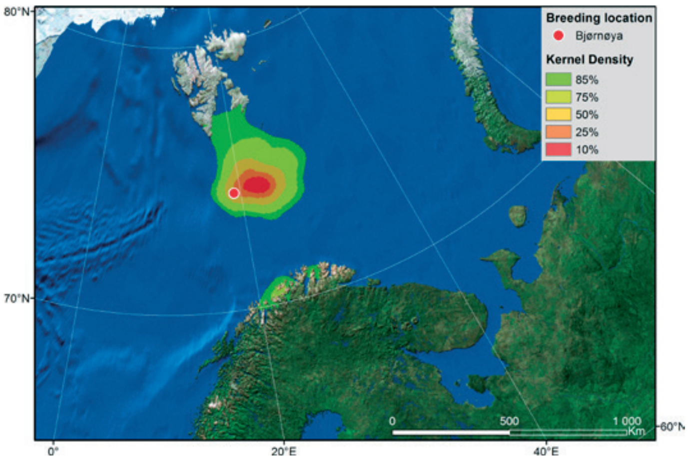

Figure 9. Kernel density estimation of common guillemots from Bjørnøya in April.

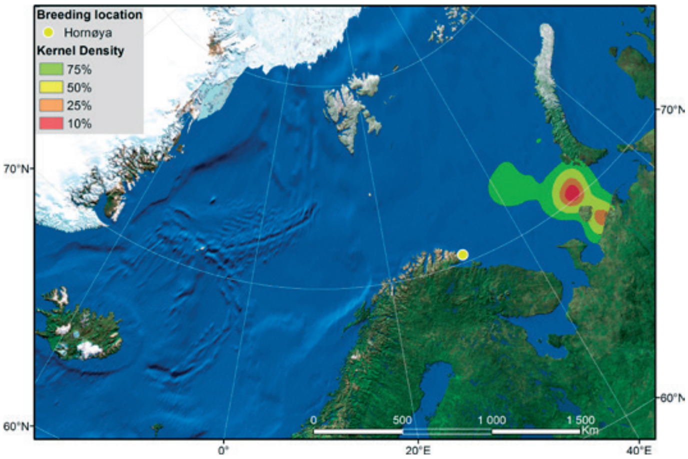

Figure 1. Kernel density estimation of Brünnich's guillemots from Hornøya in August.

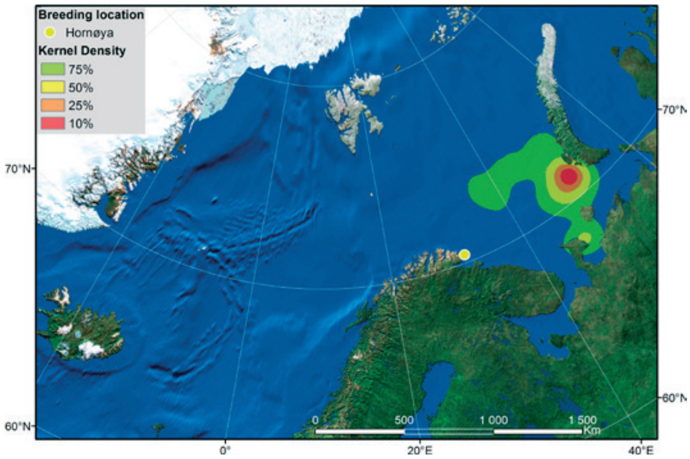

Figure 2. Kernel density estimation of Brünnich's guillemots from Hornøya in September.

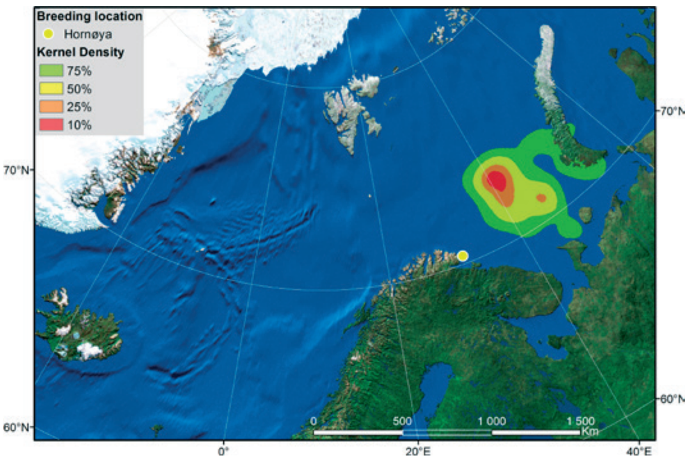

Figure 3. Kernel density estimation of Brünnich's guillemots from Hornøya in October.

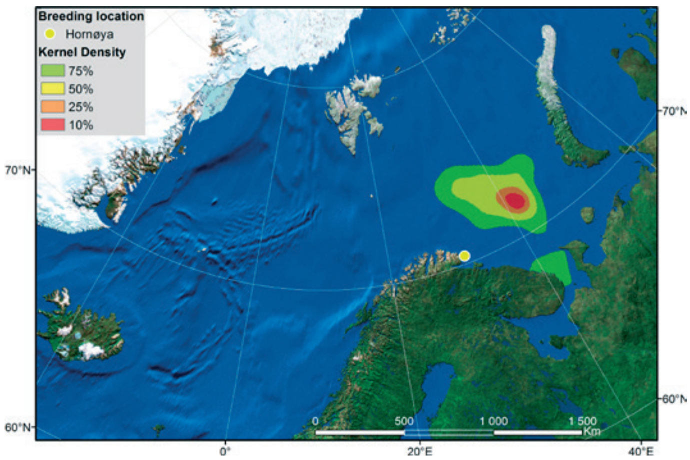

Figure 4. Kernel density estimation of Brünnich's guillemots from Hornøya in November.

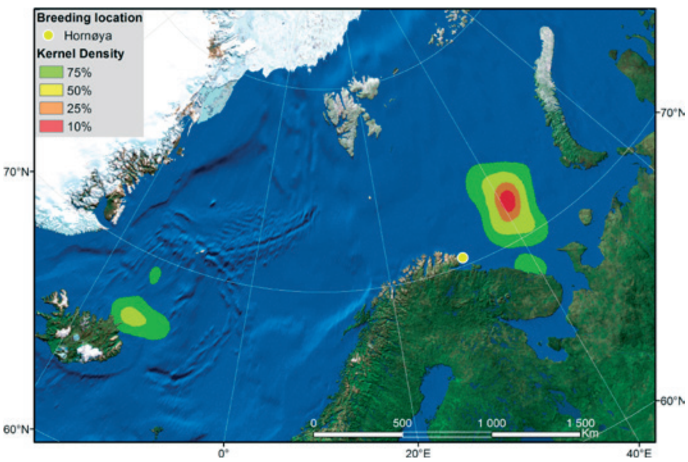

Figure 5. Kernel density estimation of Brünnich's guillemots from Hornøya in Desember.

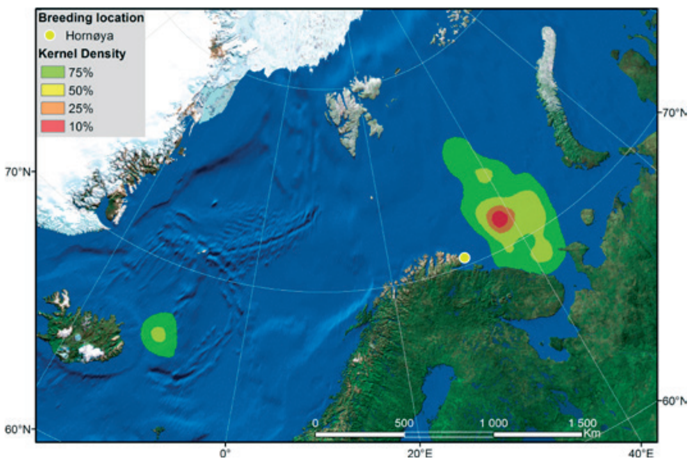

Figure 6. Kernel density estimation of Brünnich's guillemots from Hornøya in January.

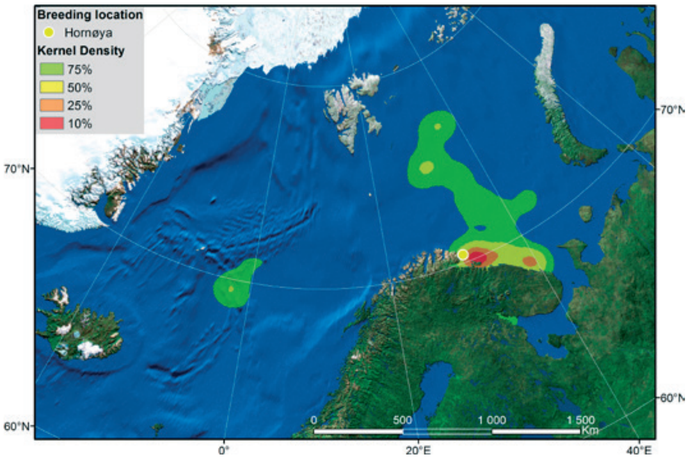

Figure 7. Kernel density estimation of Brünnich's guillemots from Hornøya in February.

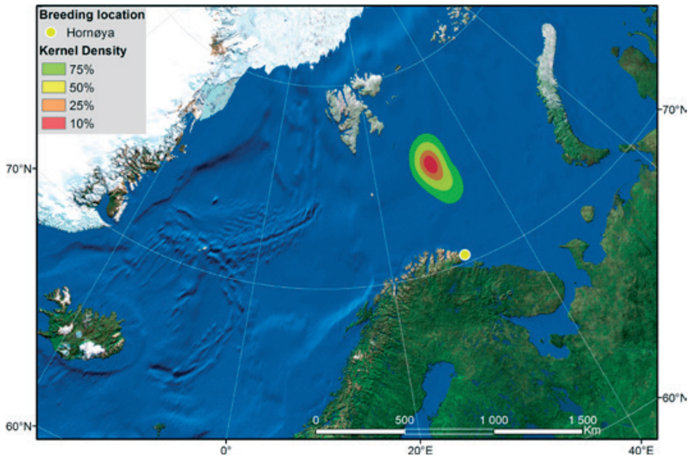

Figure 8. Kernel density estimation of Brünnich's guillemots from Hornøya in March.

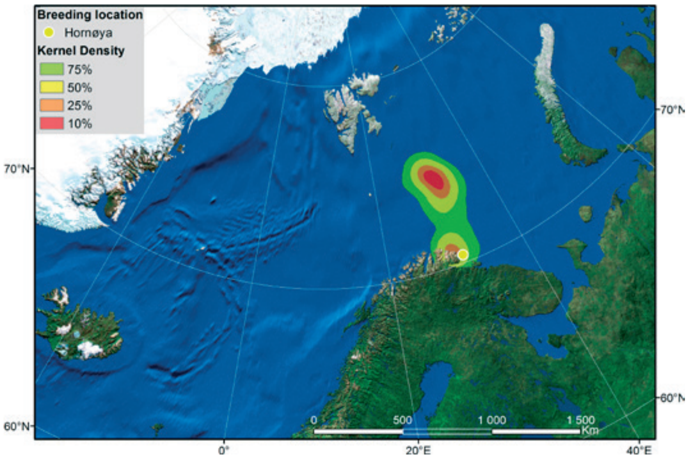

Figure 9. Kernel density estimation of Brünnich's guillemots from Hornøya in April.