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Data sheet

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Abstract: This report describes the results of a coordinated aerial and ship-based survey of seabirds, marine mammals, and physical and biological oceanography in the Disko Bay and south-eastern Baffin Bay in spring 2006. The main aim of the survey was to improve understanding of how top predators exploit the highly dynamic marginal ice zone during spring, when the ice is rapidly melting. The spatial distributions of primary production, zooplankton, seabirds and marine mammals are described, and preliminary results are presented from analyses aimed at understanding these distributions. Zooplankton biomass was dominated by *Calanus* copepods, shrimp larvae and barnacle nauplii, and the distribution of all three groups was related to ice concentration. The study area was estimated to be used by approx 1 million seabirds, including 430,000 thick-billed murres and 400,000 king eiders. King eiders were concentrated on the shallow Store Hellefiskebanke, whereas the distribution of most other seabirds was only weakly related to the physical and biological variables measured. Abundance of marine mammals was also estimated, including 1400 belugas and 450 bowhead whales.

Keywords: West Greenland, Disko Bay, Baffin Bay, oceanography, zooplankton, seabird distribution, seabird abundance, marine mammals

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Summary

As part of a Strategic Environmental Impact Assessment of oil activities in the Disko West area, the spatiotemporal distribution of marine organisms and ecosystem processes in the marginal ice zone was studied in spring 2006. The study had two main objectives: 1) identifying key areas for biodiversity at this highly dynamic time of year, and 2) evaluating factors affecting the spatial distribution of key species and groups. Two surveys were carried out simultaneously in Disko Bay and south-eastern Baffin Bay: an aerial survey of seabirds and marine mammals, and an oceanographic cruise combined with transect surveys. On the cruise, physical and biological data were recorded at 116 stations situated approx. 10 km apart, and seabirds and marine mammals were surveyed between stations. Thick-billed murres were collected at sea to assess their diet. Where appropriate, remote sensing data were used to supplement the *in situ* measurements and observations.

Vertical profiles of salinity and temperature showed that stratification progressed over the three-week study period, with some spatial variation. Nutrient concentrations were generally high, and conditions for a phytoplankton spring bloom were thus in place. Accordingly, *in situ* measurements of fluorescence as well as remote sensing data showed a gradual increase in chlorophyll concentration. The bloom seemed to occur earlier on Store Hellefiskebanke in the southern part of the study area, perhaps because the shallow depth allowed phytoplankton to remain in the photic zone before stratification was established, i.e. when the water column was fully mixed.

Mesozooplankton biomass in the upper part of the water column was dominated by *Calanus* copepods (64%), barnacle larvae (nauplii, 16%) and shrimp larvae (12%). Larger planktonic organisms were not sampled adequately by the available gear. Copepods were dominant in all areas except on Store Hellefiskebanke, where barnacle nauplii were most abundant. Total zooplankton biomass showed a high spatial variability, with few clear patterns. Statistical modelling showed that ice concentration affected the distribution of all three key groups, with a weak avoidance of ice by copepods and shrimp larvae, and a strong preference for ice by barnacle nauplii, which also preferred areas where stratification was weak. All fish larvae observed were sand lance, and these were mainly found around Store Hellefiskebanke.

Abundance estimates based on the aerial survey showed that about one million seabirds used the study area in spring. The most numerous species were thick-billed murre (430,000) and king eider (400,000), followed by northern fulmar (89,000), black-legged kittiwake (77,000) and black guillemot (21,000). King eiders were concentrated on Store Hellefiskebanke and common eiders near coastlines, areas that are shallow enough to allow them access to their benthic prey. The spatial distribution of the other common species was much more complex, partly because the study period was relatively long and birds probably redistributed themselves as food and ice conditions changed. Statistical modelling based on the ship survey data showed that northern fulmars and black-legged

kittiwakes were more likely to occur in areas where the spring bloom was well developed, whereas thick-billed murres preferred deep waters and black guillemots preferred shallow waters. None of these relationships were very strong. Further statistical analyses of the spatial distribution of seabirds based on the aerial surveys are planned, using newly developed methods.

Many thick-billed murres had empty stomachs, and among the remainder invertebrates (amphipods and squid) were more common than fish. Capelin was the only fish species positively identified in murre stomachs.

Abundance estimates of marine mammals were based on the aerial survey. These showed that the most numerous species in the study area were ringed seal (4600), beluga (1400), bearded seal (1200), bowhead whale (450) and walrus (420). However these estimates were very imprecise and almost certainly too low, because they were not corrected for submerged animals.

Sammenfatning

Den rumlige og tidslige fordeling af marine organismer og økosystemprocesser i iskant-zonen blev undersøgt i foråret 2006 som led i en Strategisk Miljøvurdering af olieaktiviteter i Disko Vest-området. Formålet var dels at identificere vigtige områder for biodiversitet på denne særdeles dynamiske årstid, og dels at identificere faktorer som påvirker den rumlige fordeling af vigtige arter og grupper. To undersøgelser blev udført samtidig: En optælling (linjetransekt) fra fly af havfugle og havpattedyr, samt et oceanografisk togt kombineret med linjetransekter. På togtet blev fysiske og biologiske data indsamlet ved 116 stationer med ca. 10 km's mellemrum, og havfugle og havpattedyr blev talt mellem stationerne. Polarlomvier blev indsamlet til havs for at undersøge deres fødevalg. Satellitbaserede målinger blev i nogle tilfælde brugt til at supplere data og observationer fra togtet.

Lodrette profiler af temperatur og saltholdighed viste at lagdelingen af vandsøjlen blev stærkere over den tre uger lange undersøgelsesperiode, med nogen rumlig variation. Koncentrationerne af næringsstoffer var generelt høje, og betingelserne for en forårsopblomstring af fytoplankton (mikroskopiske alger) var således til stede. Målinger af klorofylkoncentration fra såvel skib som satellit viste da også en stigning over undersøgelsesperioden. Opblomstringen syntes at ske tidligere på Store Hellefiskebanke i den sydlige del af undersøgelsesområdet, måske fordi området er relativt lavvandet og fytoplankton derfor forblev i den fotiske zone (hvor der er lys nok til fotosyntese) også før en lagdeling var etableret.

Biomassen af mesozooplankton (smådyr under 2 mm) i den øvre del af vandsøjlen var domineret af tre grupper: Vandlopper af slægten *Calanus* (64%), rur-larver (16%) og rejelarver (12%). Større planktondyr blev kun undtagelsesvis fanget med det tilgængelige udstyr. Vandlopper dominerede overalt i undersøgelsesområdet, undtagen omkring Store Hellefiskebanke hvor rur-larver var meget talrige. Den samlede biomasse af zooplankton varierede meget fra sted til sted uden noget klart mønster. Statistiske modeller viste at iskoncentrationen påvirkede den rumlige fordeling af alle tre hovedgrupper. Vandlopper og rejelarver var mindre hyppige i områder med megen is, mens rur-larver var betydeligt mere hyppige i områder med megen is og svag lagdeling. Alle fiskelarver var tobis, og forekom mest omkring Store Hellefiskebanke.

Antallet af havfugle i undersøgelsesområdet blev estimeret ud fra flytællingerne. Total blev området brugt af omkring en million fugle i forårsperioden. De mest talrige arter var polarlomvie (430.000) og kongeederfugl (400.000), efterfulgt af mallemuk (89.000), ride (77.000) og tejst (21.000). Kongeederfugl var koncentreret omkring Store Hellefiskebanke og almindelig ederfugl nær kysten, områder som er tilstrækkelig lavvandede til at de har adgang til de bunddyr de lever af. Den rumlige fordeling af de øvrige almindelige arter var mere kompleks, til dels fordi undersøgelsesperioden var ret lang og fuglene formodentlig ændrede fordeling efterhånden som føde- og isforholdene ændrede sig. Statistiske modeller baseret på skibstællingerne viste at mallemuk og ride optrådte

hyppigere i områder hvor forårsopblomstringen var veludviklet, mens polarlomvie foretrak dybt vand og tejst lavt vand. Ingen af disse mønstre var dog særligt stærke. Yderligere analyser af havfuglenes fordeling baseret på flytællingerne er planlagt, med anvendelse af helt nyudviklede metoder.

Mange polarlomvier havde tomme maver, og blandt de resterende var invertebrater (amfipoder og blæksprutter) mere almindelige end fisk. Den eneste fiskeart som med sikkerhed blev fundet i maverne var lodde.

Antallet af havpattedyr blev estimeret ud fra flytællingerne. De almindeligste arter i undersøgelsesområdet var ringsæl (4600), hvidhval (1400), remmesæl (1200), grønlandshval (450) og hvalros (420). Disse estimater var dog meget usikre og næsten sikkert for lave, da de ikke blev korrigeret for at dyrene er neddykket en stor del af tiden.

Eqikkaaneq

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Erngup napasuliaasap qullersaani mesozooplanktonini uumassuseqatigiit (uumasuaraaqqat 2 mm-it inorlugit angissusillit) assigiinngiiaanik pingasunit takussutissaqarfiunerupput: Erngup pississartui kinguaariit *Calanus* (64%-it), kaattungiiaat ilaasa qullugiaat (16%-it) aamma kinguppaat qullugiaat (12%-it). Atortorissaarutinik pigineqartunik planktonit uumasuaqqat anginerusut qaqutiguinnaq pisarineqartarput. Misissuiffigisami erngup pississartui sumi tamani takussaanersaapput, taamaallaat Ikkannersuarmi kaattungiiaat ilaasa takussaaffiginerpaaffigisaanni pinnatik. Zooplanktonini uumassuseqatigiit ataatsimoortut sumiiffimmit sumiiffimmut assorsuaq assigiinngiiaarput, erseqqissumik najoqqutaqarpasinngitsumik. Eqimattakkuutaani pingaarnerni pingasuni tamani inissisimassutsimi agguataarnermik sikoqassutsip sunniivigigaa naatsorsueqqissaaraluni ilusiliat takutippaat. Erngup pississartuisa kinguppaallu qullugiaasa sikortaqarpallaartut ilaatigut tikissimanaveersaartarpaat, kaattungiiaalli ilaasa sumiiffiit assorsuaq sikutaqartut annikitsumillu

ikiariissitaarisoqarfiusut annertuupilussuuffigalugit. Aalisakkat qullugiaat tassaapput putooruttut, Ikkannersarsuup eqqaani takussaanerpaallutik.

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Apparpassuit nerisaqarsimanngillat, sinnerinilu ivertebratit (amfipodit amikullu) aalisakkanit nalinginnaanerupput. Aalisakkani assigiiaat naarmiorisaat qularisassaannginnerpaaq tassaavoq ammassak.

Immami uumasut miluumasut amerlassusaat timmisartumit kisitsinernit missiliorneqarput. Misissuiffigisami assigiiaat nalinginnaanerpaat tassaapput natsiit (4600-it), qilalugaq qaqortaq (1400-it), ussuk (1200-it), arfivik (450-it) aamma aaveq (420-t). Missiliuinerilli assorsuaq isumannanngitsuupput, qularutissaagunanngitsumik ikippallaartutut missiliuutaallutik, uumasut piffissap ilarujussuani aqqaamasimanerinut naqqissorneqarsimanngitsumik pissutigalugit.

1 Introduction

1.1 Aims and objectives

In 2006 the waters off West Greenland between 67° and 71° N, the north-eastern part of Davis Strait and the south-eastern part of Baffin Bay (= the Disko West area), were opened for hydrocarbon exploration. The first licenses were granted in 2007. Prior to opening of the area for hydrocarbon exploration, a programme for Strategic Environmental Impact Assessment (SEIA) was initiated in 2004 in a co-operation between the Bureau of Minerals and Petroleum (BMP), the Greenland Institute of Natural Resources (GNIR) and the National Environmental Research Institute (NERI). In support of the SEIA a number of background studies were initiated, including the study reported here focusing on the rich life in the marginal ice zone in spring. The first results from this study conducted in 2006 were also included in the Strategic Environmental Impact Assessment (SEIA) (Mosbech et al. 2007).

The aims of this study were to a) identify ecological key areas with high concentrations of important animals, and b) attempt to identify key factors determining the distribution of important species so that models can be developed in the future to predict recurrent concentrations. We have in this report mainly focused on analysing distributions in relation to bathymetry, ice conditions and distribution of food items.

1.2 Study design and elements

In spring (April to May) 2006, a multidisciplinary study was conducted in the marginal ice zone in Disko Bay and the Disko West area. The program included aerial surveys of seabirds and mammals covering the entire region with systematic transects (**Figure 2.1**), and a synoptic ship-based biological oceanographic survey covering transects from open water and into the drifting ice at the ice edge as well as use of satellite data (**Figure 2.2**).

This report summarises data collected from the aerial and ship-based surveys. The synoptic collection of data on seabirds, zooplankton as well as biological and physical oceanographic variables in the Ice Edge project provides a unique opportunity to examine what determines the spatial distribution of major food web components during a critical part of the seasonal cycle. At the upper trophic levels, it is reasonable to assume that seabirds distribute themselves mainly according to food availability. Seabird diet at this time of the year is not well known in W Greenland (but see Falk & Durinck 1993 and chapter 3.4), but it is likely that the main components of the diet for most species are small fish (e.g. Arctic cod (*Boreogadus saida*), capelin (*Mallotus villosus*) and sand lance (*Ammodytes* spp.)) as well as large planktonic crustaceans (amphipods, euphausiids, and possibly large copepods and juvenile deep-water shrimps (*Pandalus borealis*)). Unfortunately, many of these potentially important prey organisms were either not sampled at all or not sampled very well gear used in this study. As a consequence, the analyses of seabird distribution in relation to zooplankton abundance presented here rely on the assumption that the distribution of important seabird prey is largely driven by the abundance of their respective prey, namely abundant mesozooplankton organisms which were well sampled. In addition, we test whether the distribution of key zooplankton groups as well as seabirds is linked to aspects of the physical and biological environment (depth, stability of the water column, ice concentration, chlorophyll content). Because of the complex nature of the data (see next section), statistical analysis is far from simple and the results presented here should be regarded as preliminary.

1.3 Study area

The offshore parts of the study area are north-eastern Davis Strait and south-eastern Baffin Bay. The shelf is the rather shallow waters (depths less than 200 m) near the coast. This shelf includes several large shoals or banks, which typically range between 20 and 200 m in depth. In the southern part of the study area the shelf is up to 120 km wide, while it in the northern part is narrower and less well defined towards the deep sea. The shelf is traversed by deep troughs, which separate the fishing banks. There is deep water down to 2500 m to the west of the shelf.

Disko Bay is a 10,000 km^2 large bay. Baffin Bay and the Banks of Disko border the bay. There are two entrances into Disko Bay. The southern entrance is about 60 km wide, and has a narrow channel that is about 500 m deep. However, islands and shallow depths dominate the topography at the entrance. The northern entrance, Vaigat, is a 100 km long and 10-20 km wide channel with a sill depth of about 250 m.

Upwelling often occurs along the steep sides of the fishing banks driven by the tidal current, so that upwelling usually alternates with downwelling. Hydrodynamic simulations carried out as part of the Strategic Environmental Impact Assessment programme reveal a significant upwelling area around Hareø in the mouth of Vaigat, and a prominent upwelling area on the northeast corner of Store Hellefiskebanke, where a deep wedge cuts southwards between the bank and the coast. Further model simulations south of the study area predict that upwelling also occurs west of the banks and to a lesser extent in the deep channels separating the banks (Pedersen et al. 2005).

Two types of sea ice occur in the study area: fast ice, which is stable and anchored to the coast, and drift ice, which is very dynamic and consists of floes in varying size and degree of density. The drift ice is often referred as “The West Ice” because it is formed to the west of Greenland (first-year ice). Icebergs, particularly originating from the very productive glacier at Ilulissat, are also common in the study area.

The ice conditions between 60° N and 72° N are primarily determined by the relatively warm north- or northwest-flowing West Greenland Current and the cold south-flowing Baffin Current. The West Greenland Current delays the time of ice formation in eastern Davis Strait and results in an earlier break-up than in the western parts. The Baffin Island Current conveys large amounts of sea ice from Baffin Bay to the Davis

Strait and the Labrador Sea for most of the year, especially during the winter and early spring months. During this period, sea ice normally covers most of the Davis Strait north of 65° N, except areas close to the Greenland coast, where a flaw lead or shear zone (consisting of open water or thin ice) of varying width often appears between the shore or the fast ice and the drift ice offshore as far north as latitude 67° N. The marginal ice zone of the drift is normally oriented to the southwest towards Hudson Strait or the Labrador Coast. In the beginning of the melt season, a wide lead or polynya-like feature often forms west of Disko Island and off Disko Bay. The eastern part of Davis Strait, south of Disko Island, is free of sea ice during this period, whereas drift ice dominates to the west and north.

2 Methods

2.1 Field methods – ship survey

The research vessel used for the ship-based survey, R/V Adolf Jensen (Greenland Institute of Natural Resources), did not have ice-breaking capabilities, and generally ship transects did not proceed when ice cover was above 8/10. However, in some situations when ice thickness and size of floes were manageable for the vessel, samples were taken at locations with ice concentration > 8/10. The ship survey took place from 18 April – 10 May 2006 and covered Disko Bay, Vaigat, and areas west and south of Disko including the northern half of Store Hellefiskebanke. From the vessel, oceanographic profiling of the water column and biological sampling were conducted at 116 stations, and seabirds and marine mammals were surveyed along transects between stations.

2.1.1 Oceanographic sampling

Physical and biological oceanographic sampling was carried out at 116 stations located approximately 10 km apart. Depth profiles of salinity, temperature and fluorescence were recorded from the surface to the bottom (or a maximum of 250 m) using a Seabird CTD 901. The salinity probe was calibrated against a Guildline Portasal salinometer using samples from 250 m depth at station 39. The calibration showed that the CTD had an accuracy of 0.05 salinity units. A Hydroscat-2 mounted on the CTD sampled fluorescence in the vertical water column.

Water samples for nutrients and chlorophyll were collected using Niskin bottles which were closed at specific depths. The Niskin bottle was attached to a wire and lowered with a winch. The water sample depths were 0.5 m, depth of max fluorescence (i.e. highest chlorophyll a concentration), and 50 m. The sampling depths at stations with no available fluorometer data were 0.5 m, 25 m, and 50 m.

Samples of mesozooplankton, ichthyoplankton and larger zooplankton from 0-50 m were collected using a WP-2 net (mesh size 200 µm) with a 0.25 m^2 opening area. The net was deployed and retrieved at speeds of about 10 m min^{-1}. The samples were concentrated on a 45 µm or a 200 µm filter, preserved in 2-4% buffered formalin, and stored for later enumeration and biomass estimation.

2.1.2 Bird counts

The counts followed the guidelines of Komdeur et al. (1992), in 6 parallel bands (Transect type 4; 1-50 m, 50-100 m, 100-200 m, 200-300 m, 300-400 m, 400-500 m). Counts were split in 2-minute intervals. Observations of flying birds were recorded in snapshots every second minute. In addition to position, number and other standard data, we recorded behaviour using the codes specified by Camphuysen & Garthe (2001). Ice concentration was estimated in fractions of 10 for each 2-minute interval. Counts were conducted during most periods of sailing: between oceanographic sampling stations and while transiting to and from ports and anchorages. Birds were generally not counted during oceanographic sampling at the stations and during hours of darkness.

Observations were carried out throughout the day, most days starting between 0700 and 0830, and ending between 2030 and 2200. The transect plan is shown in **Figure 2.1**. Generally, weather conditions were fine, and surveying was impossible only for a total of 4 days; more specifically on 13, 21, 22 and 26 April. The first of these days, it was due to observer motion sickness, the others due to mechanical problems.

2.1.3 Collection of specimens

The Ministry of Environment and Nature – under the Greenland Home Rule Government – granted permission to collect and export 50 thick-billed murres (*Uria lomvia*) to Denmark. All birds collected were shot from a Zodiac using a shotgun. Specimens were collected in areas where birds seemed to be foraging. The birds were frozen immediately after collection, and shipped to Denmark as frozen freight.

2.2 Field methods – aerial survey

Aerial surveys for seabirds and marine mammals were carried out in the West Greenland waters between 67° 30′ N and 71° 30′ N in the period 24 April to 8 May 2006. A set of transects were selected in advance. They were spaced with 0.8 degrees and ran east-west between the coast of Greenland and the border to Canada. A selection of these were flown, and only some of these in their full length (**Figure 2.2**). The total length of all transects flown was 6220 km.

The aircraft used was a Partenavia P-68 Observer equipped with bubble windows at the seats behind the pilot seats. All surveys were carried out as transect flights flying at an altitude of 250 feet (85 m) and with a speed of 90 knots (160 km/t). Observations were stratified into transect bands (**Table 2.1**), angles to the horizon being determined with a clinometer. Sea ice conditions were recorded by the pilot with 2 min. intervals and in fractions of 10.

Table 2.1. Transect bands.

Transect band	Angle to horizon, °	Distance from track line, m
1/A	60-25	44-164
2/B	25-15	164-285
3/C	15-10	285-433
4/D	10-4	433-1091
5/E	4-3	1091-1456

Observations of seabirds and marine mammals were recorded on a tape recorder, and each observation was dictated together with the observation time. A GPS connected to a computer recorded the flown track lines, and by combining the observation time and GPS time each observation could be geo-referenced. All clocks were synchronised with the GPS-clock. **Figure 2.2** shows the transects flown.

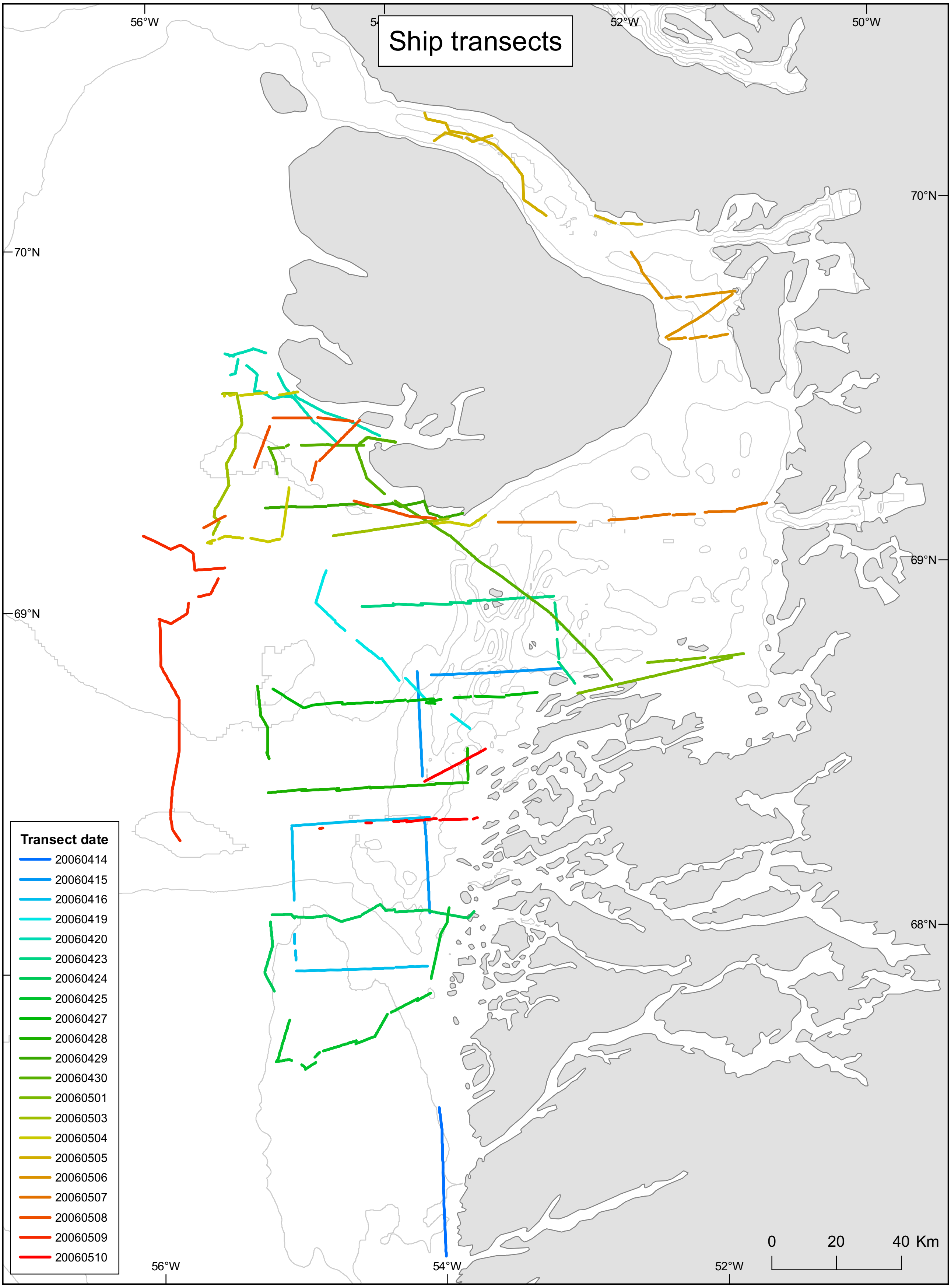

Figure 2.1. Ship transects in Disko Bay and south-eastern Baffin Bay, 14 April – 10 May 2006.

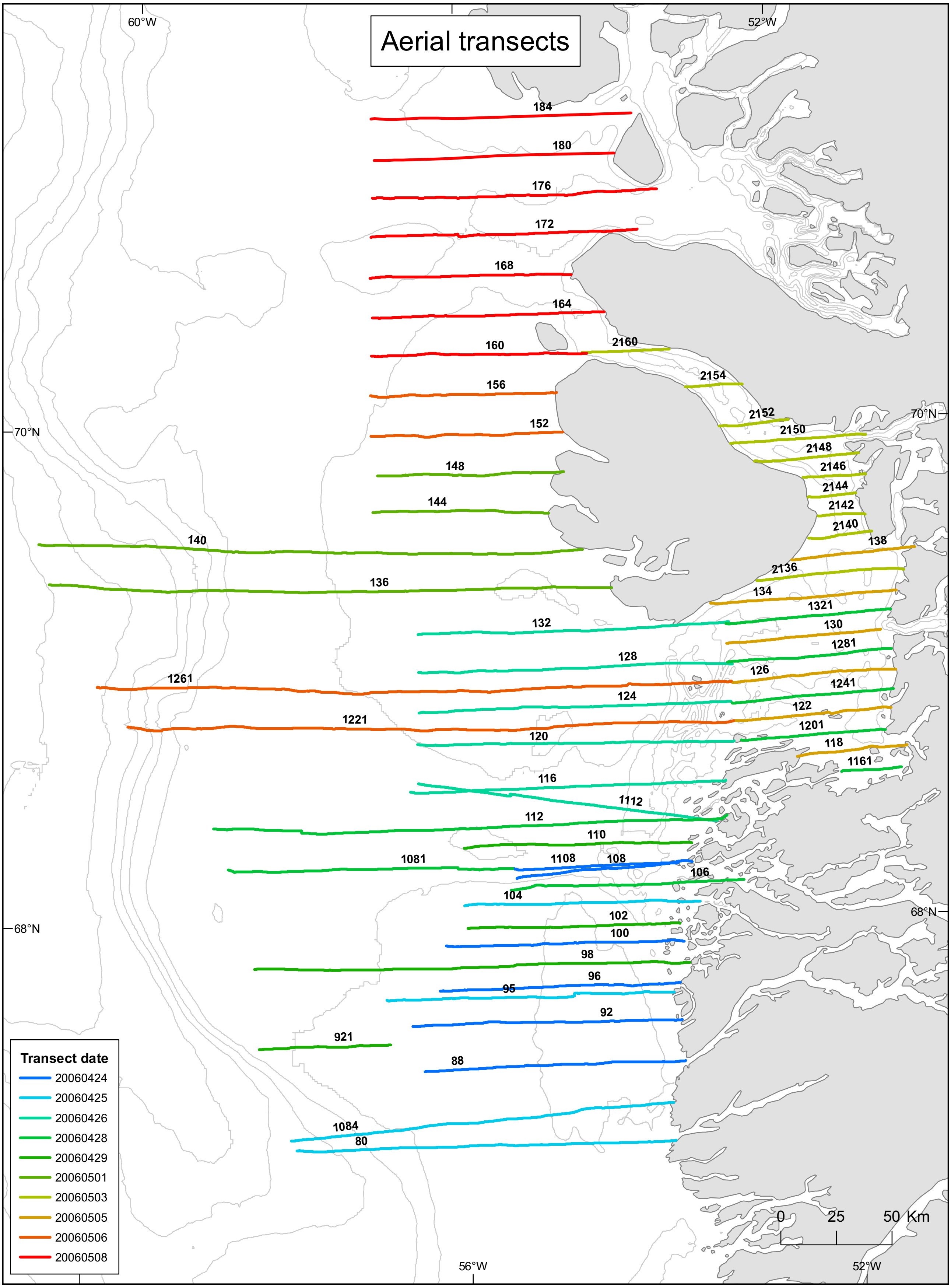

Figure 2.2. Aerial transects in Disko Bay and south-eastern Baffin Bay, 24 April – 8 May 2006 (total length 6220 km).

2.3 Remote sensing data

The surface concentration of chlorophyll derived from satellite observations is a combined product derived from MODIS and SeaWiFS data, and has been processed by Oregon State University, US. Daily and weekly averaged remote sensing data were downloaded from OceanColorWeb, NASA:

http://oceancolor.gsfc.nasa.gov/cgi/level3.pl?DAY=12Apr2006&PER=&TYP=machl&RRW=16
In this report the data are presented as weekly averaged values.

2.4 Generalised sea ice margins

Information about sea ice coverage can be derived from a variety of sources, mainly based on remotely sensed data. The problem is that these data do not always agree with each other and that some are restricted due to clouds, presence of land etc. Thus, to give a summarised impression of the sea ice situation during the survey in April and May 2006 generalised ice margins were derived from the available data.

Data used in this comparison were mainly the public ice charts from the Danish Meteorological Institute (DMI) and systematic observations made by the pilot during the aerial surveys. To support these data, archived data from the American National Ice Center (Natice) and remote sensed data from the MODIS-sensor were included sporadically.

Ice margins were derived from 13 April until 9 May, with about one week temporal resolution. On the maps, ice margins are symbolised with a simple line which could be regarded as corresponding to the bold line on the ice charts from DMI, symbolising the transition between ice-influenced areas and open water. These lines should not be regarded as the absolute truth regarding the location of the ice margin on the particular date. Instead they show in more general terms the approximate location during the days around the given date. Thus, no mathematical or statistical methods have been developed for this task as the lines are only rather subjective interpretation of the data mentioned above.

2.5 Laboratory methods

2.5.1 Chlorophyll and nutrients

Samples (0.2-0.25 litres) obtained from the routine depths described above were placed in the dark and filtered at the ship-based laboratory onto GF/F filters, 10 µm, and 50 µm, extracted in 96% ethanol (Jespersen & Christoffersen 1987) and measured spectrophotometrically (Strickland & Parsons 1972). The discrete *in situ* measures of chlorophyll a were combined with the depth profiles of fluorescence to obtain depth profiles of chlorophyll. For each profile, a linear regression of fluorescence chlorophyll against spectrophotometric chlorophyll was carried out and used to calculate the depth profile. Integrated chlorophyll was then calculated as the area under this curve.

Samples obtained from the routine depths described above for the determination of nutrient concentration (NH_4^+, NO_3^-, PO_4^{3-}, SiO_4^{3-}) were frozen on board the ship. Measurements were carried out at the National Environmental Research Institute (NERI) on a Skalar (Breda, Netherlands) autoanalyser according to Andersen et al. (2004). All nutrient samples were analysed in duplicate with a precision of 0.06, 0.09 and 0.12 µM for nitrate, phosphate and silicate, respectively.

2.5.2 Zooplankton

Zooplankton samples were processed by Arctic Agency, Gdansk, Poland. The samples were split using a plankton splitter to obtain sample sizes of approximately 500 individuals, and all identifiable zooplankton were identified to lowest possible taxonomic level and developmental stage. Prosome lengths were measured on 10 individuals from each copepodite stage, and total body length was measured on 25 to 50 nauplii. Mean individual biomass (carbon content) was estimated from length-weight regressions collected as part of previous plankton studies in the area (T.G. Nielsen, unpubl. data).

2.5.3 Thick-billed murre diet

All collected birds ($n = 49$) were dissected, aged and sexed in the lab, and the contents of the stomach and oesophagus were removed and conserved in 70% ethanol. Prey items were classified, identified and measured under microscope. Fish otoliths were identified following Härkönen (1986) and measured (length and width) to the nearest 0.03 mm. Two otoliths were considered originating from the same fish if the difference in length was less than 0.2 mm (Falk & Durinck 1993). Length and weight of fish were estimated from otolith size using equations in Härkönen (1986).

Crustaceans were identified using keys in Keast & Lawrence (1990) and Hayward & Ryland (1995). For the main species present (*Parathemisto libellula*), body length was measured or reconstructed using regressions between the size of specific segments and total body length. Weight was estimated using an equation in Bradstreet (1976). Length and weight of squid was estimated from jaw size according to Clarke (1986).

2.6 Statistical methods

2.6.1 Quantifying stability of the water column

The Simpson index (S_i) is the vertical integration of the density variability for each station, thus

$$S_i = -\frac{g}{D}\int_0^D (\rho(z) - \rho_0) z dz$$

where g is the gravity of acceleration (9.81 m s^{-2}), D (m) is the minimum value of bottom depth and 100, $\rho(z)$ is the density (kg m^{-3}) at the depth z (m), and ρ_0 is the mean density for that particular profile. A high value of the Simpson index means that it takes more energy to mix the upper water column. It is thus more likely that plankton at the surface at stations with a high Simpson index will remain near the surface where there is sufficient light to grow, compared to locations with a low Simpson index.

2.6.2 Distance sampling and density surface modelling

During the aerial and ship surveys, counts of birds and marine mammals were recorded in bands around the transect line to allow abundance of the different species within the study area to be estimated by means of distance sampling (Buckland et al. 2001). Only the abundance estimates derived from the aerial survey are given in this report (chapters 3.4-3.5), as they are considered superior to the ship survey which covers a smaller area, spans a longer period of time, and are to some extent biased by the inability of the ship to travel in waters with high ice concentrations. The analyses were performed using the software Distance (Thomas et al. 2006a).

Following Buckland et al. (2001, 37), the density of sightings (clusters of animals) are given as $D = n / (2wL^* P_a)$, where n is the total number of sightings, w is the maximum search width, L is the total length of transect line and P_a is the proportion of objects in the surveyed area a that are detected. The abundance of individuals, N, is thus given as $N = A * E(s) * D$, where A is the size of the study area, and E(s) is the expected or mean cluster size.

We estimated P_a by fitting a detection function to the data grouped into distance bands. Half-normal, uniform and hazard rate were considered as candidates for the key functions with either a simple or a Hermite polynomial or a cosine series expansion. The most likely model was generally selected on the basis of Akaike Information Criterion (AIC), but goodness-of-fit chi-square test and visual inspection of the fit were also employed. There is often a tendency for small flocks to be missed at large distances, resulting in a positive bias in mean cluster size and an inflated abundance estimate. In case of a significant regression of log(cluster size) against detection probability ($\alpha = 0.05$), we therefore used an expected cluster size at distance 0 based on the regression instead of merely the mean cluster size.

To gain insight into spatial patterning within the study area, and to reduce the variance of the estimates, the study area was post-stratified into 17 geographic regions based on effort, ice cover and bathymetry. Most of the species were analysed according to this framework, and in these cases the global estimate was worked out by pooling the regional estimates. In order to obtain reliable abundance estimates within the regions, spatial patterning of flock size was carefully addressed beforehand. As abundance within a region is derived simply by multiplying the size of the region, the global mean (or expected) cluster size, and the estimated density of clusters within the region, a region with very large flocks may come out with a lower abundance estimate than a region of comparable size with only small flocks, if the encounter rate in the latter is just a little higher. For species with pronounced spatial patterning with regard to flock size, the data were thus stratified with regard to both geographic regions and flock size, if warranted by the sample size.

Using conventional distance sampling methods, the only way to increase the spatial resolution of the result is to increase the level of geographic stratification. However, as stratification mandates that effort is exerted in each stratum, there is a limit to the level of spatial resolution that can be achieved in this way. Besides estimating abundance, uncovering spatial patterns in the distribution of seabirds and marine mammals was a key aim of the project. It was therefore decided to combine the conventional distance sampling analyses with a density surface modelling approach. Density surface modelling allows a high degree of spatial resolution, the maintenance of an abundance estimate which takes into account imperfect detection as in conventional distance sampling, and the underpinning of the spatial patterns by explanatory variables (Hedley et al. 1999; Hedley & Buckland 2004; Hedley et al. 2004). We used a beta release of the software Distance (Thomas et al. 2006b), where density surface modelling is implemented as an analysis engine[1].

In preparation of the data for density surface modelling, the line transects were divided into 3 x 3 km squares, and within each square the number of sightings of the different species in question was determined. Further, x- and y-coordinates, depth, sea bottom slope and distance to coast were determined for each square using GIS software.

The first stage of the modelling process proceeds as conventional distance sampling, where P_a is estimated on the basis of a detection function fitted to the grouped distance data. We used half-normal and hazard rate as key functions without series expansion. Problems with positive bias in cluster size were resolved by including cluster size as a covariate affecting the scale of the key function, and in many cases the model fit (AIC) was also improved by incorporating observer identity as a covariate.

Based on P_a, the number of groups within each square is estimated, and this forms the response variable in the second stage of the modelling process. We used Generalized Additive Models (GAM) with x, y, depth, sea bottom slope and distance to coast as possible predictor variables, and selected models on the basis of Generalized Cross Validation scores (GCV). In some cases, the maximum number of knots in the smoothing terms was reduced due to over-fitting, resulting in the selection of a model with slightly higher GCV-scores than the same model with the default number of knots.

Finally the GAM models were used to make predictions over a grid of 3 x 3 km cells, populated with the explanatory variables and covering the study area. Most models performed poorly outside the range of observed data, and for this reason the prediction grid covers a somewhat smaller area than the regions used in the conventional distance sampling. Variance was estimated by performing 999 bootstrap replicates, and the reported confidence intervals include both the uncertainty associated with the GAM model and the fitting of the detection function.

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[1] We wish to sincerely thank Eric Rexstad, Centre for Research into Ecological and Environmental Modelling, University of St. Andrews, for patiently answering questions with regard to density surface modelling, and for continuously and rapidly fixing software problems encountered in Distance.

2.6.3 Analyses of factors affecting zooplankton and seabird distribution

As described above (section 2.1), data were collected on different scales. Physical and biological oceanographic data were collected at 116 stations, spaced approximately 10 km apart. In contrast, seabirds were counted along continuous transects between stations, and observations were summarised into 2-minute intervals. For each of these intervals, ice concentration was also noted. In order to examine factors affecting seabird distribution, we assigned each 2-minute interval to the nearest station, but only used intervals which were located less than 6 km from a station and sampled on the same day. A total of 2320 intervals were included; 3 of the 116 stations had no associated bird count intervals, and for the remaining stations the number of intervals ranged from 4 to 53 (mean 20).

Biomass of each zooplankton taxon or developmental stage was estimated as the product of mean individual biomass and the counted number of individuals in the sample, and scaled to the unit mg C m^{-2} in the top 50 m of the water column. Total zooplankton biomass was then estimated as the sum of all groups. A few taxa were not included in the estimate of total biomass, either because they had not been measured or because length-weight regressions could not be found. However, expert opinion suggests that the groups included are likely to account for 95-98% of true total mesozooplankton biomass. Larger and more mobile forms are more likely to have escaped the sampling gear and are thus not included in the biomass estimates. No forms larger than 10 mm were regularly caught, although a few individual euphausiids, amphipods and chaetognaths of this size did occur.

The frequency distributions of plankton biomass estimates were highly right-skewed, i.e. dominated by many small values and a few very large values. Analyses of factors affecting the spatial distribution of the most important taxa (*Calanus* copepods, shrimp larvae and barnacle nauplii, see Results) were therefore performed on ln-transformed data. *Calanus* copepods occurred at all stations, and barnacle nauplii were only absent at one station (87). In contrast, shrimp larvae were absent at 49 of the 116 stations. The analysis was therefore carried out both for the 67 stations with shrimp larvae and for all stations, in the latter case using an $\ln(x+1)$ transformation. The following predictors were used in the models: Simpson index, depth, integrated chlorophyll concentration and mean ice concentration for all 2-minute intervals associated with the station. Integrated chlorophyll was only available for 86 of the 116 stations, so all analyses were performed both with and without this predictor. Standard multiple regression was used, with all possible models being fitted, excluding interactions. Model 'quality' was assessed with Akaike's Information Criterion corrected for sample size (AIC_c; Burnham & Anderson 2002), and the importance of each predictor was assessed as evidence ratios, i.e. the ratio of the summed Akaike weights (Burnham & Anderson 2002) of all models including the predictor to the summed weight of all models not including it. Evidence ratios > 10 indicate moderate to strong support for the predictor.

Seabird data from the ship-based survey were used to identify factors affecting spatial distribution, as these data were collected simultaneously with potential explanatory oceanographic variables. Four seabird species occurred sufficiently regularly to warrant analysis: northern fulmar (*Fulmarus glacialis*), black-legged kittiwake (*Rissa tridactyla*), thick-billed murre and black guillemot (*Cepphus grylle*). The frequency distribution of seabird counts was even more strongly right-skewed than for zooplankton, and did not fit any parametric distribution (including the negative binomial). In particular, there were a very large number of zeros, combined with occasional very high counts. Such frequency distributions are very difficult to analyse. As a first step, we used the presence or absence of each seabird species in each 2-minute interval as the response parameter. Logistic regression was used to analyse these data, with bird data aggregated at the station level where all predictors (except ice concentration) were measured. The following predictors were used in the models: Simpson index, depth, mean ice concentration, *Calanus* biomass, shrimp larvae biomass and barnacle nauplii biomass. Because field work took place before egg laying and all seabird species included roost on the water, we did not include distance to coast or nearest major colony as a predictor (see Discussion). An iterative backwards stepwise model selection strategy was used, starting from a model including all predictors but no interactions. The least significant predictors were sequentially eliminated from the model, with a threshold type III *P* value of 0.15. At each step, previously eliminated predictors were tested again, with a threshold *P* value for inclusion of 0.1. To correct for overdispersion, a scale factor was applied, calculated as the deviance of the starting model divided by its residual degrees of freedom.

3 Results

3.1 Physical oceanography

Relatively low values of sea surface salinity were observed in Disko Bay, and at the westernmost stations within the marginal ice zone, e.g. stations 91-99, and stations 108-111 (**Figure 3.1**). In south-eastern Baffin Bay there was a general tendency for a decrease in sea surface salinity with increasing latitude and time. The sea surface salinity was typically 33.7 at the northern part of Store Hellefiskebanke (stations 24-28), and 33.5 along the east-west transects west of Disko Island (stations 55-60, stations 62-66, and stations 75-79). An estimate of the decrease in sea surface salinity with time can be found by comparing two neighbouring transects, e.g. stations 49-54 with stations 112-116. These two transects show that sea surface salinity decreased about 0.3 salinity units over six days (from April 28 to May 4). Mixed layer depth observed within the region ranged between 5 and 150 m (**Figure 3.2**). Mixed layer depth at stations in south-eastern Baffin Bay mostly ranged from 25-50 m, and was below 25 m in Disko Bay. As for the sea surface salinity, it seems that mixed layer depth also decreased with time. Söderkvist et al. (2006) showed that upwelling of warmer and more saline waters from below during late winter and spring 1997 and 2005 was the main driving mechanism for decreases in sea surface salinity and mixed layer depth. Melting of sea ice and solar heating are two other possible mechanisms for changes in hydrography during spring. Detailed studies of individual vertical profiles of temperature and salinity are needed to identify the driving mechanism for changes in sea surface salinity and mixed layer depth.

The highest values of the Simpson index, and thus the most stratified areas, were found in Disko Bay and at the northernmost stations west of Disko Island (**Figure 3.3**). Low values of the Simpson index were observed at Store Hellefiskebanke, west of Disko Island, and at the entrance of Disko Bay. However, since Store Hellefiskebanke is relatively shallow, plankton remained in the photic zone despite the well-mixed water column indicated by a low Simpson index.

Vertical profiles of density (measured as sigma-theta which is the density [kg m^{-3}] – 1000) along an east-west transect south of Disko Bay entrance on April 27 showed some horizontal variation in surface density, while the density at 100 m depth was about 1027.2 kg m^{-3} at all stations along the transect (**Figure 3.4**). The strength of the vertical stratification and mixed layer depth affects the concentration of chlorophyll (see below). Along a transect sampled on May 10 approximately 50 km further south, the density in the surface layer and at 100 m depth were similar to the earlier transect (compare panels a and c in **Figure 3.4**). It seems that horizontal variability in density in this region is larger than temporal changes over this two-week period.

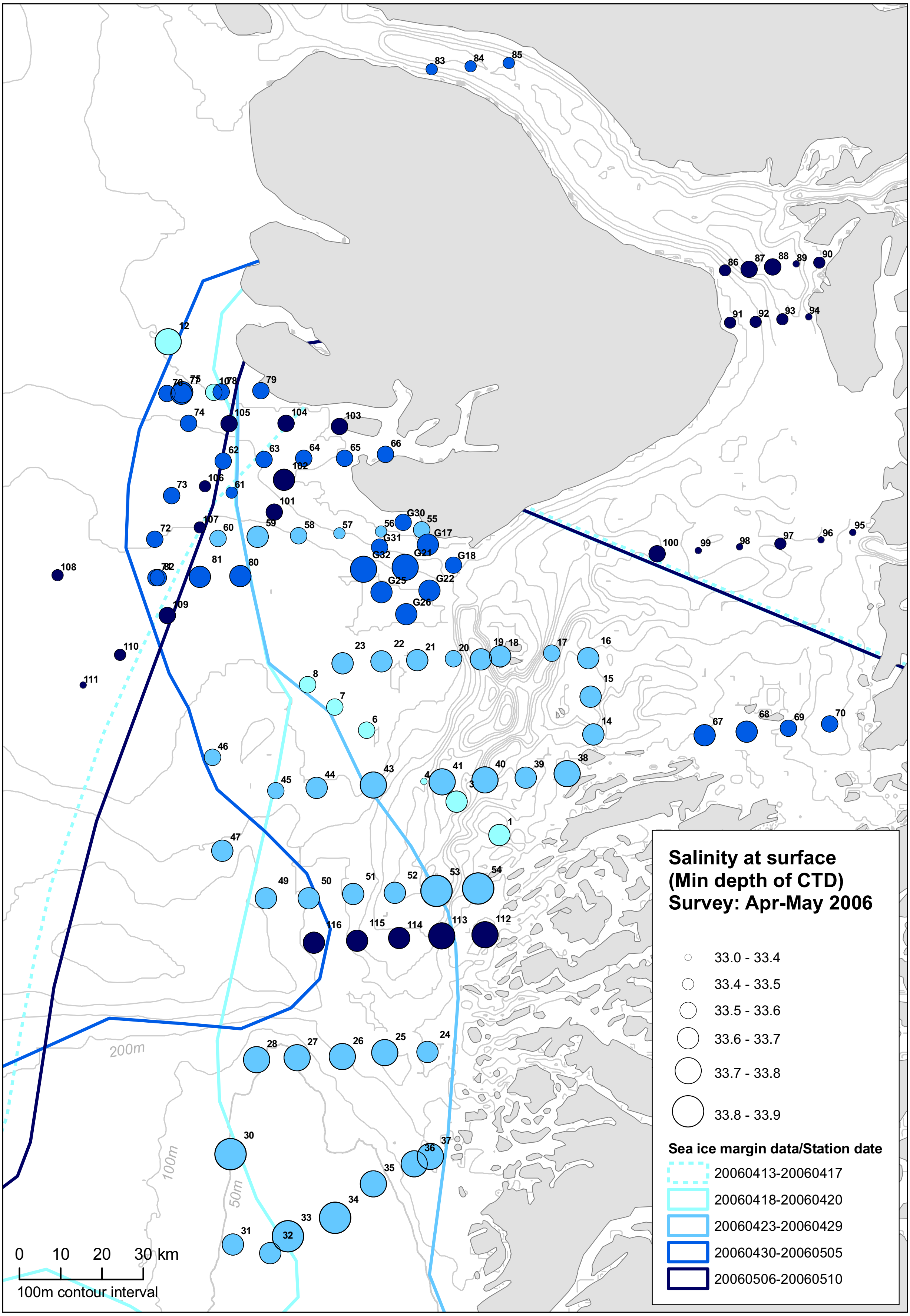


Figure 3.1. Map showing observed sea surface salinity. The circles indicate the location of the stations, circle size indicates salinity interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

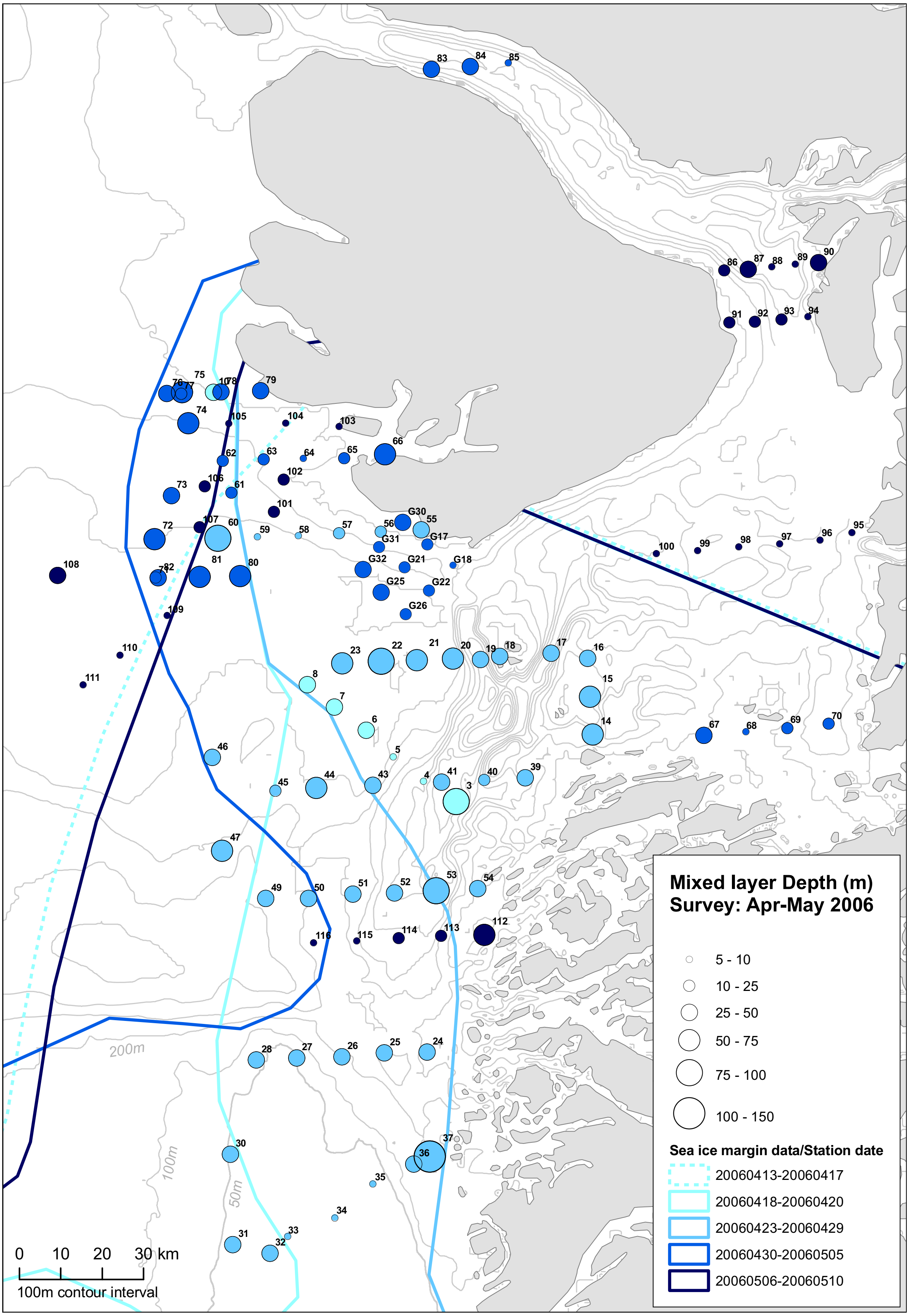


Figure 3.2. Map showing observed mixed layer depth. The circles indicate the location of the stations, circle size indicates mixed layer interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

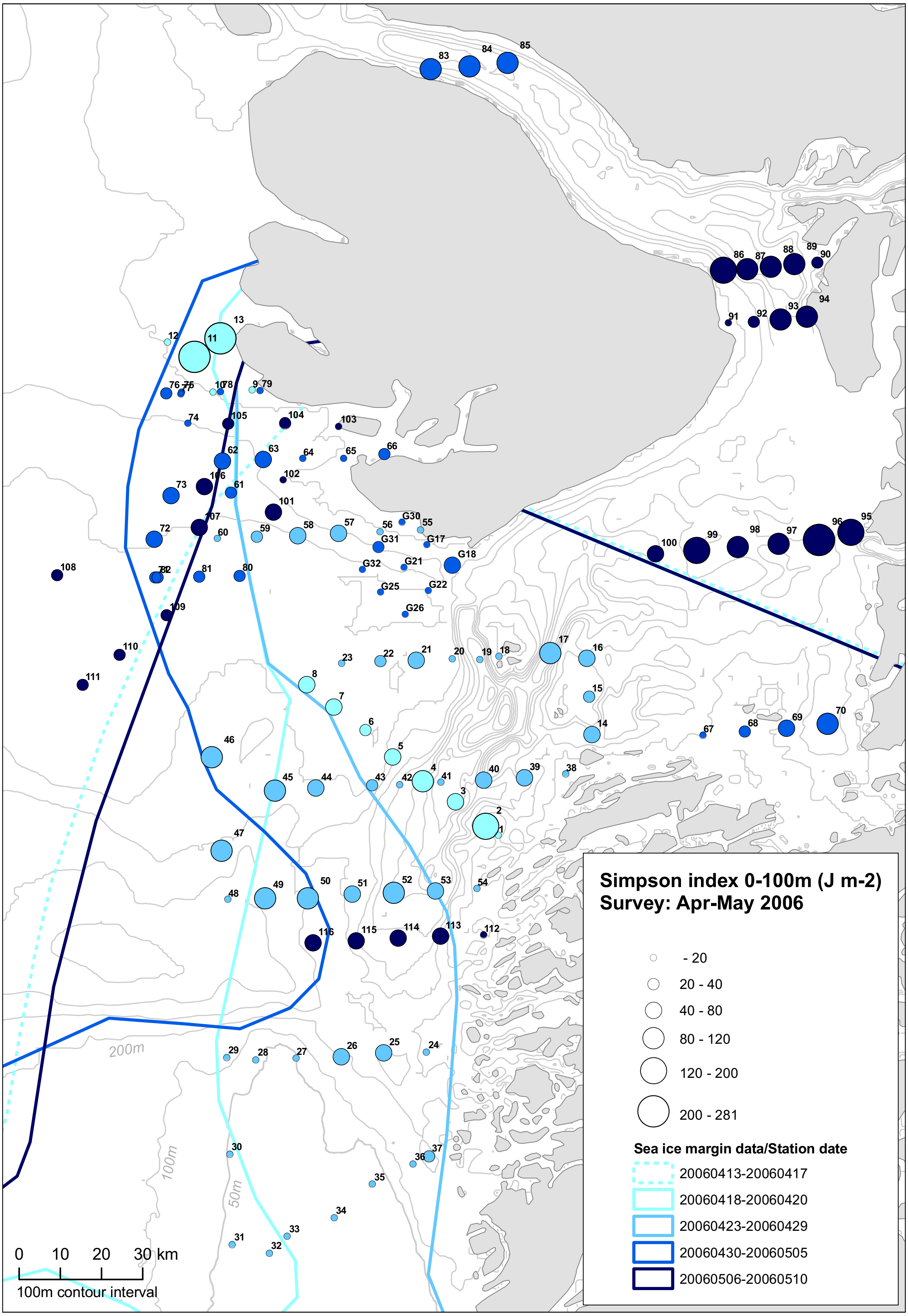


Figure 3.3. Map showing observed Simpson index. The circles indicate the location of the stations, circle size indicates Simpson index interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

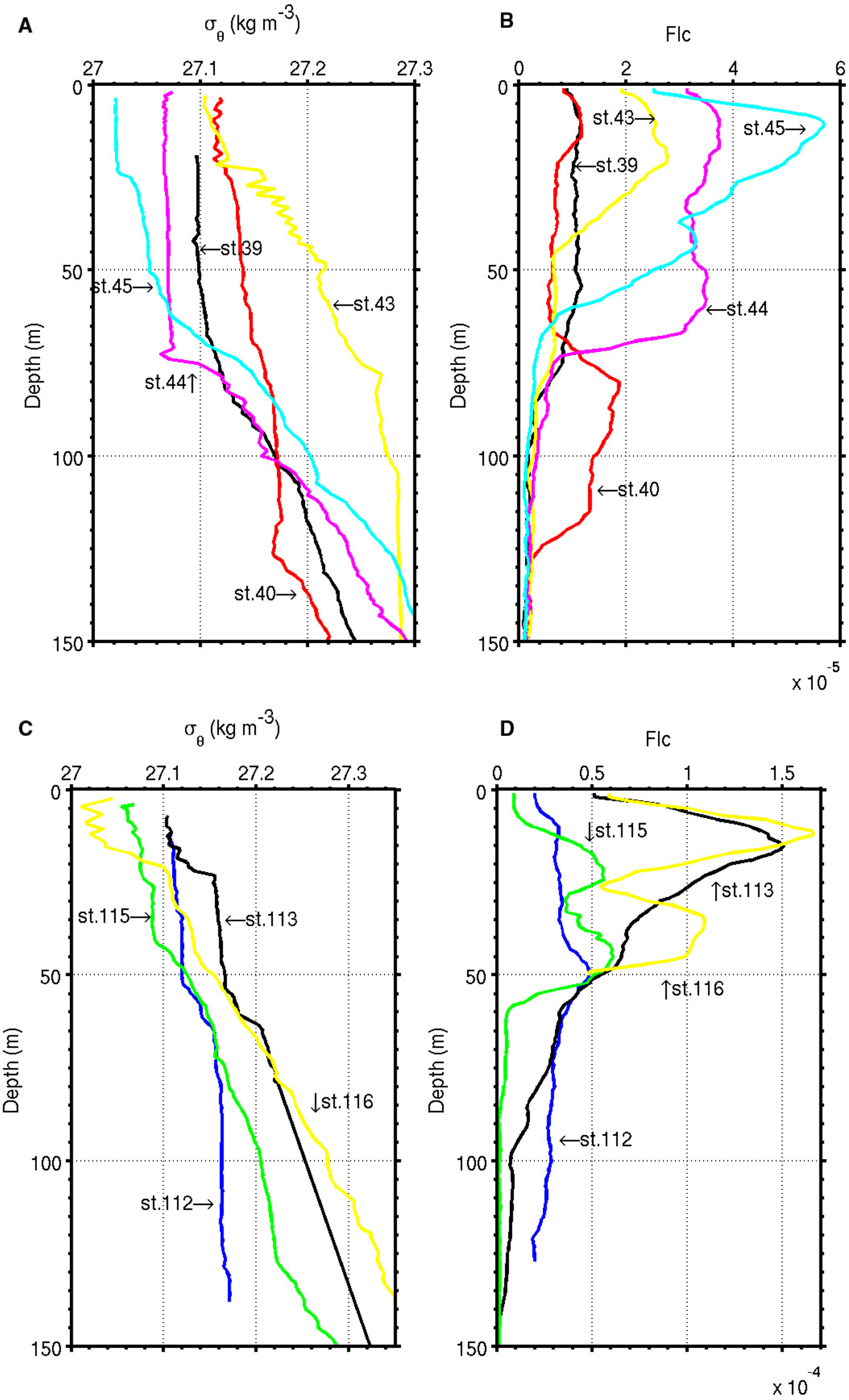
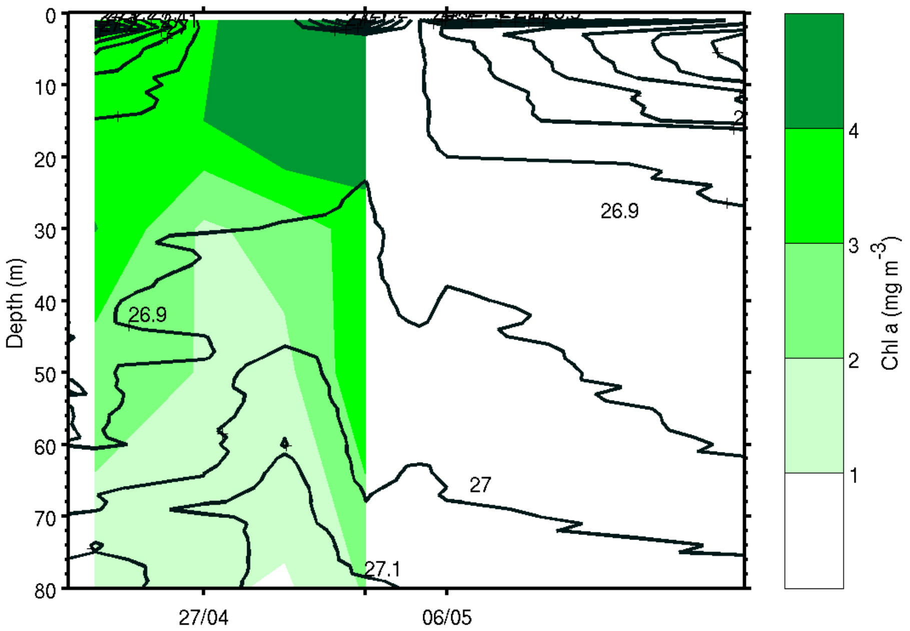


Figure 3.4. Vertical profiles of sigma-theta (density [kg m^{-3}] – 1000) and fluorescence along two east-west transects southwest of the mouth of Disko Bay. The station number is shown in each figure, see **Figure 3.1** for the location of each station. Panels a) and c) show the vertical variation of sigma-theta, and figures b) and d) show the vertical variation of fluorescence.

Time series of vertical stratification at the permanent station S of Disko (69°15’N, 53°33’W) showed that during the period April 22 - May 3 there was an upwelling of dense (more saline) water from below 80 m up to about 20 m depth (**Figure 3.5**). After May 3, the dense water descended to greater depths. The density of the surface layer decreased, due to both decreased salinity and increased temperature. The change in surface hydrography suggests that solar heating was strong enough in early May to melt sufficient amounts of sea ice to change the vertical stratification, and in turn inhibit vertical mixing.

Figure 3.5. Time series of sigma-theta (density [kg m^{-3}] – 1000) and chlorophyll at the permanent station Qeqertarsuaq (69°15'N, 53°33'W) for the period April 22 – May 17. Black lines show sigma-theta, and the green colour scale shows the concentration of chlorophyll.



Nitrate (NO_3^-), phosphate (PO_4^{3-}) and silicate (SiO_4^{3-}) are three main nutrients for the primary producers. During the initiation of the plankton bloom the nutrients are rapidly consumed by the primary producers, and concentrations decrease in the surface layer. At the beginning of the expedition (19 April – 28 April), nitrogen available to the primary producers (mainly NO_3^- and NH_3^+) southwest of Disko Bay entrance (stations 2-54) was typically 7-9 µmol l^{-1} (**Figure 3.6**). For the same period, the concentration was below 4 µmol l^{-1} at most stations at Store Hellefiskebanke, and above 9 µmol l^{-1} west of Disko Island. During the following two days the sum of nitrate and ammonium west of Disko Island decreased from above 9 to about 6 µmol l^{-1}, and to below 4 µmol l^{-1} in early May. In Disko Bay the sum of nitrate and ammonium was below 4 µmol l^{-1} at most stations. The concentration of phosphate showed a similar horizontal pattern as the sum of nitrogen and ammonium (**Figure 3.7**). Silicate (SiO_4^{3-}) is another important nutrient that some primary producers use. Thus horizontal and temporal variability of silicate may give an estimate of the relative importance of specific species. The variability of silicate was much lower than for nitrogen and phosphate (**Figure 3.8**). Low values were found at Store Hellefiskebanke. High values were found in the marginal ice zone around mid-May.

3.2 Phytoplankton biomass (chlorophyll)

Surface concentrations of chlorophyll were measured at stations indicated with circles on **Figure 3.9**, and from satellites. We use these two types of information to identify highly productive regions. For reference, the winter concentrations in the region are typically 0.05 mg m^{-3}, and 2 mg m^{-3} during the early stage of plankton bloom.

The overall distribution of chlorophyll during the sampling period was that *in situ* surface chlorophyll (1 m) as well as integrated chlorophyll (from surface to max sampling depth) showed relatively high levels in central and southern part of Disko Bay as well as west of southern Disko (west of Disko Fjord), (**Figure 3.9** and **Figure 3.10**). On the northern part of Store Hellefiskebanke chlorophyll levels were also relatively high. In the deep water "wedge" between the bank and the coast east and north-east of Store Hellefiskebanke there were higher levels in the deep water layers (integrated chlorophyll) compared to the surface chlorophyll. Chlorophyll levels were relatively low at the Disko Bay entrance (Aaasiaat-Qeqertarsuat) and west of the entrance (**Figure 3.9**). At some stations, there were high surface values and low values of integrated chlorophyll, and vice versa. This difference can be explained by low concentration in chlorophyll at the surface, and larger concentrations at greater depths, or vice versa. It seems that low surface and large subsurface concentrations were most pronounced during the period 27 April – 4 May (stations 37-76). Conversely, there are stations where most chlorophyll in the water column is concentrated to the surface, e.g. stations 34, 70, and 103. The vertical profiles of density and fluorescence, which is a linear function of chlorophyll concentration) along two transects south west of Disko Bay entrance presented above (stations 39-45 and stations 112-116) showed that chlorophyll was more concentrated to the surface layer at stations with strong stratification near the surface (**Figure 3.4**). This was particularly clear at the end of the cruise. Stations with weak stratification in the upper 100 m had much lower concentrations of chlorophyll (e.g. stations 39, 40, and 112). The high concentration at station 44, where the upper 80 m were rather well mixed, needs further analyses to explain. The effect of ice concentration on chlorophyll concentration is difficult to quantify. Remote sensing data of ice concentration are rather coarse, and may not be well related to chlorophyll concentration. However, the low concentration of chlorophyll observed at the westernmost stations located within the ice (stations 11-13, 72, 75, 76, and 108) may be due to high ice concentration.

Comparisons between chlorophyll distribution measured from the vessel and surface chlorophyll measured from satellite (MODIS and SeaWiFS data) show that the *in situ* measurements from the vessel generally had higher values and with less temporal progression. The satellite data are more sensitive to the vertical distribution of the algae and there seems to be a lack of proper calibration of the actual values derived from the satellite with the standard data processing we have used. The absolute values of the remote sensing data will therefore not be used in the present study. The relative values are however used to identify high and low productive areas in regions with no *in situ* observations. Future analyses will examine the quality of the remote sensing data of chlorophyll.

Surface chlorophyll measured from satellite (MODIS and SeaWiFS data) showed a clear increase in surface chlorophyll levels from the first week of the survey (15-22 April) to the last week (9-16 May); compare **Figure 3.11** and **Figure 3.14**. In about half of the area there was nearly a ten time increase in chlorophyll levels. Maximum levels were located in central Disko Bay, at the northern Store Hellefiskebanke and west of southern Disko corresponding to the vessel data, but the satellite data also showed high levels west of the Disko Bay entrance in the last week.

The large increase in chlorophyll concentration with time during the sampling period makes it difficult to identify highly productive regions. We therefore divided the data into four one-week periods (**Figure 3.11** – **Figure 3.14**). Along the transect located south-west of Disko Bay entrance (stations 1-8) (**Figure 3.11**) the concentration at the first station near the coast was just below 2 mg m^{-3} (sampled 18 April), and between 2 and 5.2 mg m^{-3} at stations 2-9 (sampled 19 April). Thus it seems that the primary production was in the early stage of a plankton bloom in this region. The 8 day mean value of the remote sensing data of surface chlorophyll (mg m^{-3}) for the period 15 – 22 April showed relatively high values of chlorophyll at Store Hellefiskebanke and lower concentration in Disko Bay and westwards towards the ice edge. Some local areas with high chlorophyll concentration were also observed at Disko Bay entrance and central Disko Bay. The areas with relative large concentration of chlorophyll indicate that the plankton bloom had already started before 15 April, or was just about to start. For the period 23 – 30 April the *in situ* chlorophyll concentration were above 2 mg m^{-3} at almost all stations (**Figure 3.12**). At Store Hellefiskebanke the surface chlorophyll concentration was typically 10-25 mg m^{-3}. North of Store Hellefiskebanke, west of Disko Bay and west of Disko Island the concentration ranged between 1.5 and 13.3 mg m^{-3}, with the highest values west of Disko Island within the marginal ice zone. The remote sensing concentration of chlorophyll was largest at Store Hellefiskebanke and the central part of Disko Bay. During the period 1 – 8 May the *in situ* chlorophyll concentration was typically 10-20 mg m^{-3} west of Disko Island and in the eastern part of Disko Bay (**Figure 3.13**). The highest remote sensing values were observed in Store Hellefiskebanke and central Disko Bay. During the period 9 – 16 May the *in situ* observations at the ice edge west of Disko Bay were typically 15-20 mg m^{-3}, and around 2 mg m^{-3} to the west (**Figure 3.14**), where the ice concentration was higher (not shown). The observed concentration of chlorophyll northwest of Store Hellefiskebanke varied between 1.6 and 10 mg m^{-3}. The chlorophyll concentrations using remote sensing data for this period were high at the Store Hellefiskebanke, central part of Disko Bay and outside Disko Bay. Low values were observed south-west of Disko Bay, west of Disko Island, and in the northern channel connecting the eastern part of Disko Bay with Baffin Bay (the Vaigat).

3.3 Zooplankton

3.3.1 Distribution, composition and total biomass

The mesozooplankton (i.e. the zooplankton organisms > 200 μm) in the upper 50 m of the study area was dominated by large calanoid copepods. In biomass terms, the three *Calanus* species were the most important contributors to the surface copepod community and between them accounted for on average 64% of total mesozooplankton biomass (*C. finmarchicus* 42%, *C. hyperboreus* 15%, *C. glacialis* 4%). *Calanus* copepods migrate from deep overwintering zones offshore to the surface layer prior to the spring phytoplankton bloom, so that they can spawn, graze and refuel their lipid stores during the peak of the spring bloom. Biomass estimates of the three *Calanus* species were highly correlated among stations (all $r > 0.64$, all $P < 0.0001$), and therefore we only present total *Calanus* biomass here. *Calanus* biomass was notably low around Store Hellefiskebanke, but otherwise high in most areas (**Figure 3.15**). The only other important contributors to total mesozooplankton biomass were zoea larvae of deep-water shrimp (*Pandalus borealis*) (12%) (**Figure 3.16**), and barnacle nauplii (16%) (**Figure 3.17**).

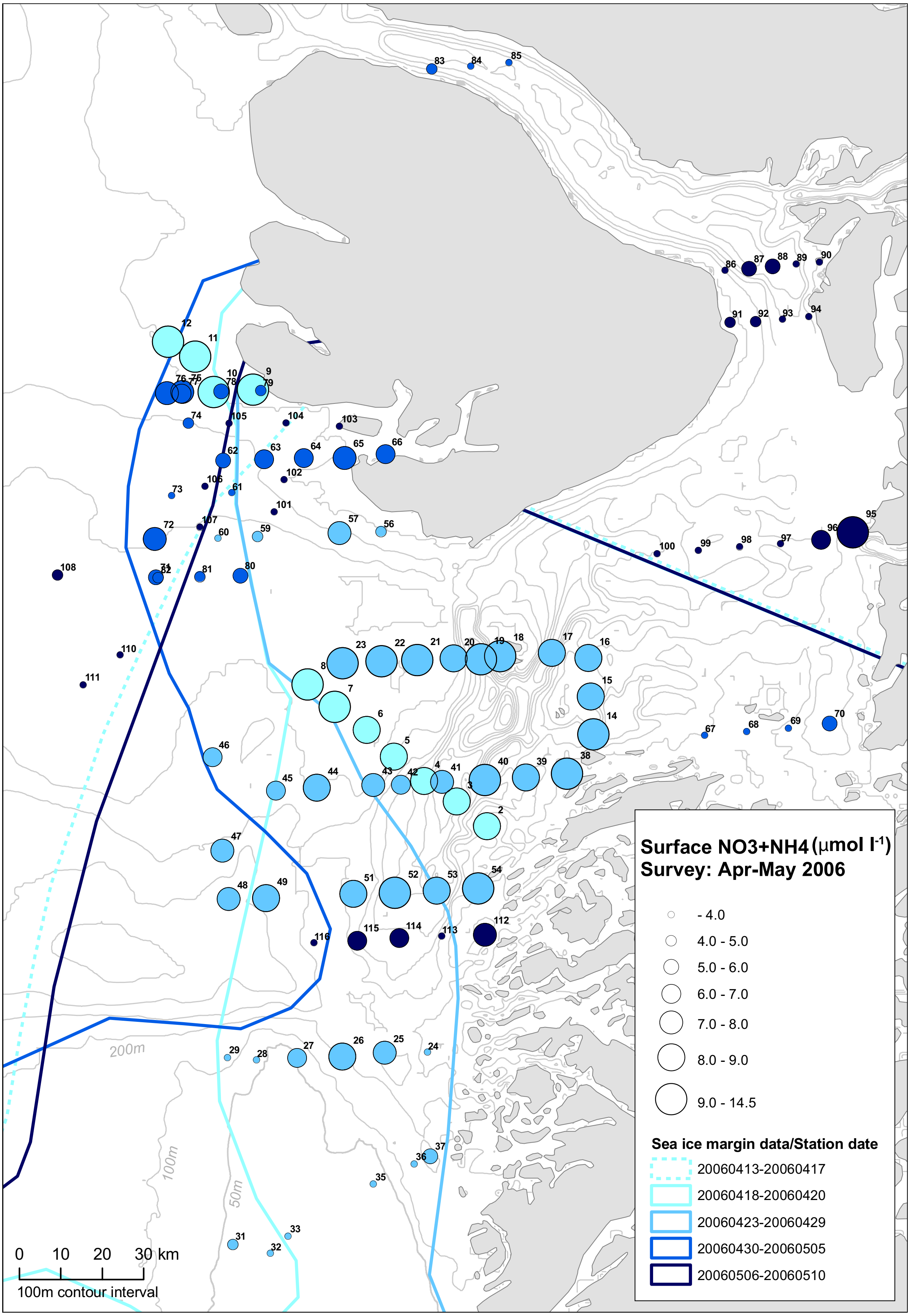


Figure 3.6. Map showing observed nitrate and ammonium concentrations. The circles indicate the location of the stations, circle size indicates concentration interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

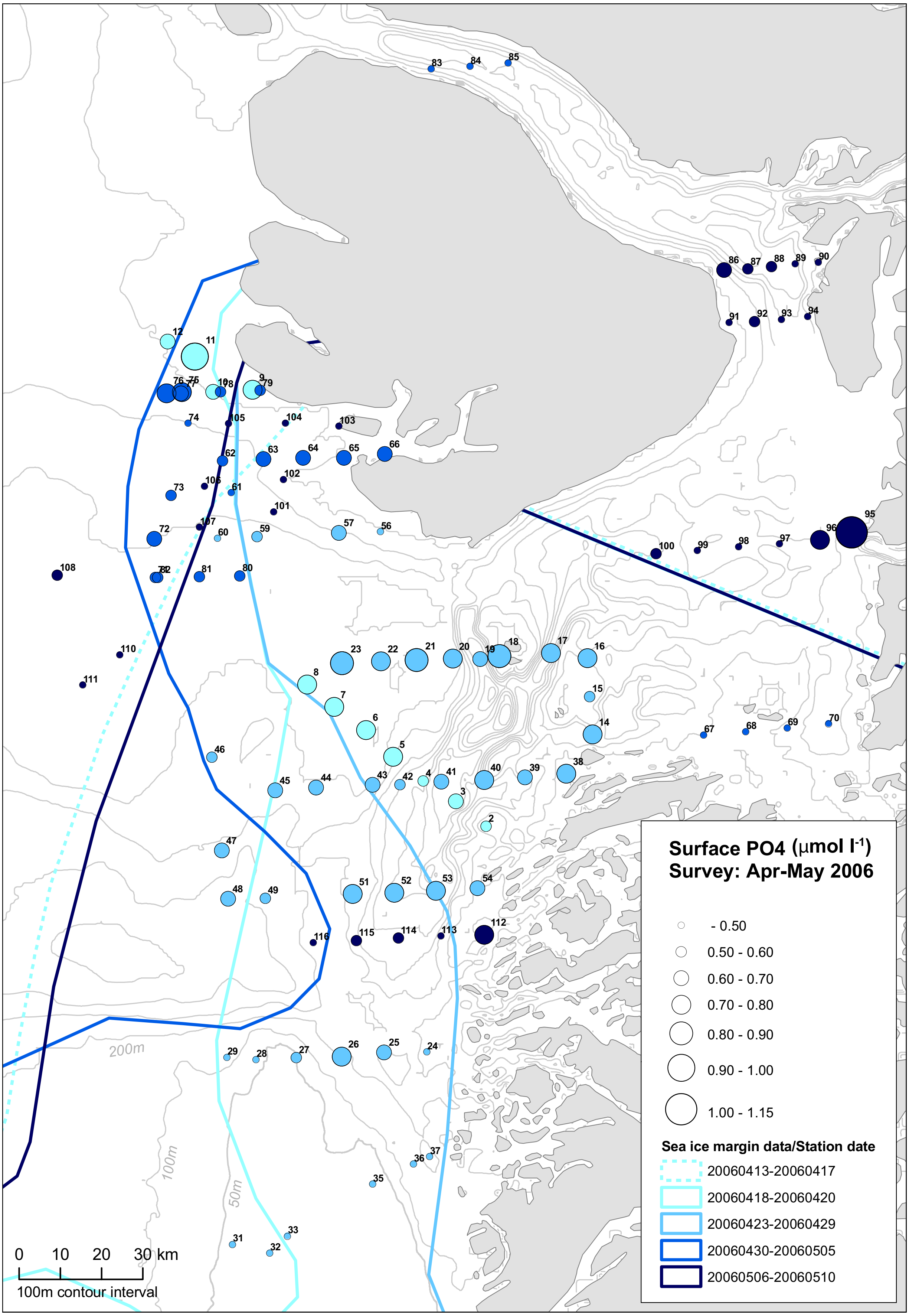


Figure 3.7. Map showing observed phosphate concentrations. The circles indicate the location of the stations, circle size indicates concentration interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

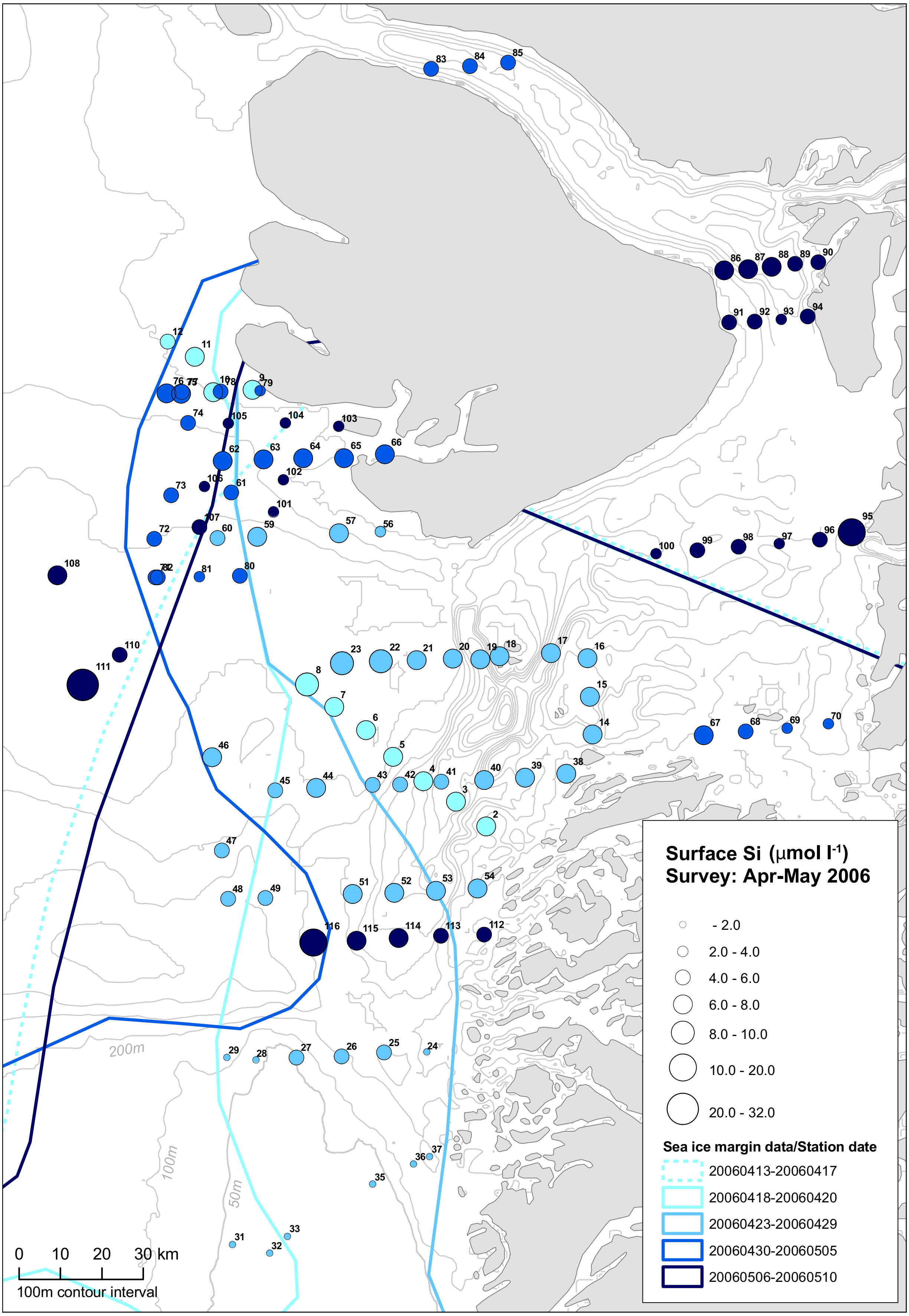


Figure 3.8. Map showing observed silicate concentrations. The circles indicate the location of the stations, circle size indicates concentration interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

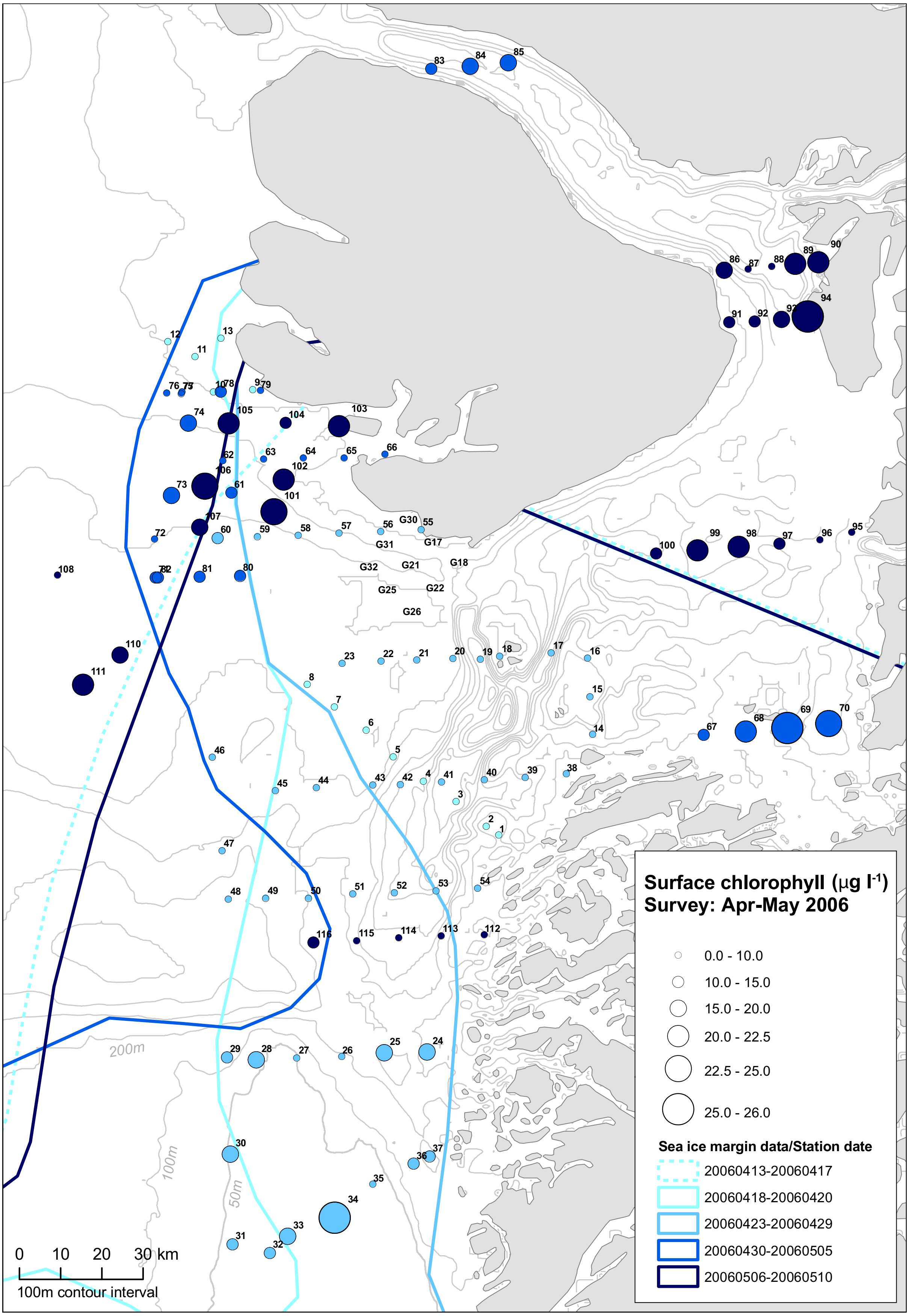


Figure 3.9. Map showing observed surface chlorophyll concentrations. The circles indicate the location of the stations, circle size indicates concentration interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

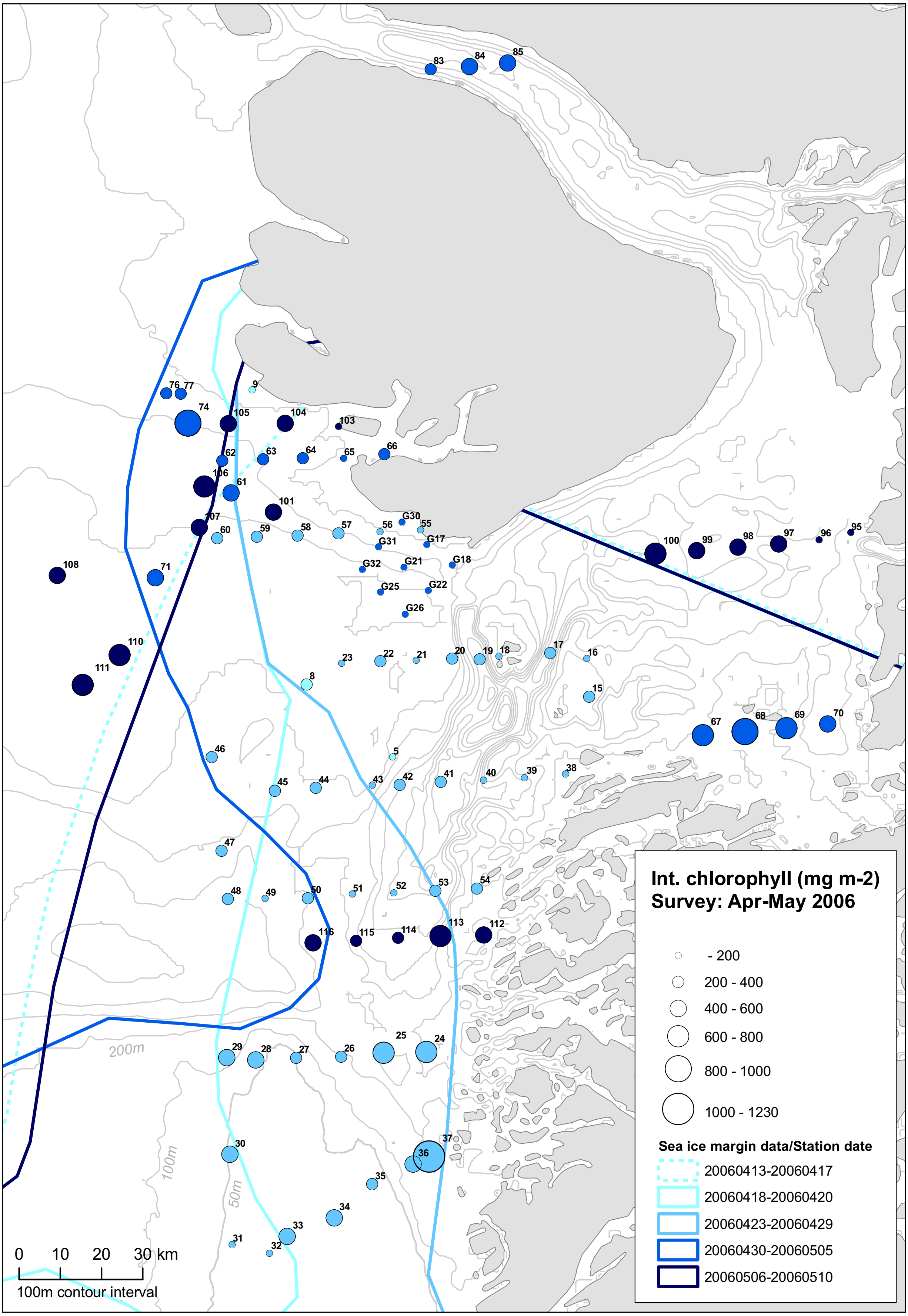


Figure 3.10. Map showing observed integrated chlorophyll concentrations. The circles indicate the location of the stations, circle size indicates concentration interval, and the colour indicates in which time period the observations were collected. The coloured lines indicate the location of the ice edge for different time periods, with the specific time period indicated by the colour.

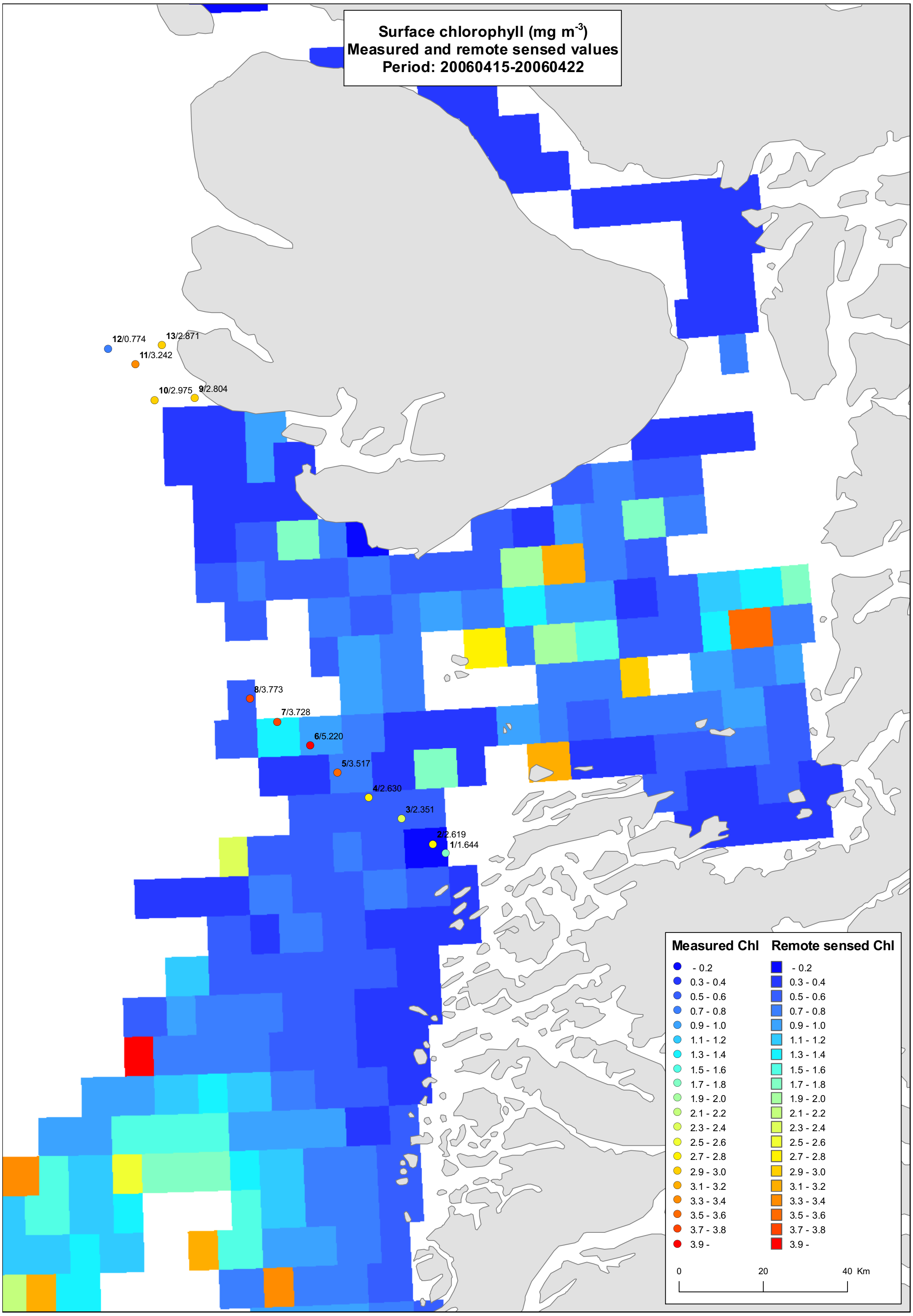


Figure 3.11. Map showing surface concentration of chlorophyll (mg m^{-3}) for the time period 15 – 22 April. The colour map shows the concentrations using remote sensing data. The coloured dots give the *in situ* concentration. The numbers right next to the coloured dot indicate the station number and the absolute value of the concentration. Note that the colour scale for remote sensing data and *in situ* observations is the same.

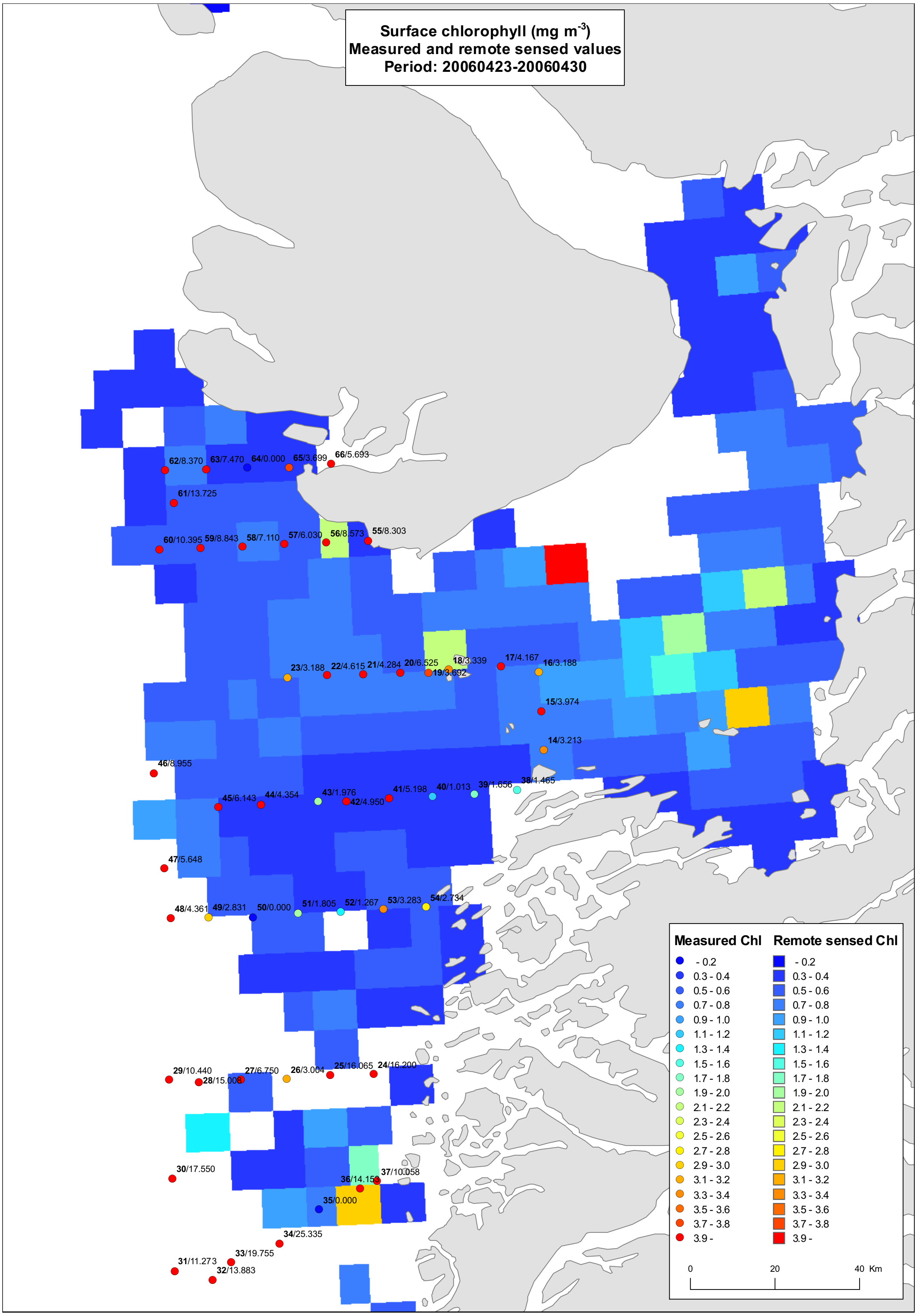


Figure 3.12. Map showing surface concentration of chlorophyll (mg m^{-3}) for the time period 23 – 30 April. The colour map shows the concentrations using remote sensing data. The coloured dots give the *in situ* concentration. The numbers right next to the coloured dot indicate the station number and the absolute value of the concentration. Note that the colour scale for remote sensing data and *in situ* observations is the same.

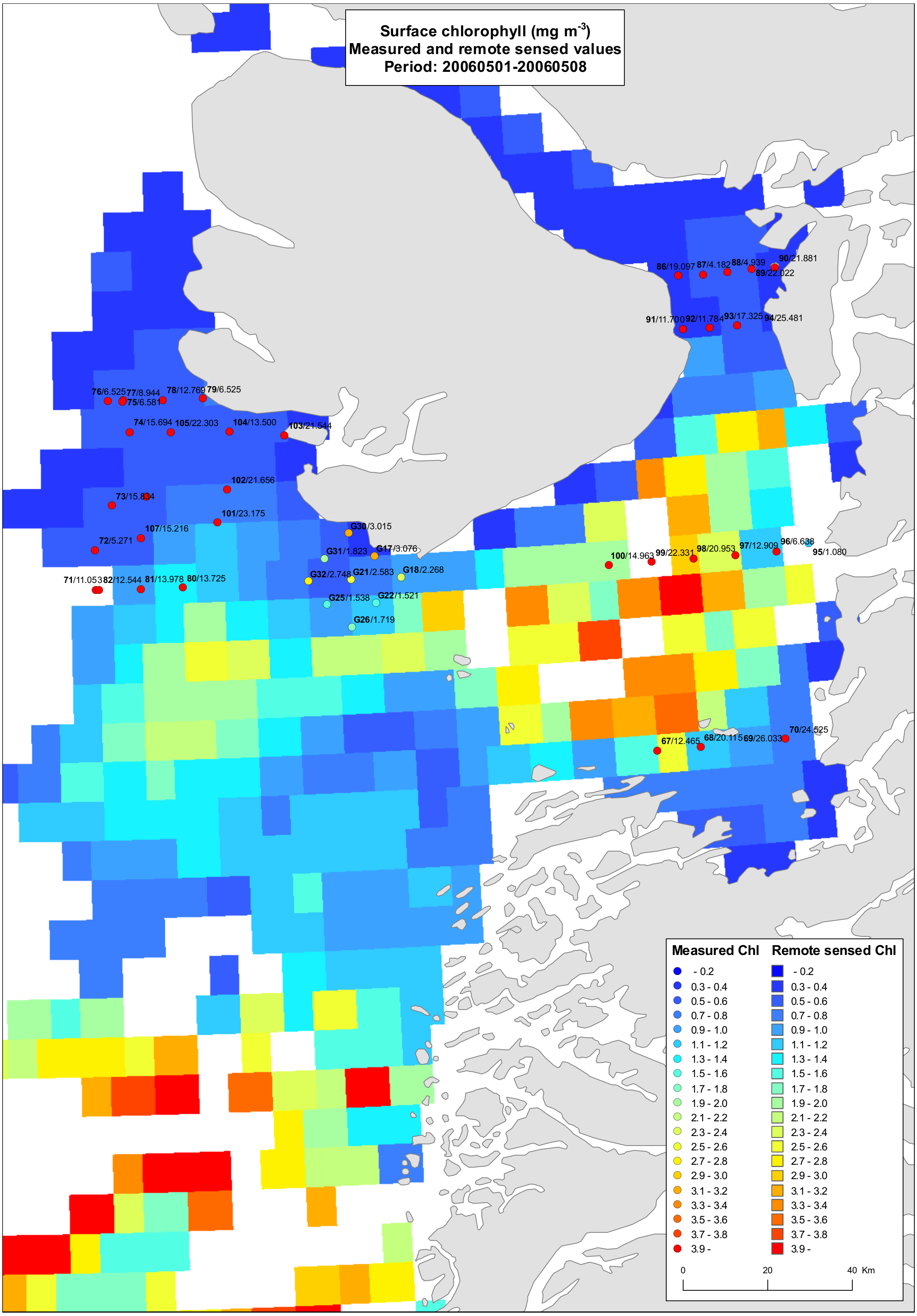


Figure 3.13. Map showing surface concentration of chlorophyll (mg m^{-3}) for the time period 1 – 8 May. The colour map shows the concentrations using remote sensing data. The coloured dots give the *in situ* concentration. The numbers right next to the coloured dot indicate the station number and the absolute value of the concentration. Note that the colour scale for remote sensing data and *in situ* observations is the same.

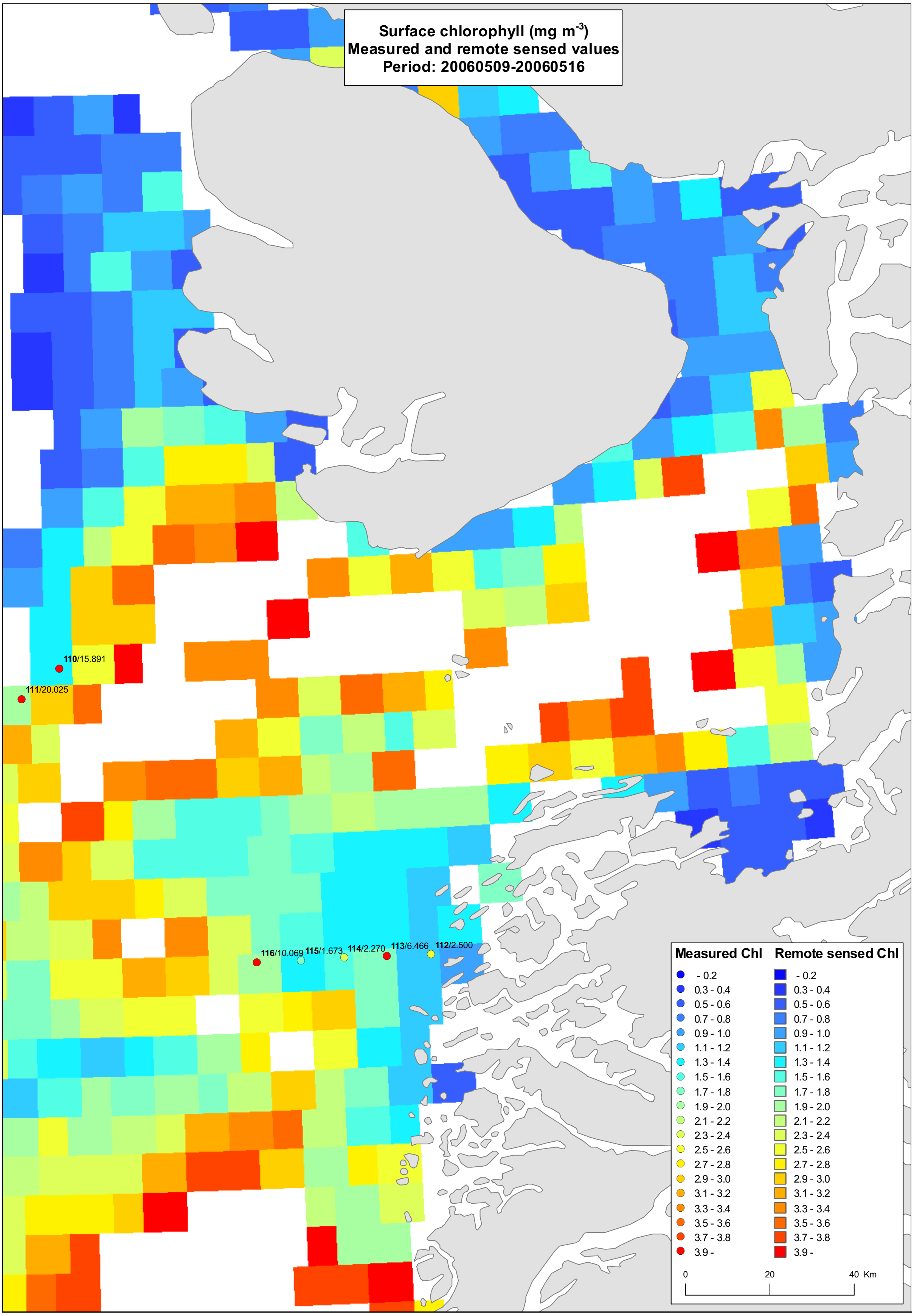


Figure 3.14. Map showing surface concentration of chlorophyll (mg m^{-3}) for the time period 9 – 16 May. The colour map shows the concentrations using remote sensing data. The coloured dots give the *in situ* concentration. The numbers right next to the coloured dot indicate the station number and the absolute value of the concentration. Note that the colour scale for remote sensing data and *in situ* observations is the same.

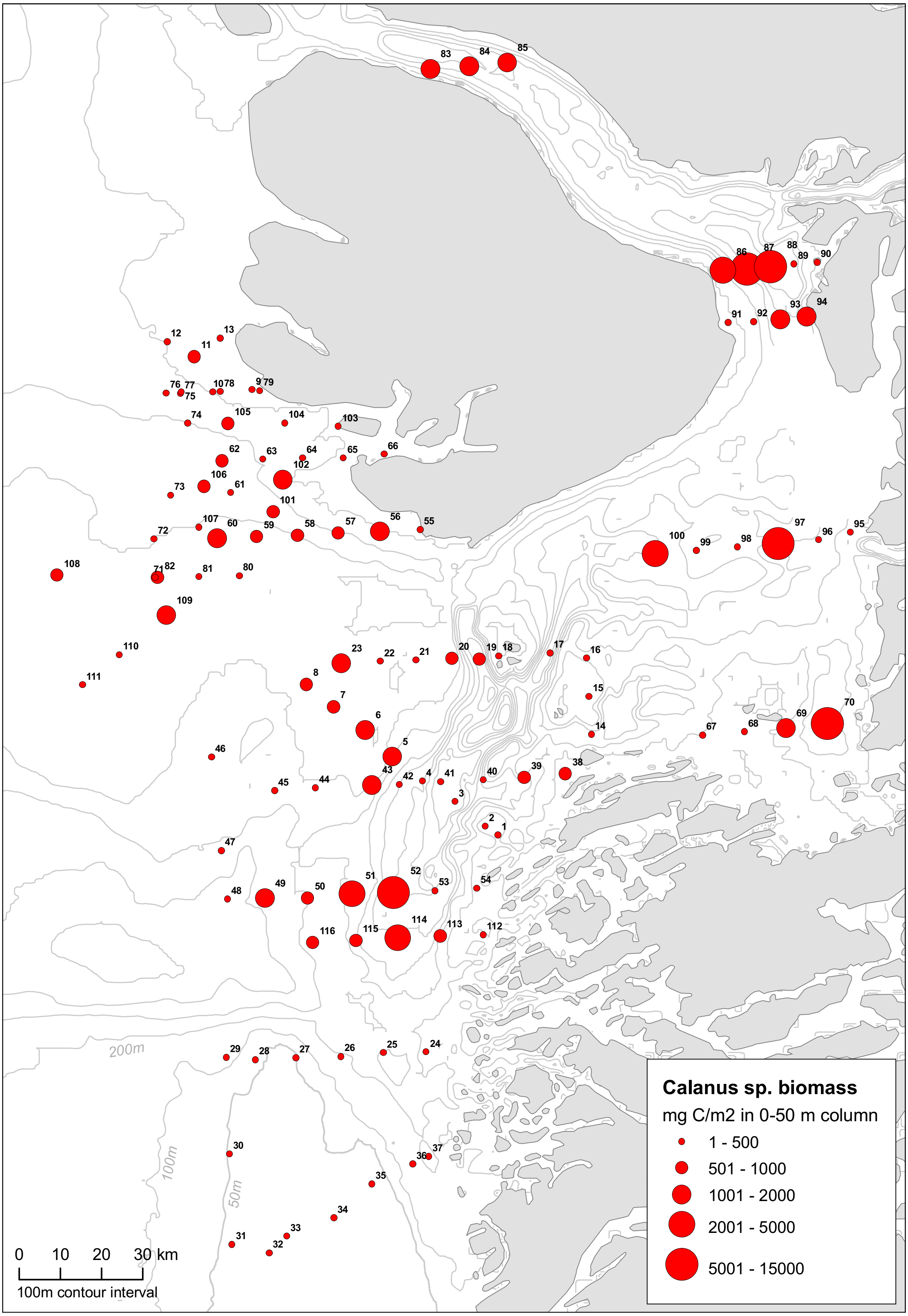


Figure 3.15. Biomass of *Calanus* copepods (all species and stages) at the 116 oceanographic stations.

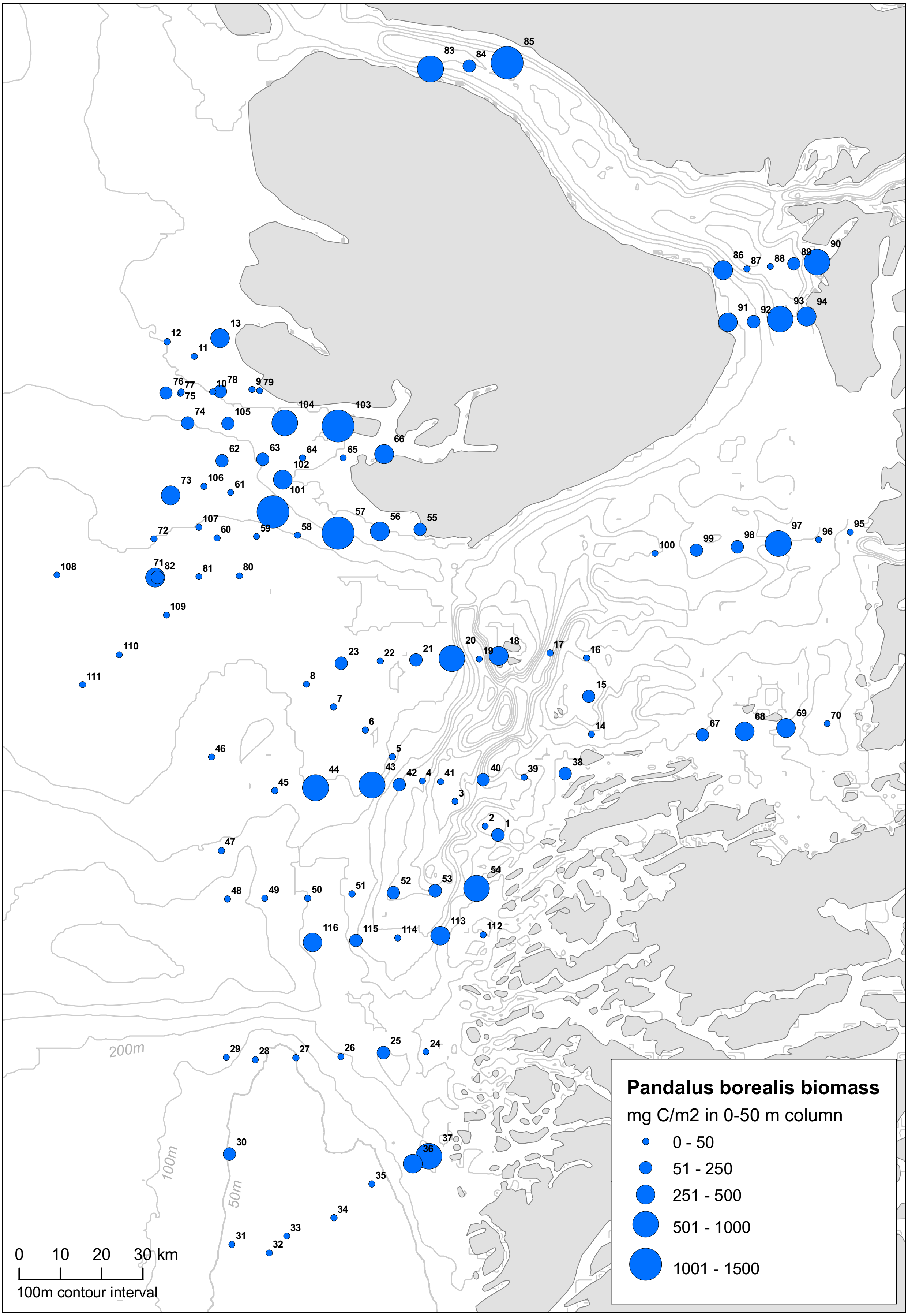


Figure 3.16. Biomass of deep-water shrimp (*Pandalus borealis*) larvae at the 116 oceanographic stations.

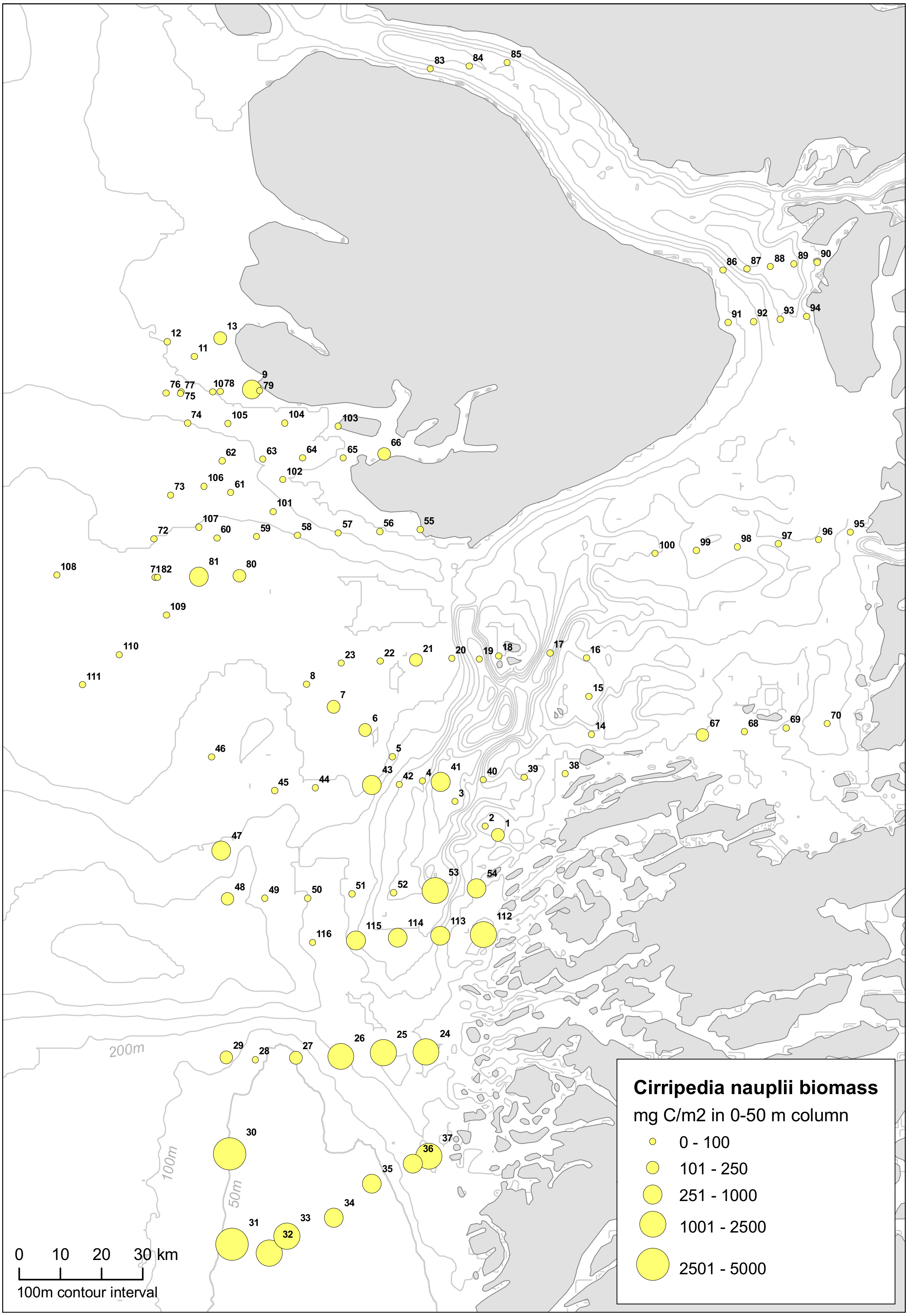


Figure 3.17. Biomass of barnacle (Cirripedia) nauplii at the 116 oceanographic stations.

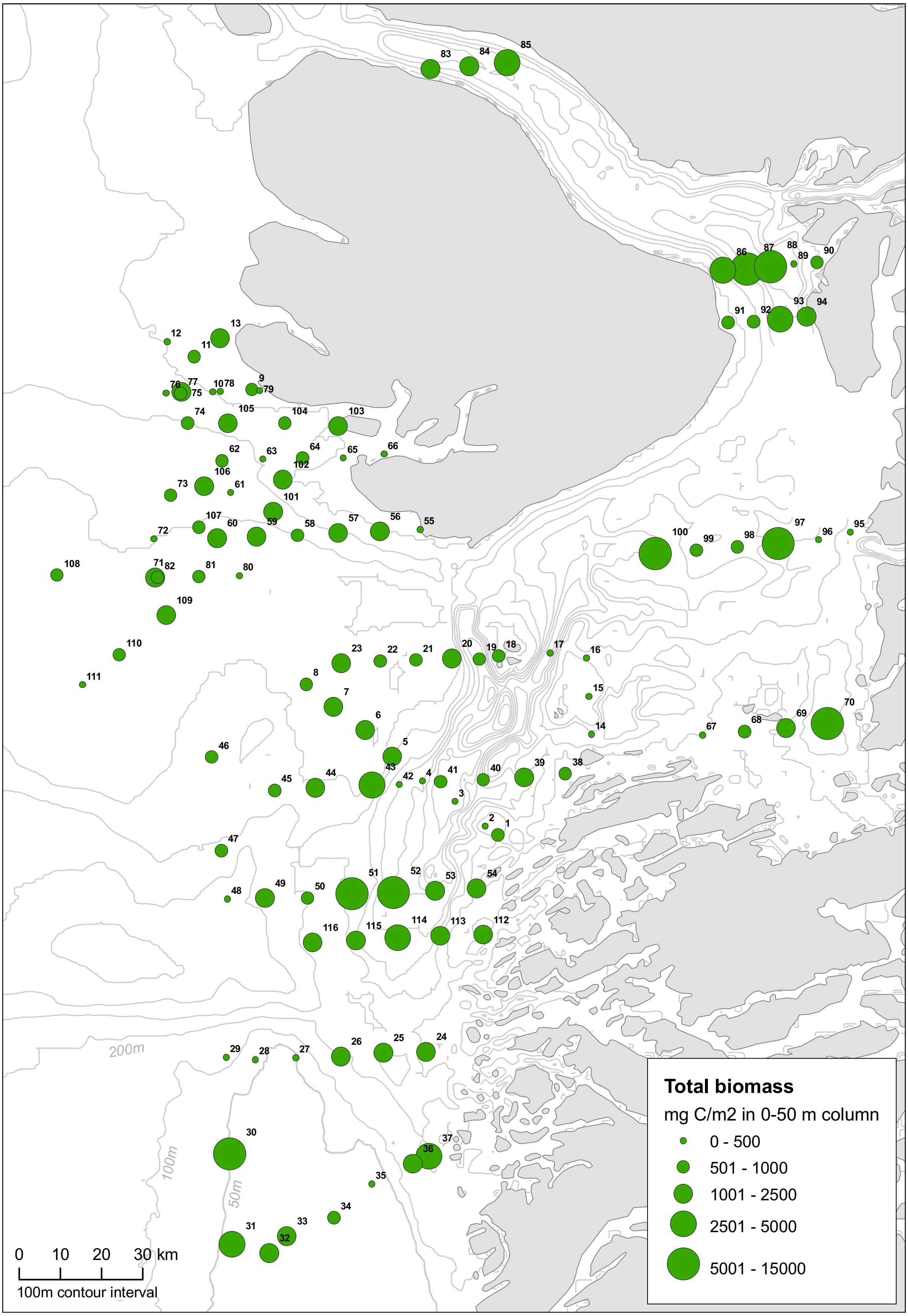


Figure 3.18. Total estimated mesozooplankton biomass at the 116 oceanographic stations.

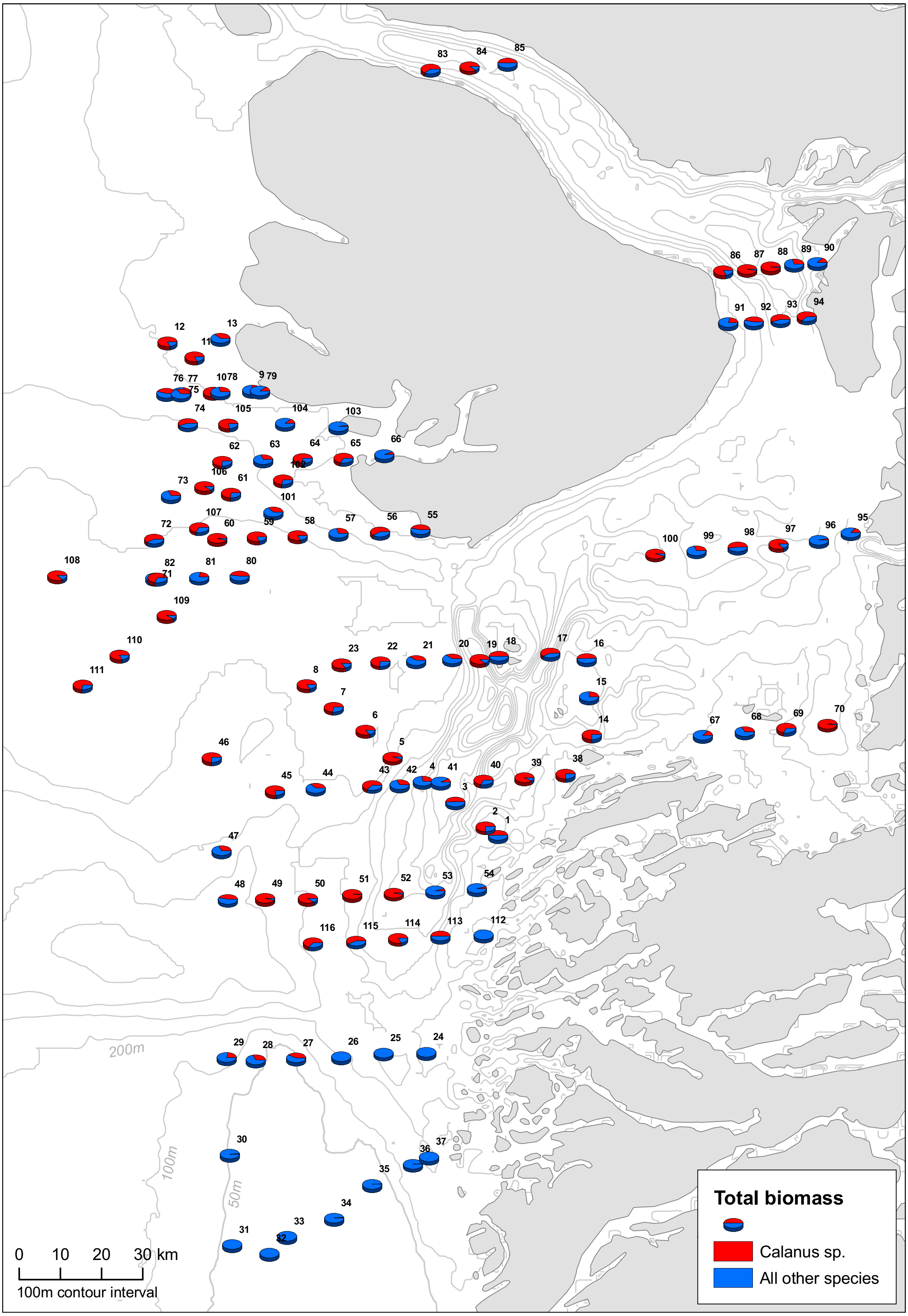


Figure 3.19. The contribution of *Calanus* copepods to total mesozooplankton biomass at the 116 oceanographic stations.

Figure 3.20. Abundance of fish larvae (# m^{-2}) at the 116 oceanographic stations.

Total mesozooplankton biomass in the upper 50 m varied widely, between 36 and 14400 mg C m^{-2}, but showed few clear spatial trends (**Figure 3.18**). *Calanus* copepods constituted a high proportion of total biomass at most stations, except around Store Hellefiskebanke (**Figure 3.19**).

All fish larvae recorded during the survey were sand lance. Length ranged from 4 to 22 mm, with a mean of 9.5 mm. Densities were generally low; most larvae occurred around and north of Store Hellefiskebanke, with very low densities west of Disko and in inner Disko Bay (**Figure 3.20**).

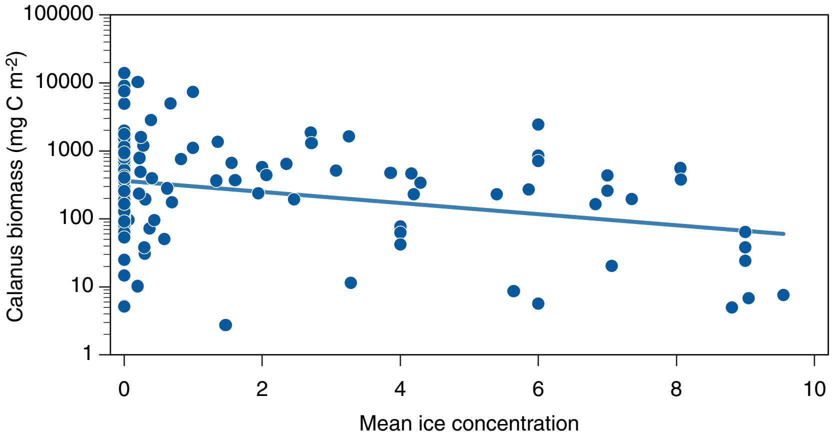
3.3.2 Factors affecting spatial distribution

For *Calanus*, the results differed somewhat depending on whether data from all stations or only from stations with chlorophyll data were included (**Table 3.1**). However, mean ice concentration was consistently selected as an important predictor of *Calanus* distribution. **Figure 3.21** shows the relationship between *Calanus* biomass and mean ice concentration, using data from all stations ($F_{1,112} = 10.49$, $P = 0.0016$, $R^2 = 8.6\%$). There was thus substantial evidence that *Calanus* biomass was smaller in areas where ice concentration was high, although much unexplained variation remained.

Table 3.1. Evidence ratios for covariates potentially affecting spatial distribution of *Calanus* biomass (ln-transformed). Values > 10 indicate moderate to strong evidence for the covariate. Bold values indicate covariates included in the model selected by AIC$_c$.

Covariate	All stations	Stations with chlorophyll data
Simpson index	2.32	0.44
Depth	1.53	4.50
Integrated chlorophyll	-	0.33
Mean ice concentration	28.75	9.04

Figure 3.21. The relationship between ln-transformed *Calanus* biomass and mean ice concentration.



For shrimp larvae, results also differed depending on whether data from all stations or only from stations with chlorophyll data were included (**Table 3.2**). Mean ice concentration was consistently selected as an important predictor of shrimp larvae distribution, but chlorophyll also seemed to be important. **Figure 3.22** shows the relationship between shrimp larvae biomass and mean ice concentration, using data from all stations where any larvae occurred ($F_{1,63} = 10.50$, $P = 0.0019$, $R^2 = 14.3\%$), and **Figure 3.23** shows the relationship with integrated chlorophyll, using data from stations where this covariate was measured ($F_{1,51} = 5.10$, $P = 0.0282$, $R^2 = 9.1\%$). Results were very similar, although slightly less clear, when stations with no shrimp larvae were included. There was thus substantial evidence that shrimp larvae biomass was smaller in areas where ice concentration was high and some evidence that it was higher in areas with high chlorophyll concentration.

Table 3.2. Evidence ratios for covariates potentially affecting spatial distribution of *Pandalus* shrimp larvae biomass (ln-transformed). Values > 10 indicate moderate to strong evidence for the covariate. Bold values indicate covariates included in the model selected by AIC_c.

Covariate	All stations	Stations with chlorophyll data
Simpson index	0.75	0.33
Depth	0.57	0.48
Integrated chlorophyll	-	12.44
Mean ice concentration	62.50	92.78

Figure 3.22. The relationship between ln-transformed *Pandalus* biomass and mean ice concentration.

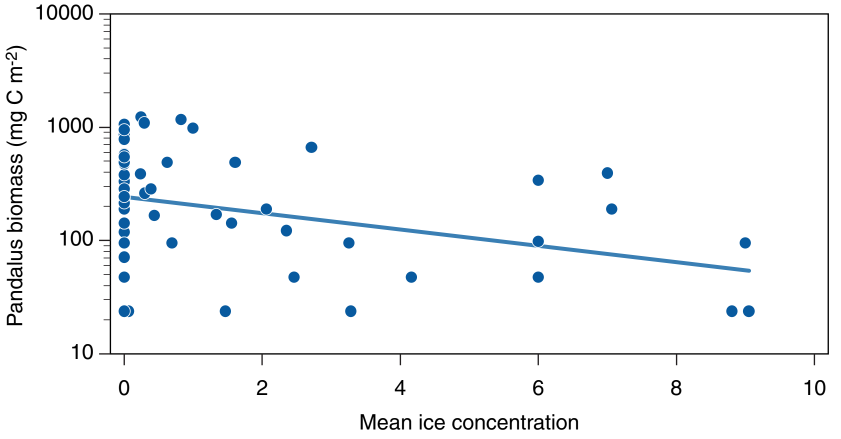
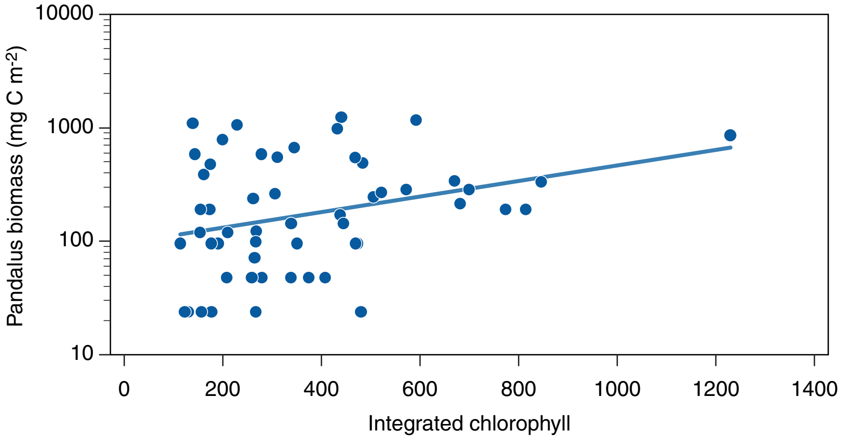


Figure 3.23. The relationship between ln-transformed *Pandalus* biomass and integrated chlorophyll.



For barnacle nauplii, there was very strong evidence that both water column stability (Simpson index) and mean ice concentration affected biomass (**Table 3.3**). **Figure 3.24** and **Figure 3.25** show the relationships between barnacle nauplii biomass and respectively mean ice concentration and Simpson index, using data from all stations (mean ice concentration: $F_{1,111} = 16.20$, $P = 0.0001$, $R^2 = 12.7\%$; Simpson index: $F_{1,111} = 12.88$, $P = 0.0005$, $R^2 = 10.4\%$). Barnacle nauplii thus tended to occur in large numbers where stratification was weak and ice concentration high, conditions typical of a pre-bloom situation.

Table 3.3. Evidence ratios for covariates potentially affecting spatial distribution of barnacle nauplii biomass (ln-transformed). Values > 10 indicate moderate to strong evidence for the covariate. Bold values indicate covariates included in the model selected by AIC$_c$.

Covariate	All stations	Stations with chlorophyll data
Simpson index	819.51	2187.05
Depth	0.41	1.57
Integrated chlorophyll	-	0.49
Mean ice concentration	4329.17	2033.93

Figure 3.24. The relationship between ln-transformed barnacle nauplii biomass and mean ice concentration.

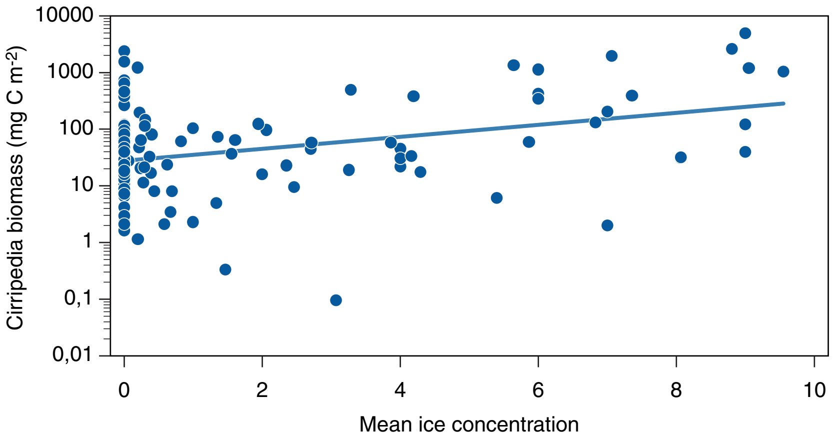
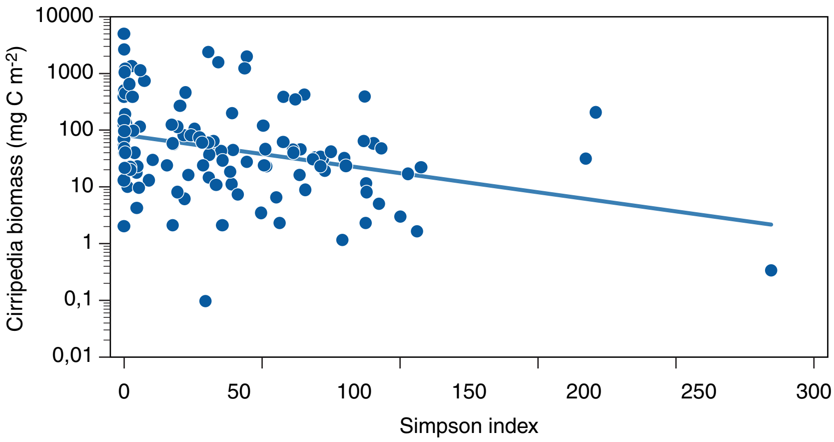


Figure 3.25. The relationship between ln-transformed barnacle nauplii biomass and Simpson index.



3.4 Seabirds

3.4.1 Distribution and abundance estimates

Table 3.4 summarises the seabirds and other birds observed during the aerial and ship surveys. The distribution and abundance of the most common and important species is mapped and described below. Besides the species shown on maps, great cormorants (*Phalacrocorax carbo*), mallards (*Anas platyrhynchos*), red-breasted mergansers (*Mergus serrator*) and purple sandpipers (*Calidris maritima*) were observed frequently in coastal waters and on the shores. Glaucous gulls (*Larus hyperboreus*), Iceland gulls (*Larus glaucoides*) and great black-backed gulls (*Larus marinus*) were common also mainly in coastal waters. Very few ivory gulls (*Pagophila eburnea*) were seen, all in areas with ice. A white-tailed eagle (*Haliaeetus albicilla*) was seen in the southern part of Disko Bay on 28 April. Ravens (*Corvus corax*) were occasionally seen far out in the drift ice, the most remarkable was seen on 6 May near the border to Canada in an area with many polar bear (*Ursus maritimus*) tracks and approx. 205 km southwest of Disko Island. On 8 May two flocks of white-fronted geese (*Anser albifrons*) migrated northwards just south of Svartenhuk Peninsula.

Table 3.4. Birds observed on and off survey transects.

Species	Aerial survey		Ship survey	
	On transect (6220 km)	Off transect	On transect (1782 km)	Off transect
Great northern diver		1		
Northern fulmar	2796	225	3017	2931
Great cormorant	79		6	51
White-fronted goose	124			
Mallard	67	11		
Long-tailed duck	2631	12	33	180
Common eider	18892	12000	2177	2306
King eider	57100	81	1932	7060
Common/King eider			5000	
Red-breasted merganser	13	2		
Purple sandpiper	79			23
Pomarine skua				5
Arctic skua	1			3
Lesser black-backed gull			1	
Glaucous gull	62		47	94
Iceland gull	55		369	527
Glaucous/Iceland gull	3459	652		
Great black-backed gull	34		6	11
Black-legged kittiwake	4910	58	280	1648
Ivory gull	4			
Unidentified gull	1200			
Arctic tern			59	85
Thick-billed murre	34150	256	7292	9436
Razorbill			3	
Black guillemot	1889	25	692	811
Little auk			32	123
Atlantic puffin				4
Northern wheatear				2
Common raven			15	14
Snow bunting			1	5

Abundance estimates were based on the aerial survey (**Table 3.5**). In total about one million seabirds were estimated to be present in offshore areas of the survey region in late April and early May 2006. Approx. 42% of these were thick-billed murres and another 39% were king eiders (*Somateria spectabilis*).

Table 3.5. Abundance estimates of the most common seabirds, derived from stratified distance sampling and from density surface modelling. The two estimates are not directly comparable, as the density surface model covers a smaller area (88452 km^2 vs 105711 km^2, see figures). Estimates for king eider only refer to Store Hellefiskebanke.

Species	Distance sampling		Density surface model	
	Estimate	95% C.I.	Estimate	95% C.I.
Northern fulmar	89012	64461 – 122910	95820	69087 – 132898
King eider	400000	227000 – 709000		
Black-legged kittiwake	76772	52118 – 113088	84593	60412 – 118452
Thick-billed murre	429814	345555 – 534619	338940	257716 – 445765
Black guillemot	20818	14481 – 29927	19266	15153 – 24495

Northern fulmar

Fulmars were observed almost throughout the surveyed region. They were only absent from areas with solid drift ice, but even here single birds were seen migrating over the ice (**Figure 3.26** and **Figure 3.28**).

The stratified distance sampling abundance estimate was approx. 89,000. This is only a fraction of the population breeding in the Baffin Bay area (in NW Greenland > 80,000 pairs (but quality of this estimate is very low and population probably much bigger) and NE Canada ~ 200,000 pairs, Gaston et al 2006, Bakken et al. 2006).

The result of the density surface model is shown in **Figure 3.27**. Higher densities are apparent in two areas of Disko Bay. Both are well-known areas for the species, and associated with well-known hydrodynamic discontinuities – the upwelling area west of the mouth of the bay and the Jakobshavn Isfjord glacier. High fulmar densities are also apparent in the drift ice of the south-western part of the survey area.

Long-tailed duck (*Clangula hyemalis*)

This species was mainly found on the shallow part of Store Hellefiskebanke where approx. 2000 birds were counted on aerial transects (**Figure 3.29**, see also **Figure 3.30**). A few flocks were moreover seen at ice-free coasts here and there.

King eider

Except for a few flocks, king eiders were observed on the well-known wintering area on the shallow part of Store Hellefiskebanke (**Figure 3.31** and **Figure 3.32**, cf. Mosbech & Johnson 1999). More than 55,000 were observed on aerial transects, and the total population in this area was estimated at 400,000 birds. This number is similar to earlier estimates (Boertmann et al. 2004, Mosbech et al. 2006a, 2007).

Common eider (Somateria mollissima)

Large numbers of common eiders were observed both on the aerial transects (30,892), between the aerial transects (31,163) and on the ship-based transects (4,183). Almost all common eiders were observed along the coasts (**Figure 3.33** and **Figure 3.34**). The highest concentrations were observed on the west coast of Disko, in the archipelago between Aasiaat and Kangaasiaq and in south-western Disko Bay, where it is known that common eiders stage on the spring migration to colonies further north in Greenland and Canada (Mosbech et al. 2006b) while relatively few eiders breed in these areas.

Black-legged kittiwake

Kittiwakes were mainly observed in the areas with more or less open waters (**Figure 3.35** and **Figure 3.38**). The stratified distance sampling abundance estimate was approx. 77,000 birds.

The result of the density surface model is shown in **Figure 3.36** and **Figure 3.37**. Particularly in inner Disko Bay and in the waters off Kangaatsiaq, high concentrations were apparent, but densities were also high in the north-eastern part of the survey area. There was a marked difference in flock size between inner Disko Bay and the waters of Baffin Bay. In inner Disko Bay the concentrations were mainly from single birds and small (<5) flocks), while larger flocks dominated in the waters of Baffin Bay (**Figure 3.36** and **Figure 3.37**). The inner Disko Bay is close to the main breeding sites in the region – the Torsukattaq and Ritenbenk, where approx. 20,000 pairs bred in 2005 (Boertmann 2006). It is therefore tempting to interpret these birds as local breeders and the larger flocks occurring further west as migrating birds on the move northwards.

Thick-billed murre

Thick-billed murres were observed throughout the region where open waters were present (**Figure 3.39** and **Figure 3.41**). Even very far from the shore in the extensive drift ice fields there were numerous murres in cracks and leads, and high densities were recorded for example in stratum 3 (**Figure 3.39**). Very few were observed in northern Disko Bay and in Vaigat, and the only birds here were close to the breeding colony at Ritenbenk. The stratified distance sampling abundance estimate was approx. 430,000 individuals. This is far more than the breeding population in the study area (= approx. 2000 pairs, Boertmann 2006), and the major part were birds on spring migration towards breeding colonies in northern Baffin Bay (approx 300,000 pairs in NW Greenland and 400,000 pairs in NE Canada, Falk & Kampp 1997, Nettleship & Birkhead 1985).

The result of the density surface model is shown in **Figure 3.40**. The highest concentrations of this very numerous species were found in south-eastern Disko Bay and west of Kangaatsiaq. But high densities are also apparent in stratum 3A, where ice cover was dense. In south-eastern Disko Bay, the model shows high densities along the southernmost transect (1161), where no birds were observed. This is due to the model, and probably does not reflect reality. Although no birds were observed, high density is predicted in this area because transect 1161 represent very little effort and the neighbouring transects, which are considerably longer, consistently show high densities. Further, transect 1161 is on the very border of the study area with no other transects in the vicinity to support the low density. With the smoothing involved in model, the lack of sightings on transect 1161 are thus not given weight.

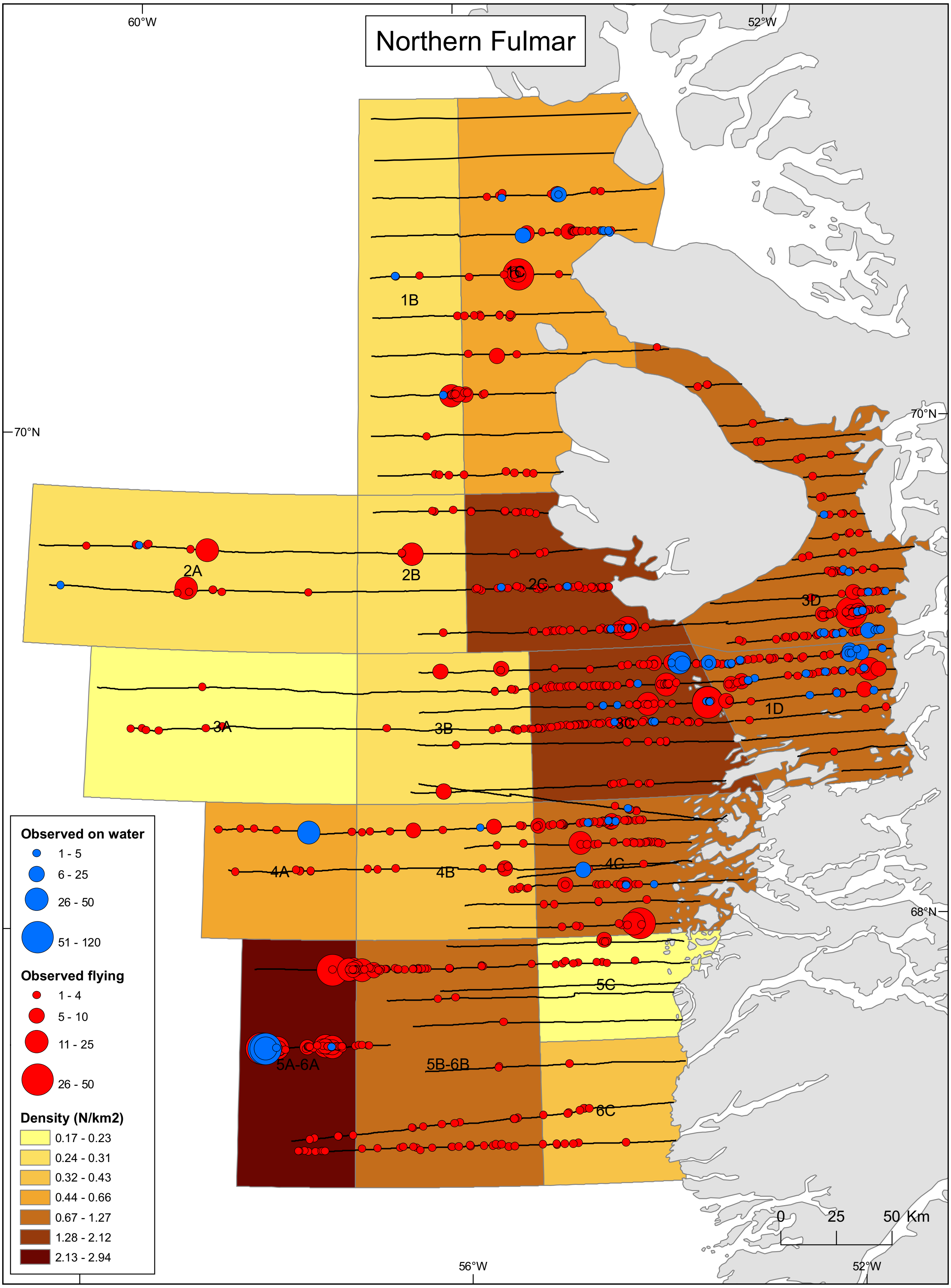


Figure 3.26. Distribution of northern fulmars (n = 2796) observed on aerial transects in April and May 2006. Stratum densities are shown with nuances of brown.

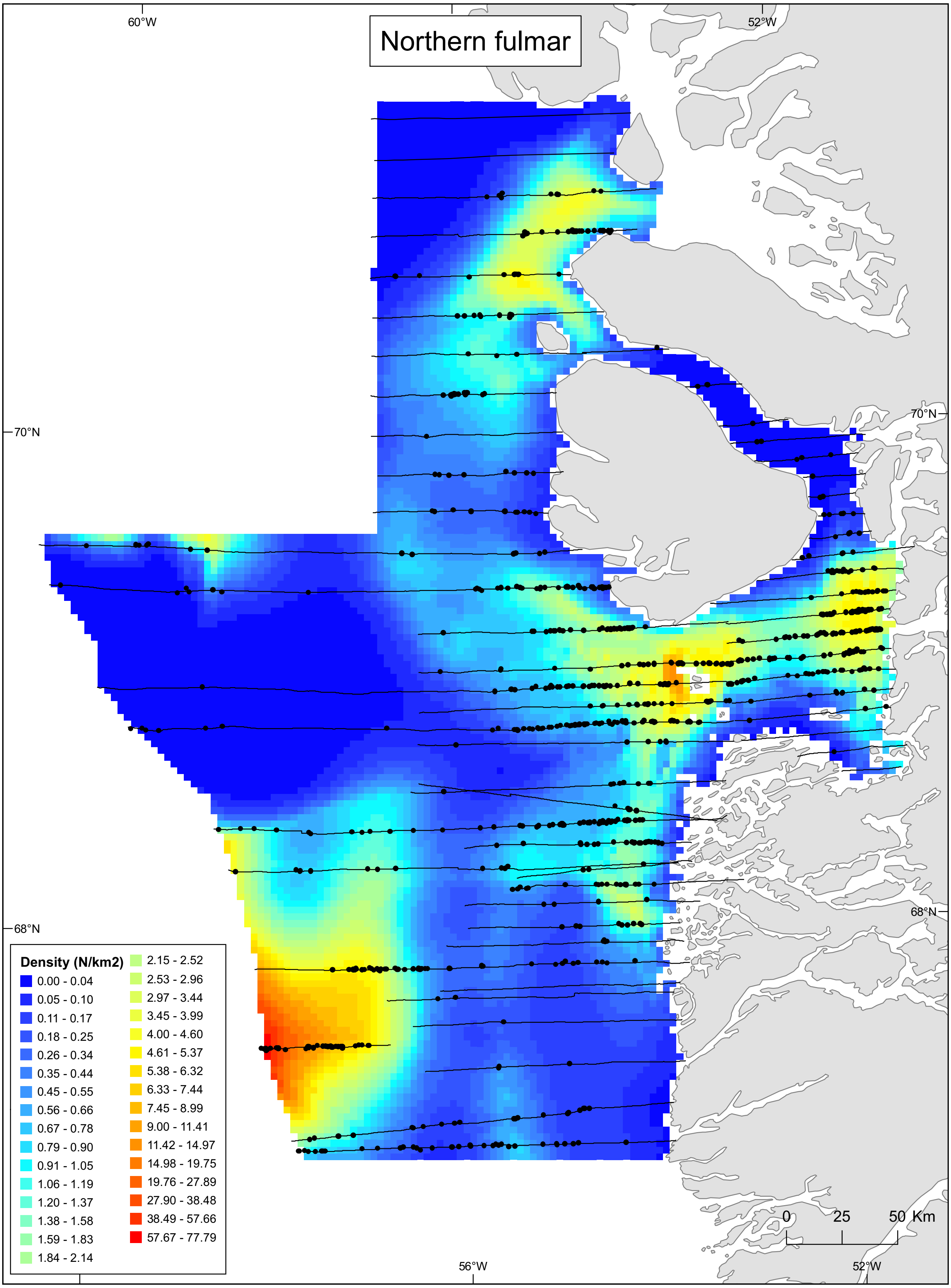


Figure 3.27. Density surface model of northern fulmars in late April/early May 2006. Observations on aerial transects are also shown as dots. Note that the densities shown are smoothed model predictions, and that the reliability of these predictions decreases with distance from transect lines.

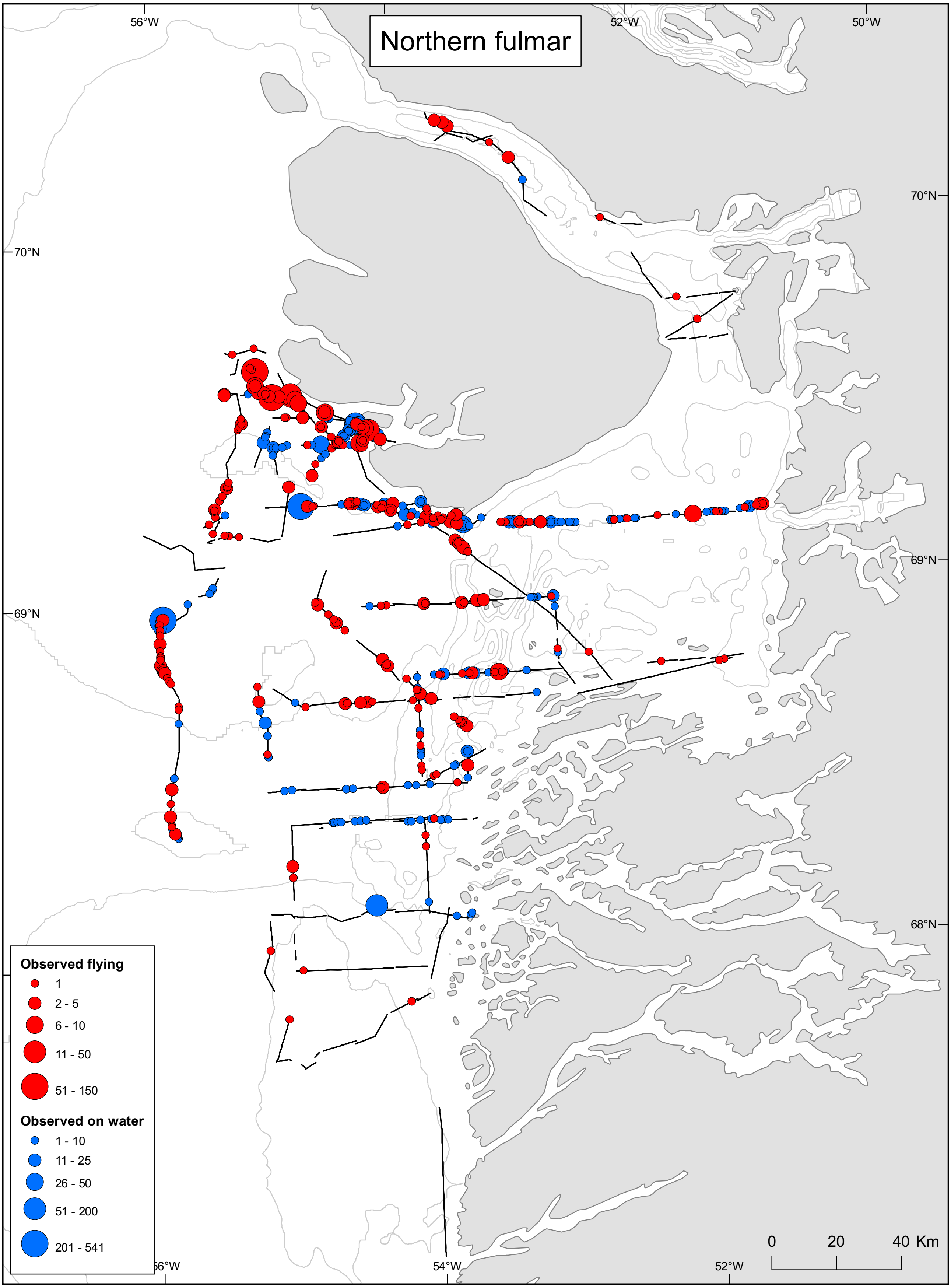


Figure 3.28. Observations of northern fulmars (n = 3017) on ship transects in April and May 2006.

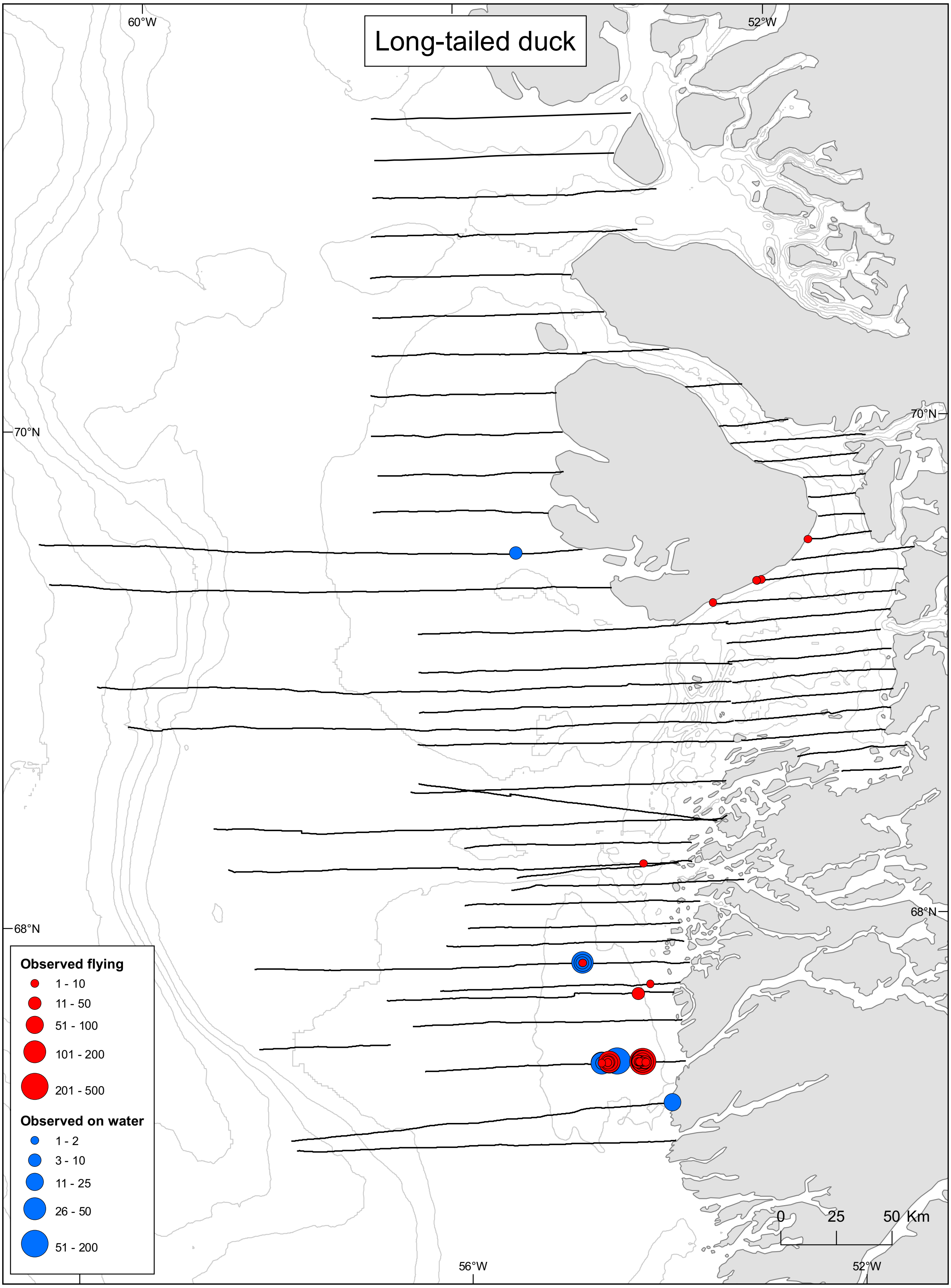


Figure 3.29. Distribution of long-tailed ducks (n = 2631) observed on aerial transects in April and May 2006.

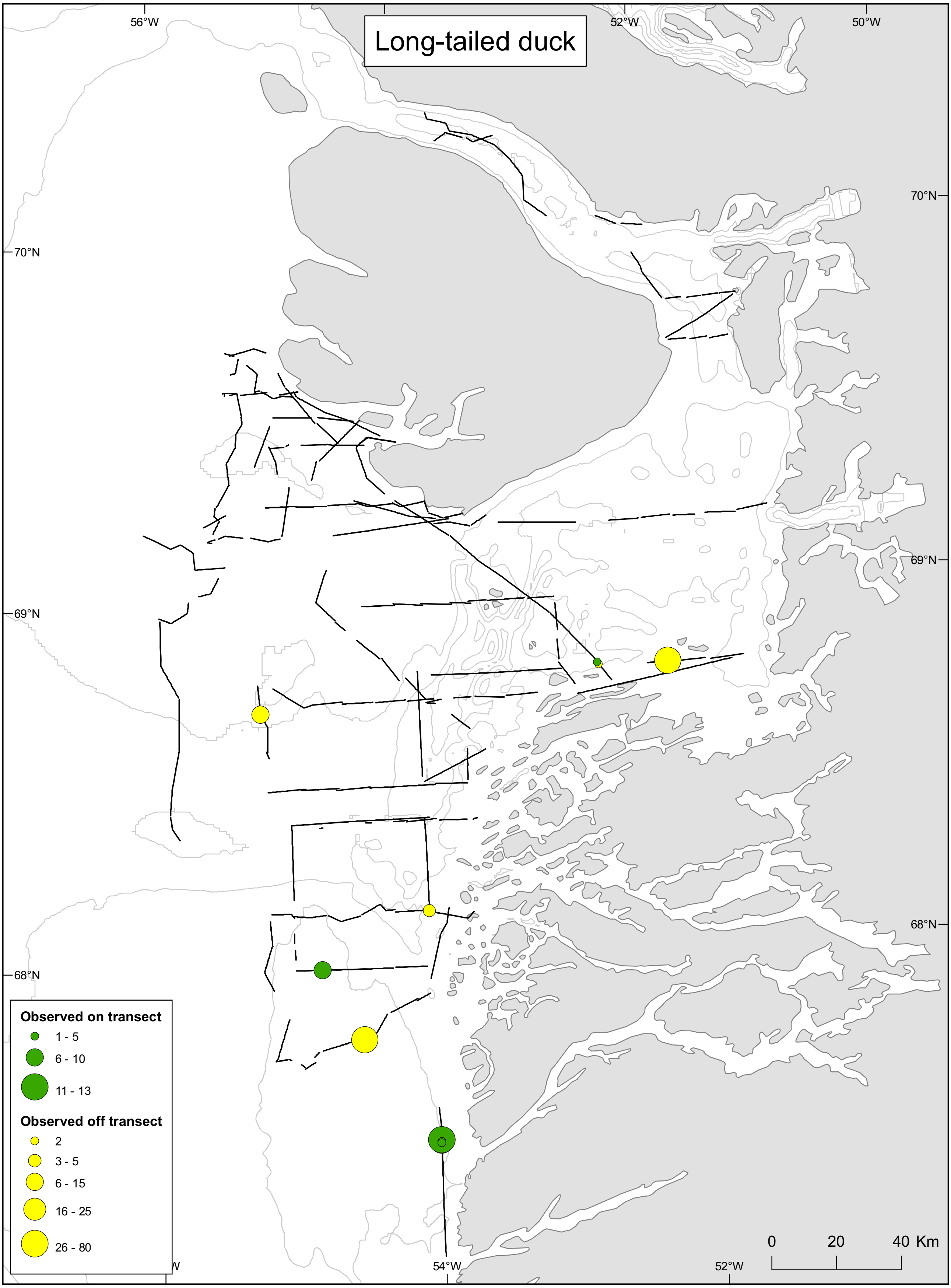


Figure 3.30. Observations of long-tailed ducks (n = 213) on and off ship transects in April and May 2006.

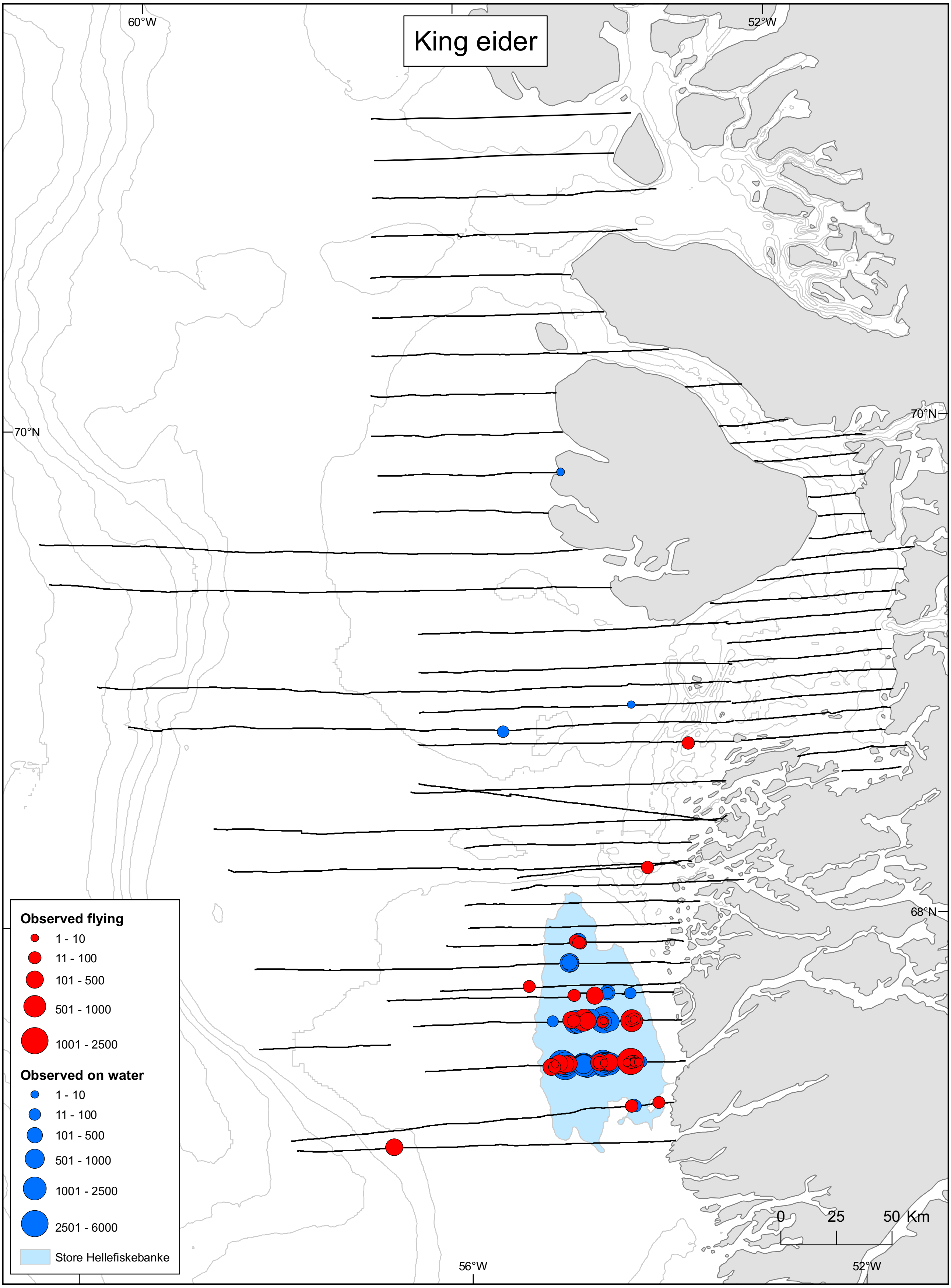


Figure 3.31. Distribution of king eiders (n = 57100) observed on aerial transects in April and May 2006. The abundance estimate of king eiders is based on the blue area corresponding to the 50 m isobath of Store Hellefiskebanke.

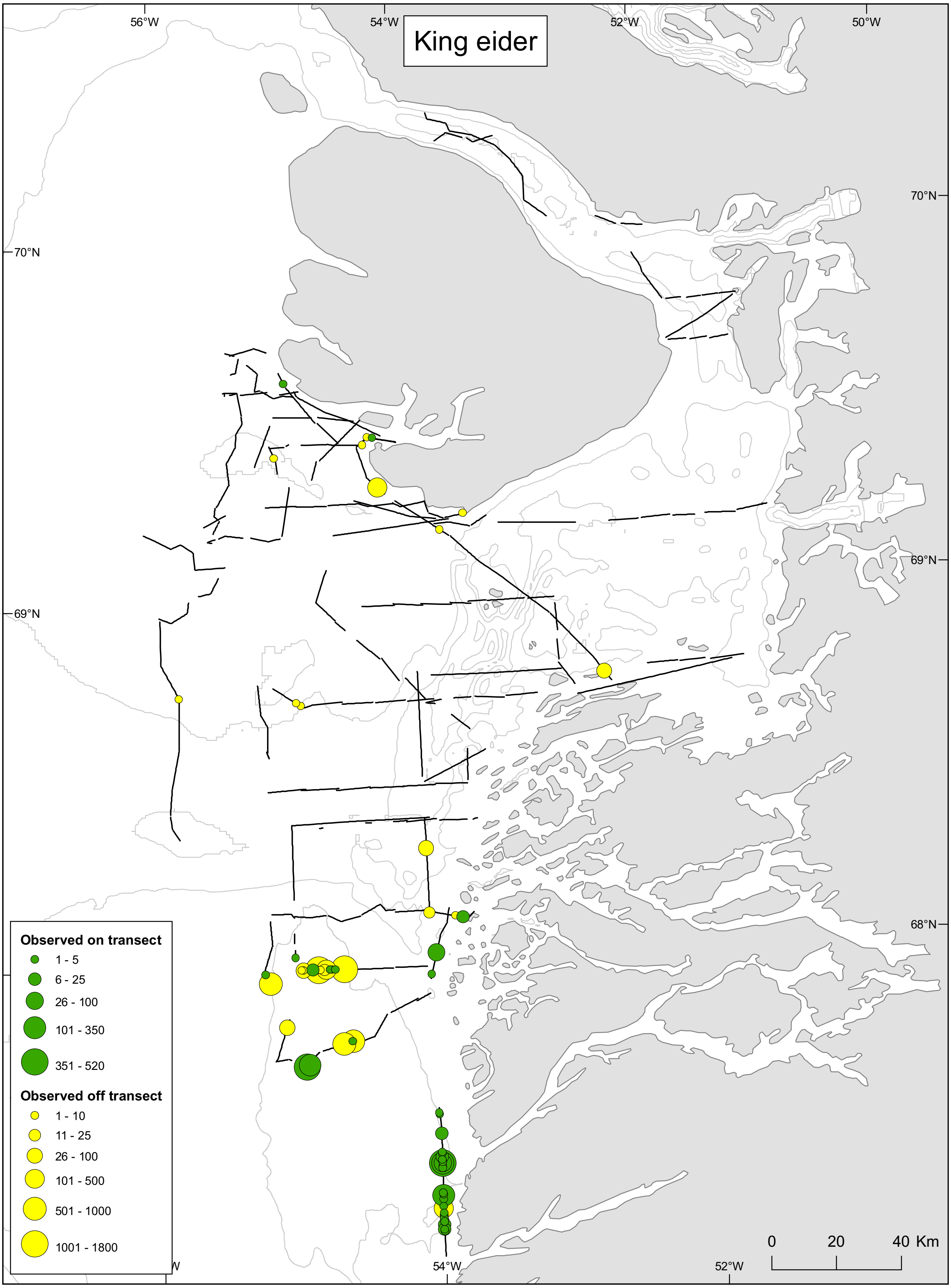


Figure 3.32. Observations of king eiders (n = 8992) on and off ship transects in April and May 2006.

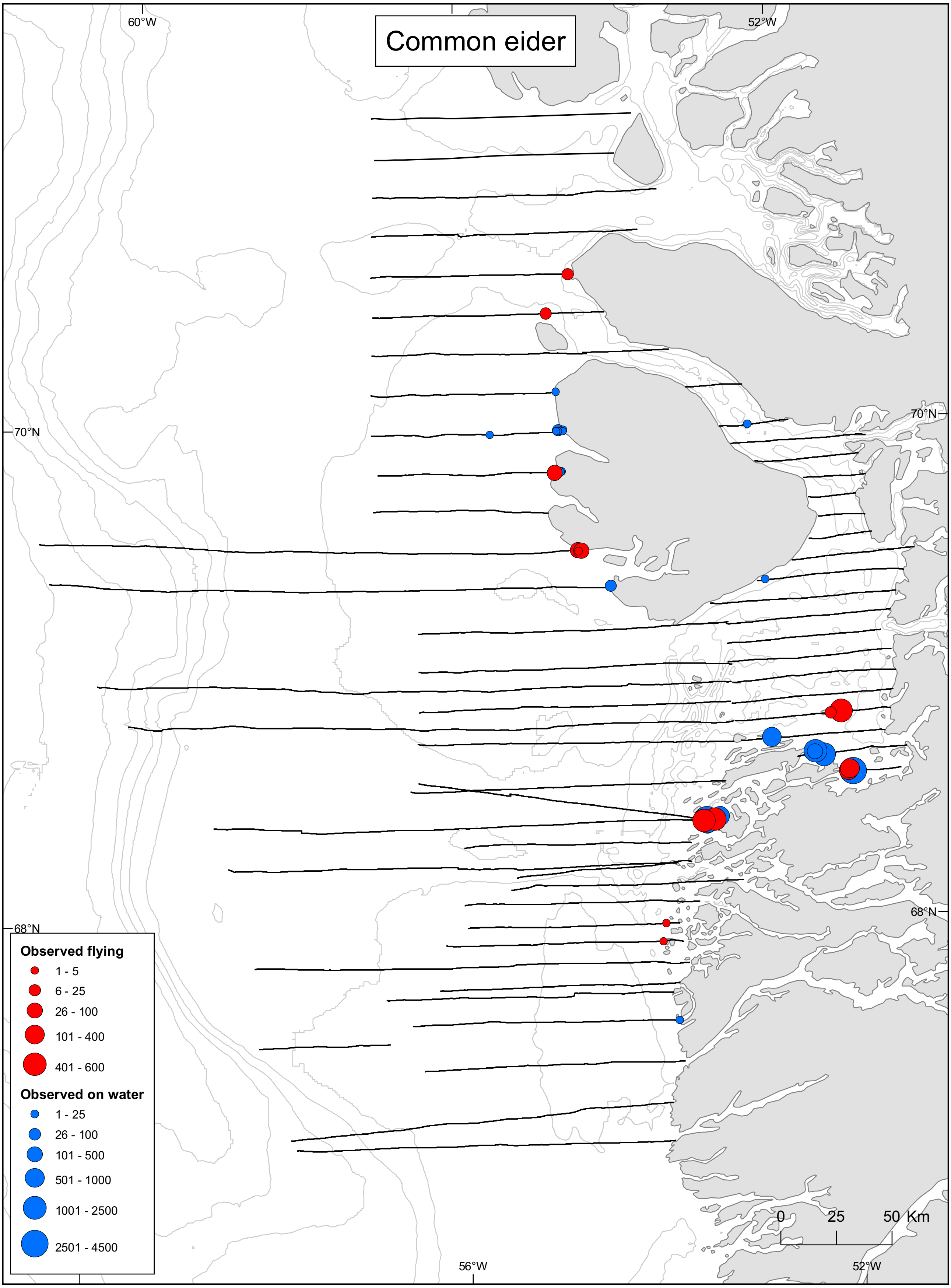


Figure 3.33. Distribution of common eiders (n = 18892) observed on aerial transects in April and May 2006.

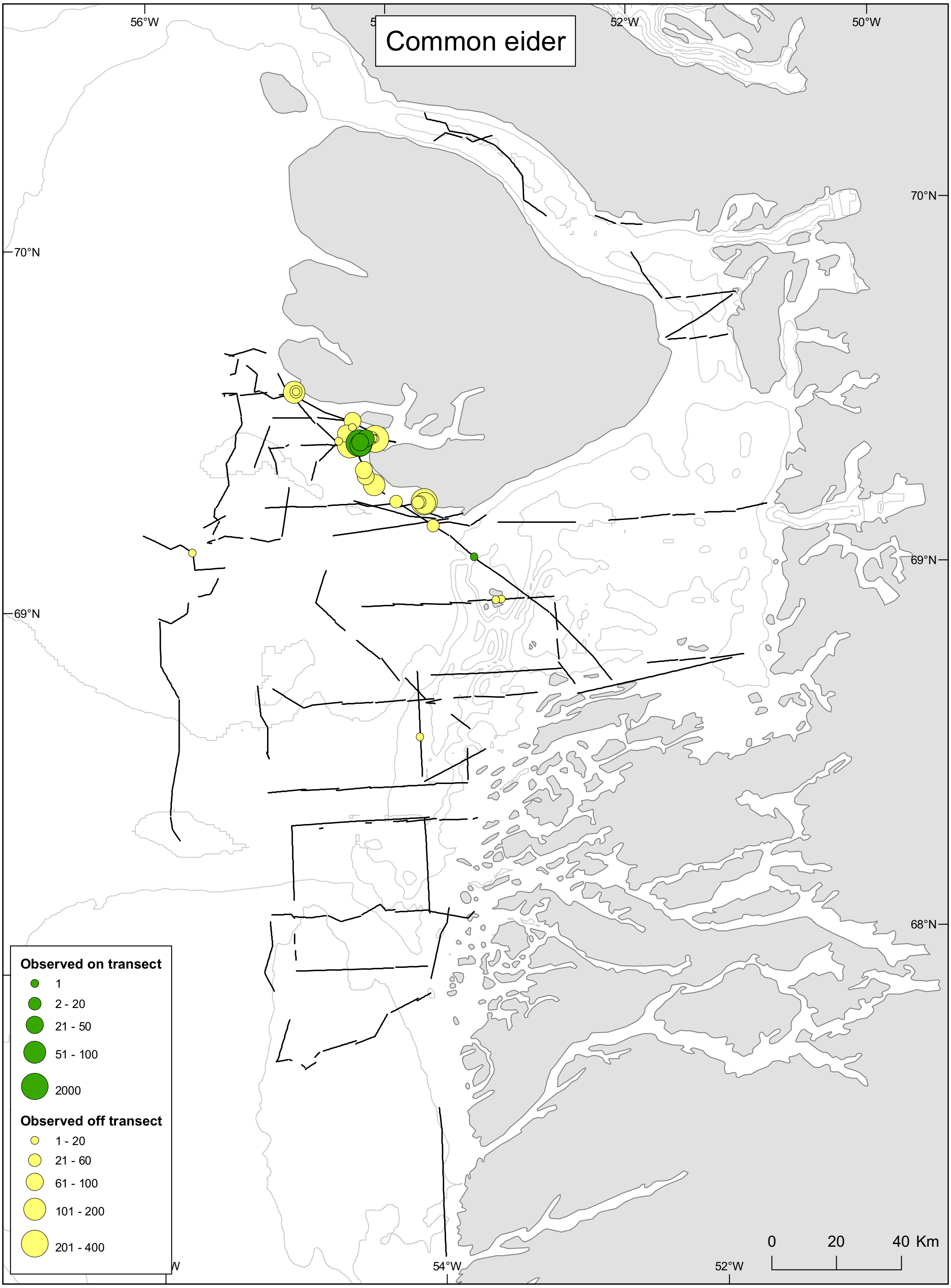


Figure 3.34. Observations of common eiders (n = 4483) on and off ship transects in April and May 2006.

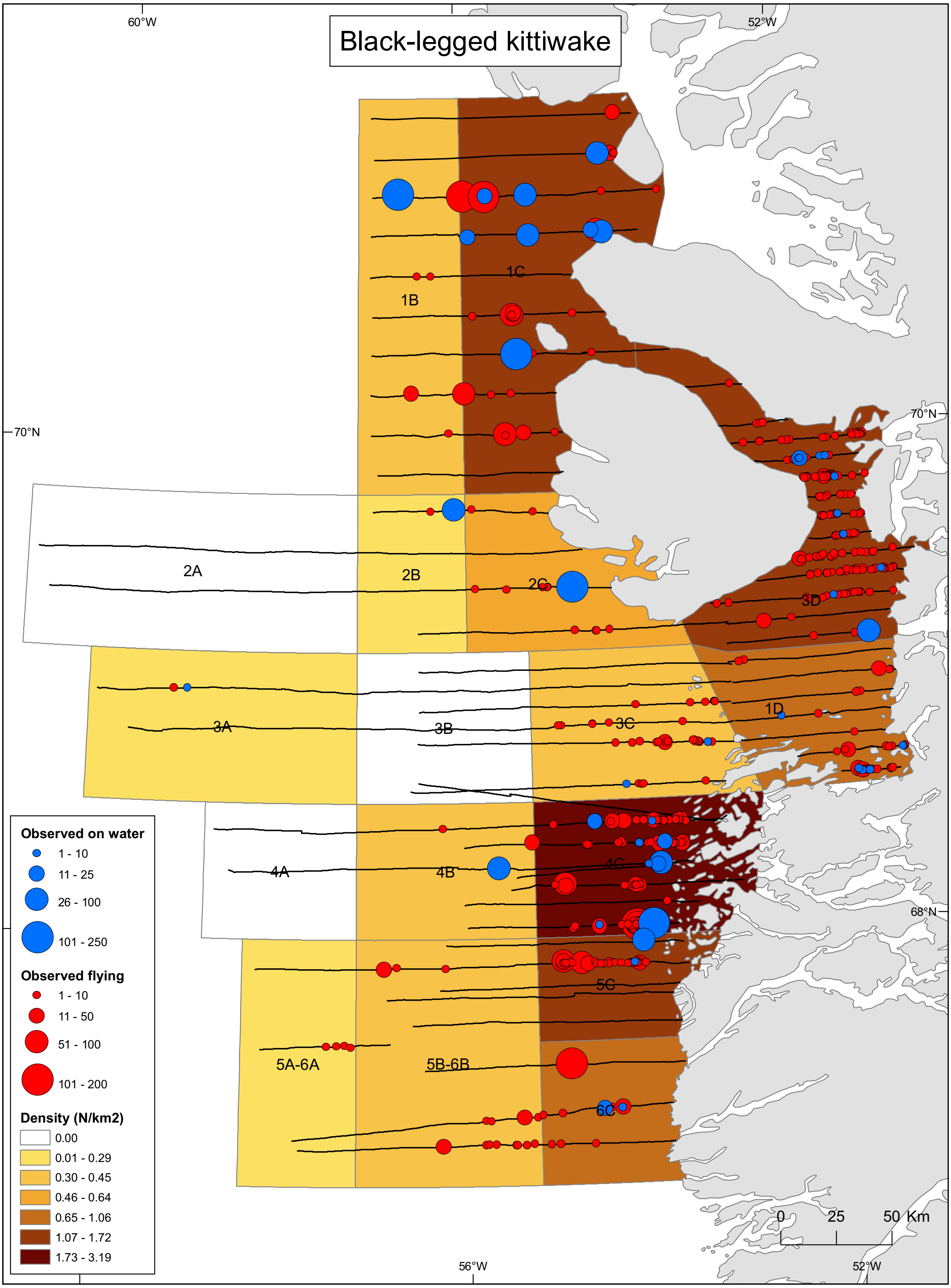


Figure 3.35. Distribution of black-legged kittiwakes (n = 4910) observed on aerial transects in April and May 2006. Stratum densities are shown with nuances of brown.

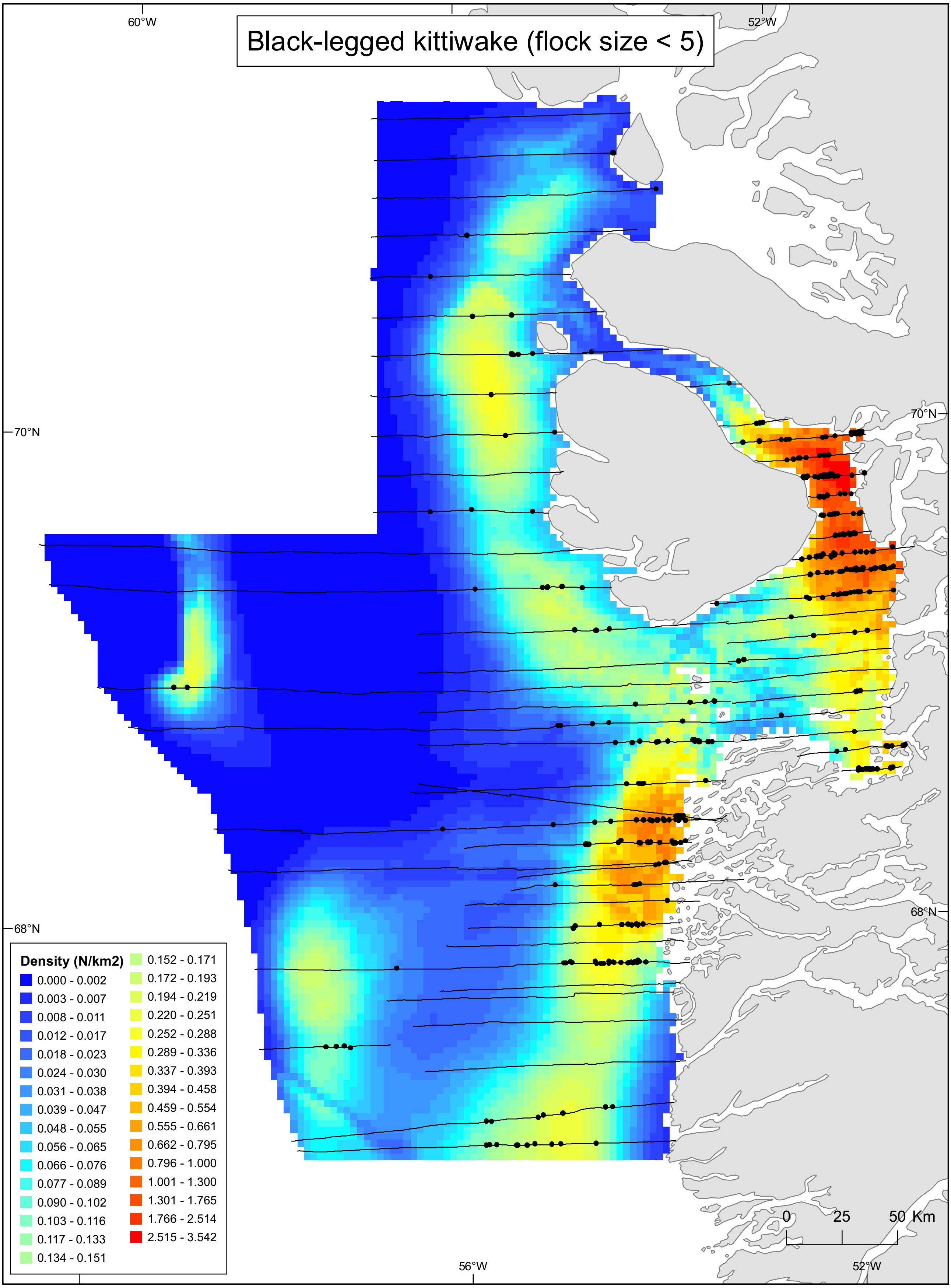


Figure 3.36. Density surface model of black-legged kittiwakes (flocks <5 individuals) in late April/early May 2006. Note that the densities shown are smoothed model predictions, and that the reliability of these predictions decreases with distance from transect lines.

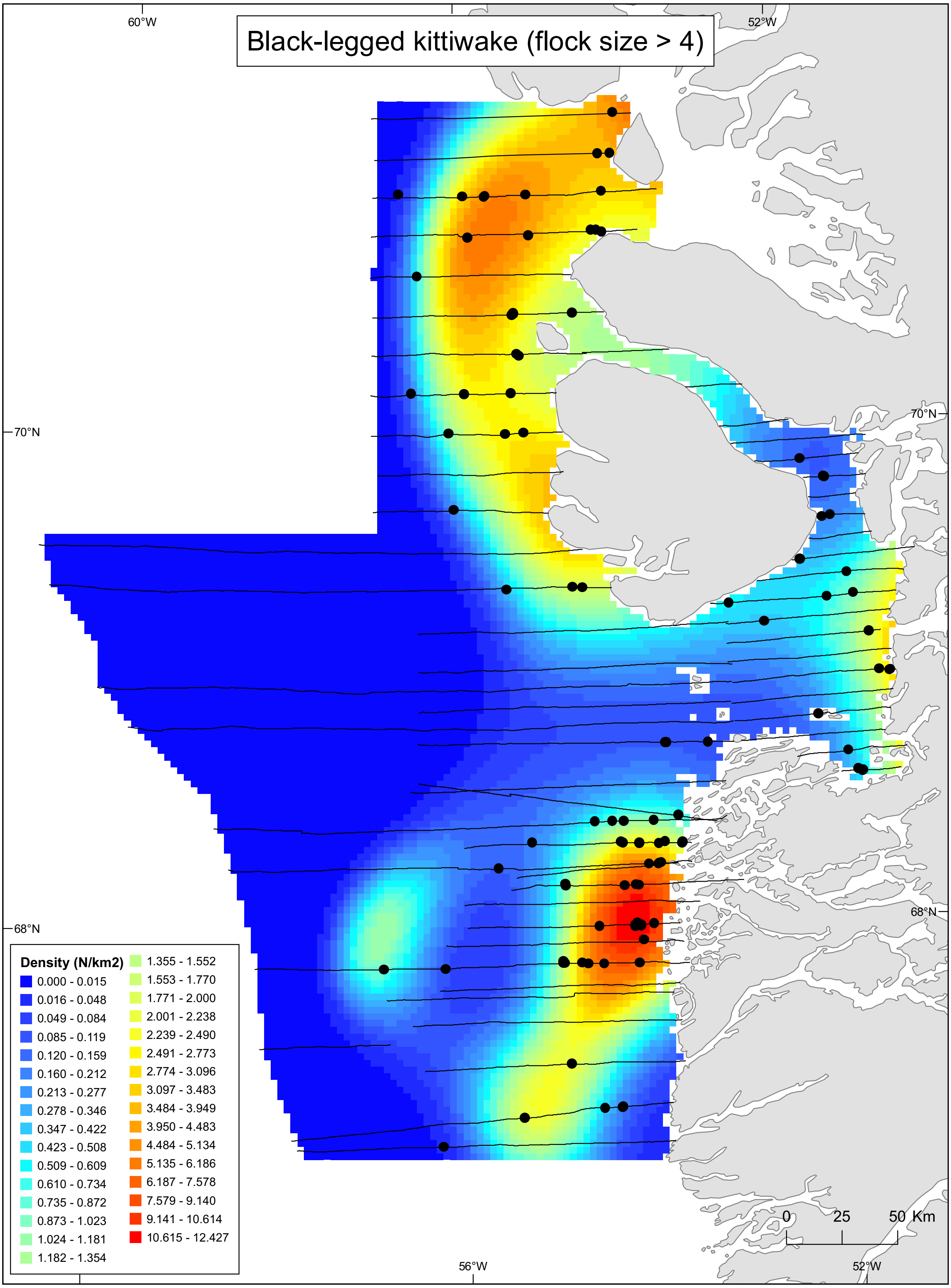


Figure 3.37. Density surface model of black-legged kittiwakes (flocks >4 individuals) in late April/early May 2006. Note that the densities shown are smoothed model predictions, and that the reliability of these predictions decreases with distance from transect lines.

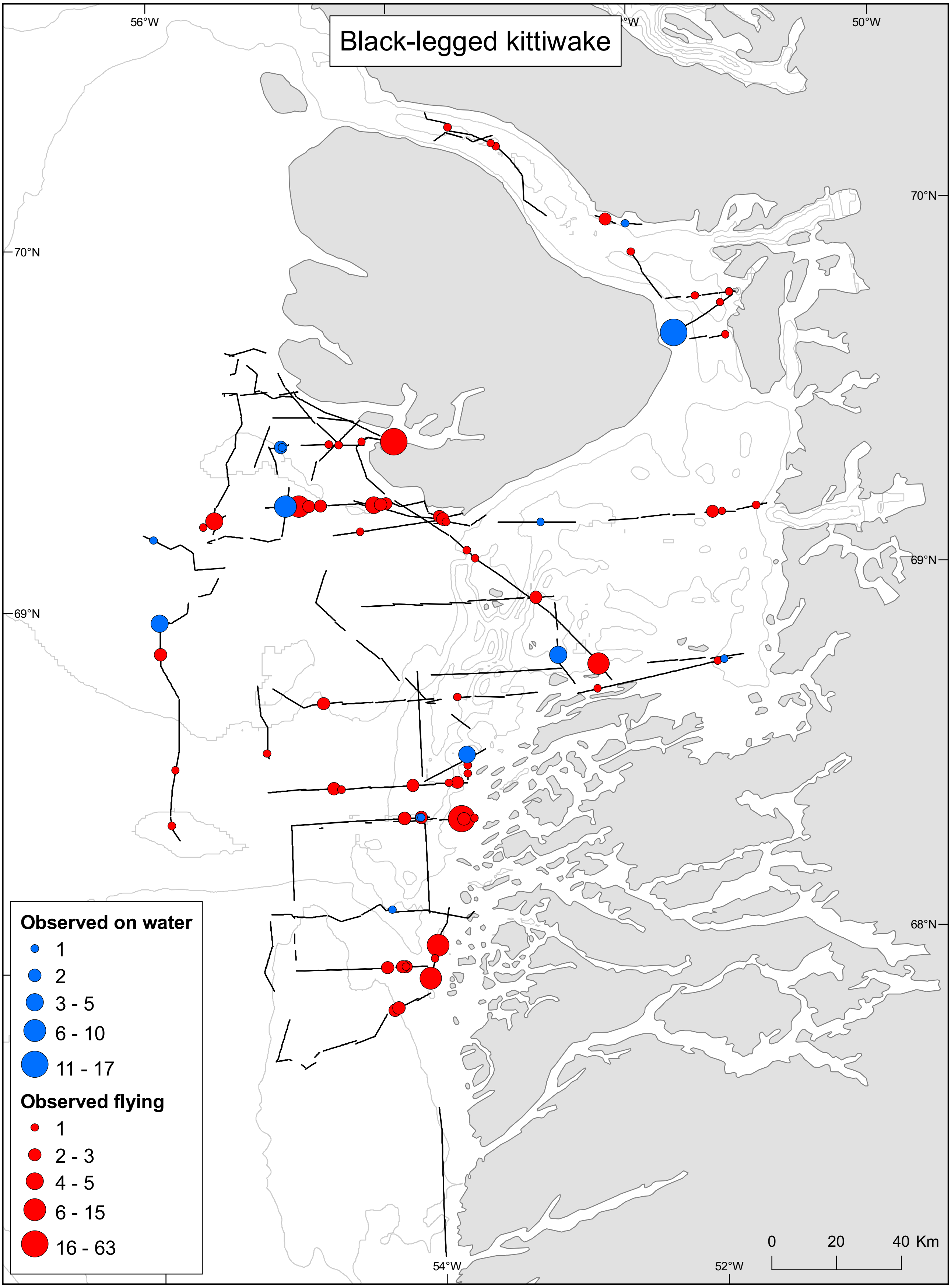


Figure 3.38. Observations of black-legged kittiwakes (n = 280) on ship transects in April and May 2006.

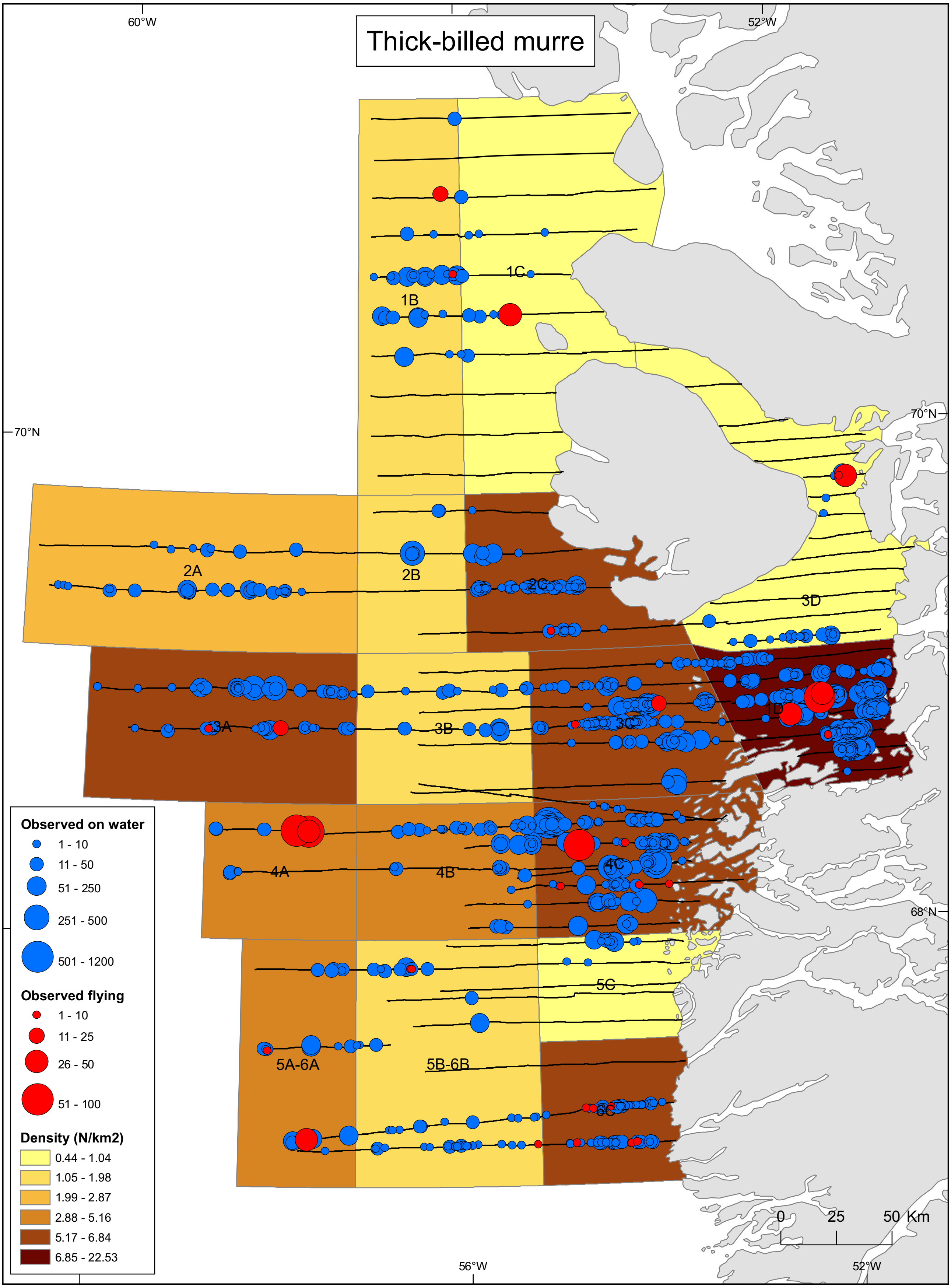


Figure 3.39. Distribution of thick-billed murres (n = 34150) observed on aerial transects in April and May 2006. Densities calculated in each of the 18 strata and shown in nuances of brown.

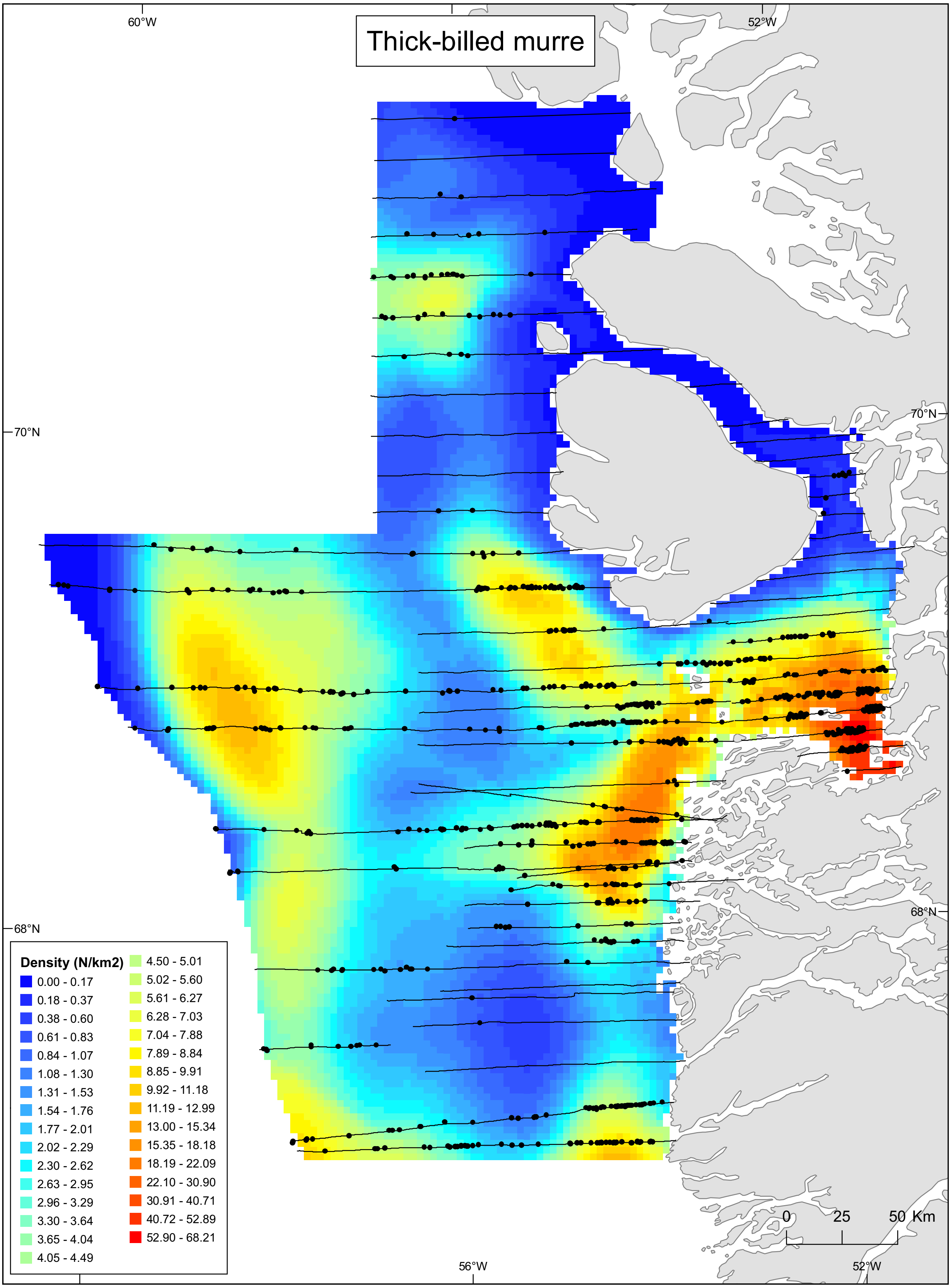


Figure 3.40. Density surface model of thick-billed murres in late April/early May 2006. Note that the densities shown are smoothed model predictions, and that the reliability of these predictions decreases with distance from transect lines.

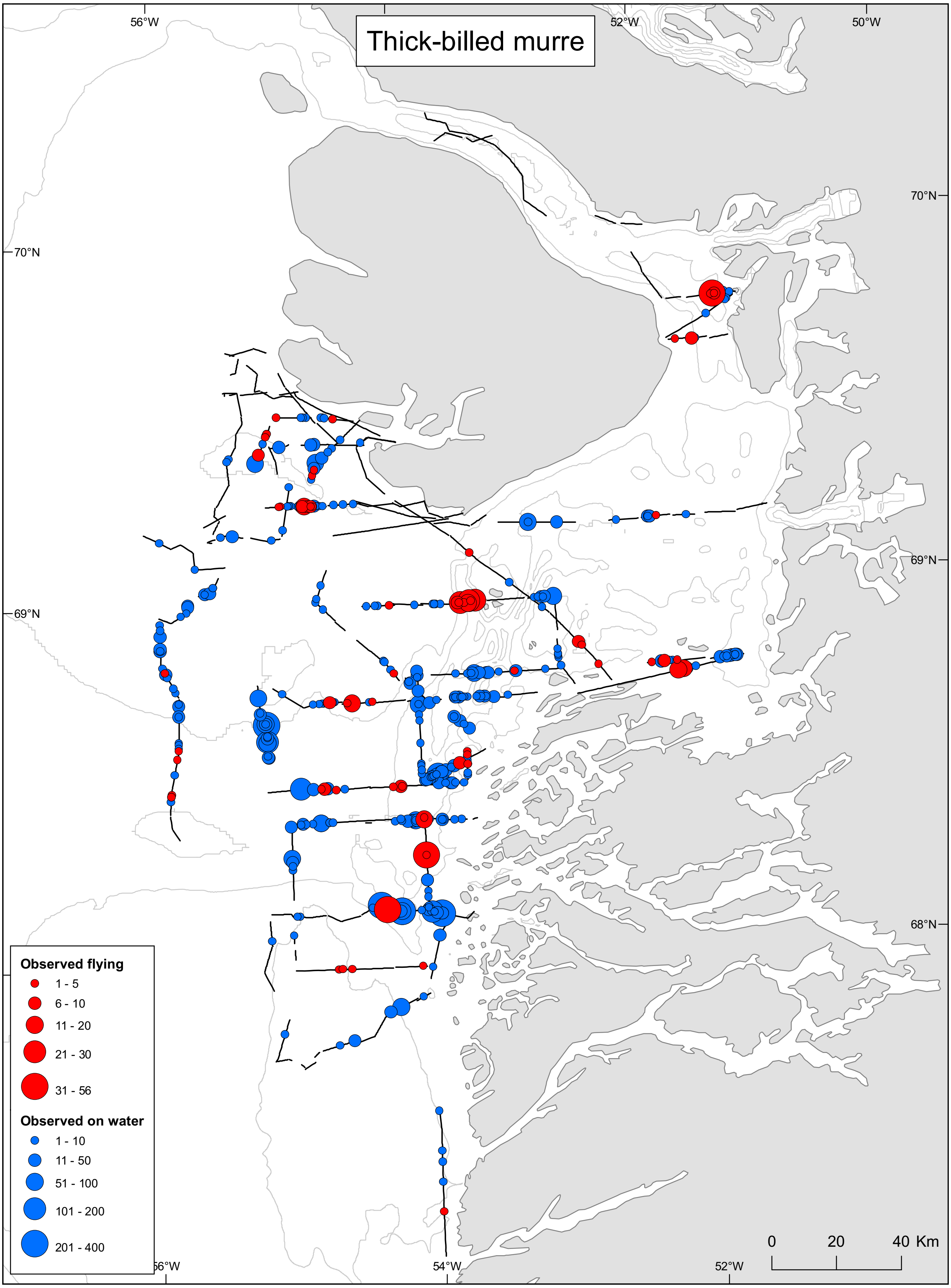


Figure 3.41. Observations of thick-billed murres (n = 7292) on ship transects in April and May 2006.

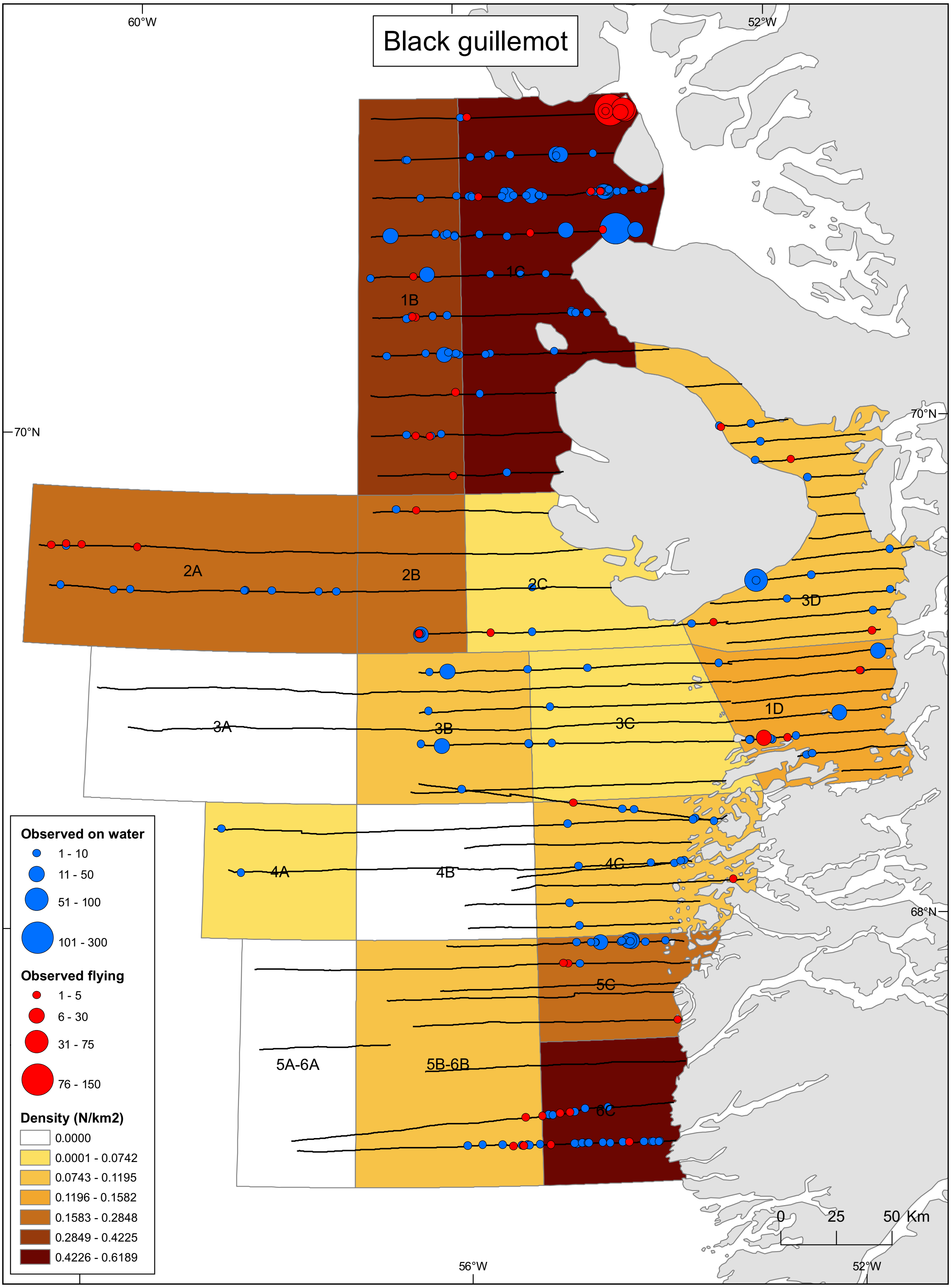


Figure 3.42. Distribution of black guillemots (n = 1889) observed on aerial transects in April and May 2006. Densities calculated in each of the 18 strata and shown in nuances of brown.

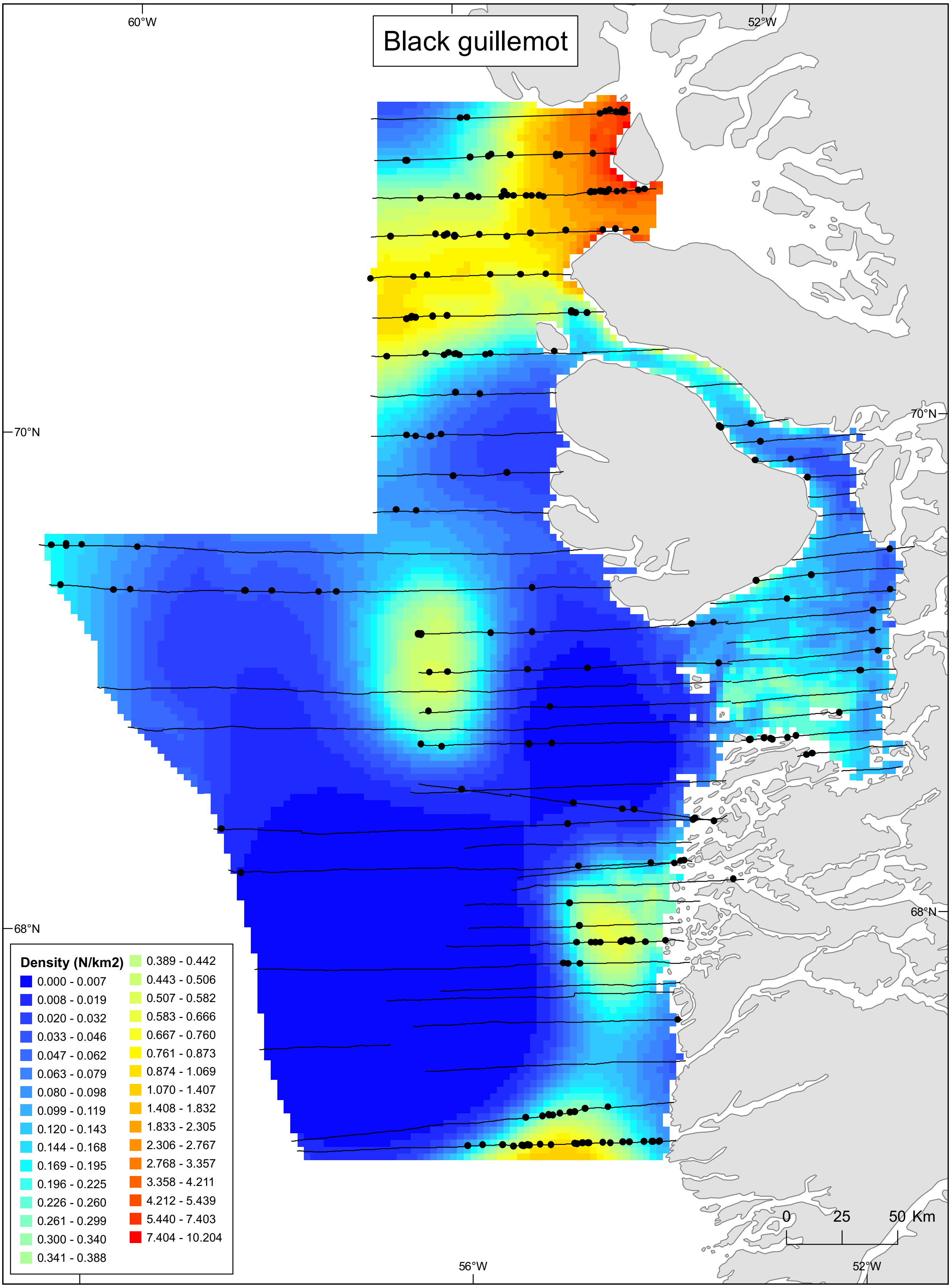


Figure 3.43. Density surface model of black guillemots in late April/early May 2006. Note that the densities shown are smoothed model predictions, and that the reliability of these predictions decreases with distance from transect lines.

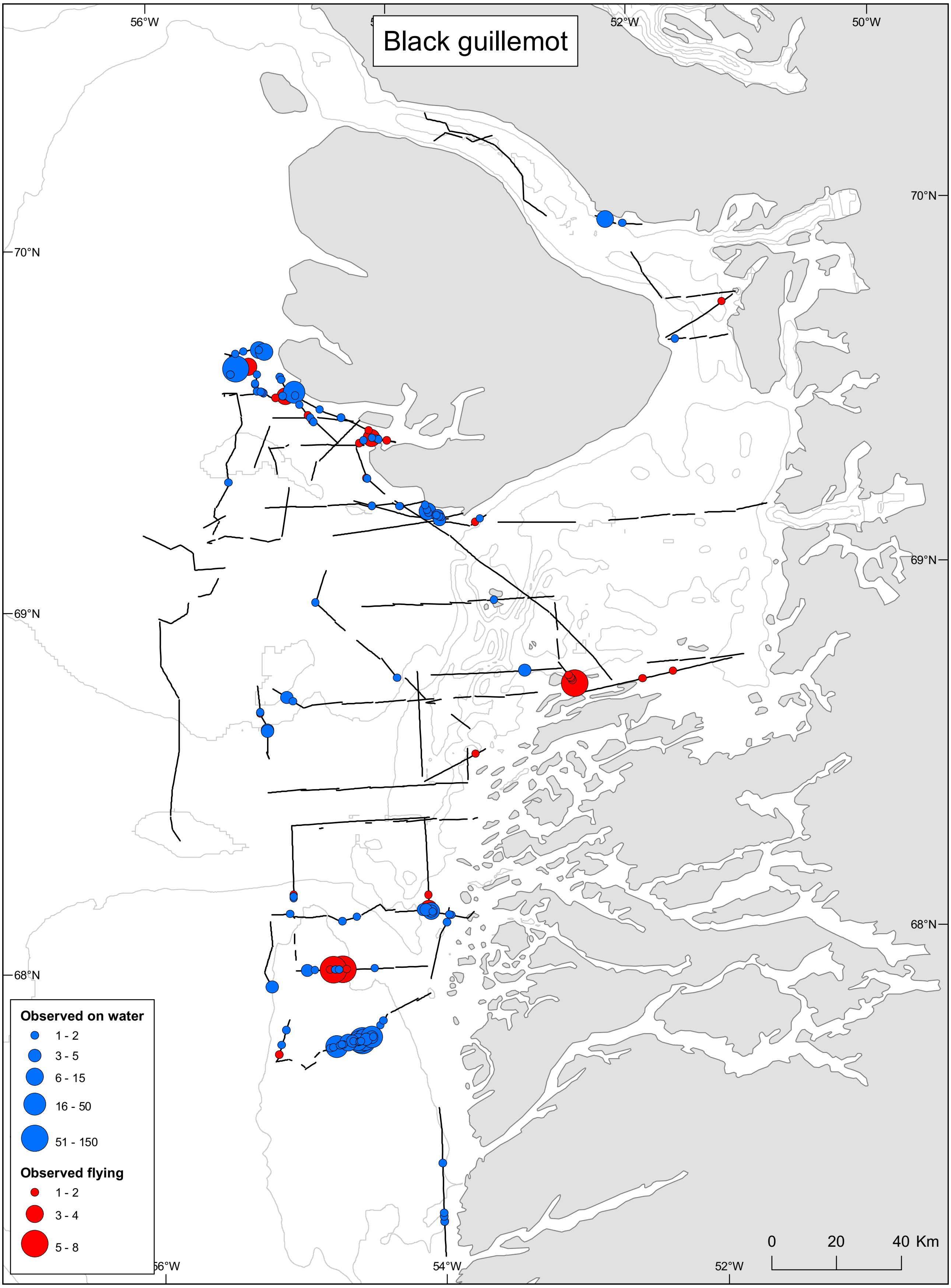


Figure 3.44. Observations of black guillemots (n = 692) on ship transects in April and May 2006.

Black guillemot

This species was observed dispersed in the extensive drift ice field and in the coastal waters off south-western Disko (**Figure 3.42** and **Figure 3.44**). The highest numbers were seen along the fast ice edge along the eastern part of the northernmost transect. The stratified distance sampling abundance estimate was approx. 21,000 black guillemots in the surveyed region.

The result of the density surface model is shown in **Figure 3.43**. The high densities in Uummannaq Fjord were associated with the fast ice edge.

3.4.2 Factors affecting spatial distribution

Data from the synoptic ship-based surveys were used to identify environmental factors covarying with the presence of seabirds. Because of data constraints, these analyses were only carried out for the four most widespread species. The ship-based data are biased by the inability of the ship to enter dense ice, whereas simultaneous oceanographic data were unavailable for the aerial survey data. A more detailed analysis combining the two data sets will be performed later.

Northern fulmar

The final model included two covariates, shrimp larvae biomass (χ^2 = 7.93, P = 0.0049, **Figure 3.45**) and barnacle nauplii biomass (χ^2 = 8.46, P = 0.0036, **Figure 3.46**). Northern fulmars were thus more likely to occur in areas with many shrimp larvae and few barnacle nauplii, i.e. potentially in areas where the spring bloom was relatively well developed.

Figure 3.45. The relationship between the probability of observing northern fulmar during a 2-minute interval and the biomass of *Pandalus* shrimp larvae at the associated oceanographic station.

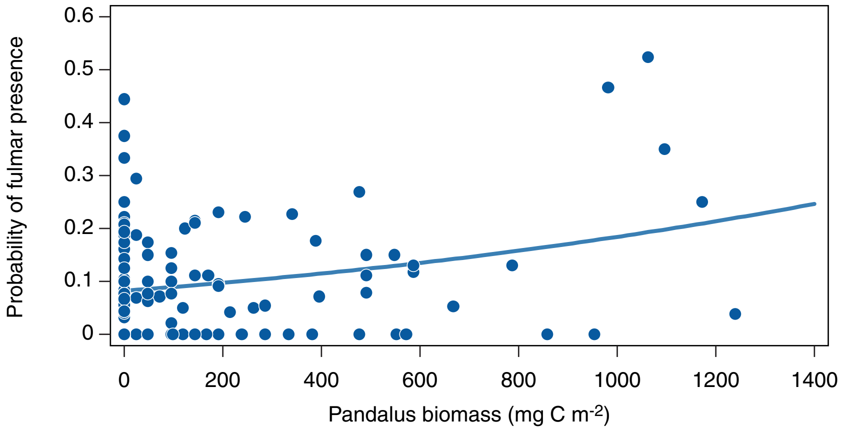
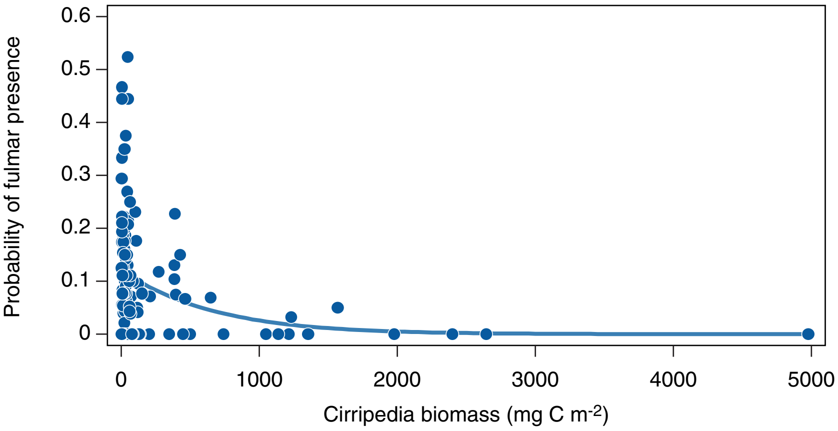


Figure 3.46. The relationship between the probability of observing northern fulmar during a 2-minute interval and the biomass of barnacle nauplii at the associated oceanographic station.



Black-legged kittiwake

The final model included two covariates, mean ice concentration (χ^2 = 4.98, P = 0.0257, **Figure 3.47**) and shrimp larvae biomass (χ^2 = 5.79, P = 0.0161, **Figure 3.48**). Black-legged kittiwakes were thus more likely to occur in areas with many shrimp larvae and little ice, i.e. potentially in areas where the spring bloom was relatively well developed. However, these relationships were not very strong.

Figure 3.47. The relationship between the probability of observing black-legged kittiwake during a 2-minute interval and the mean ice concentration at the associated oceanographic station.

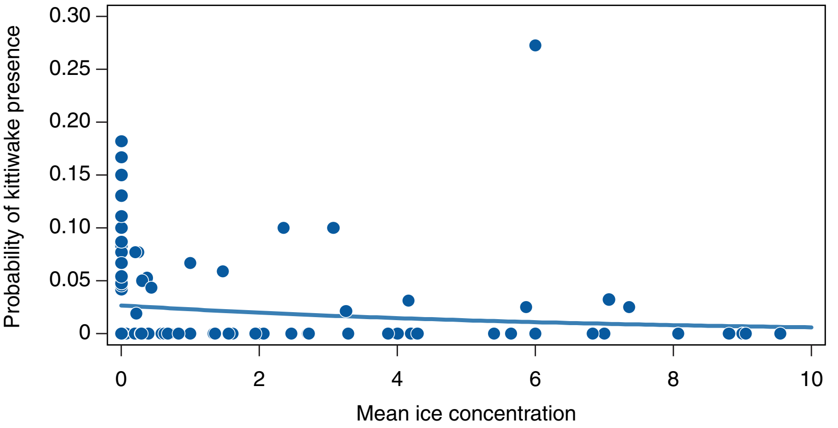
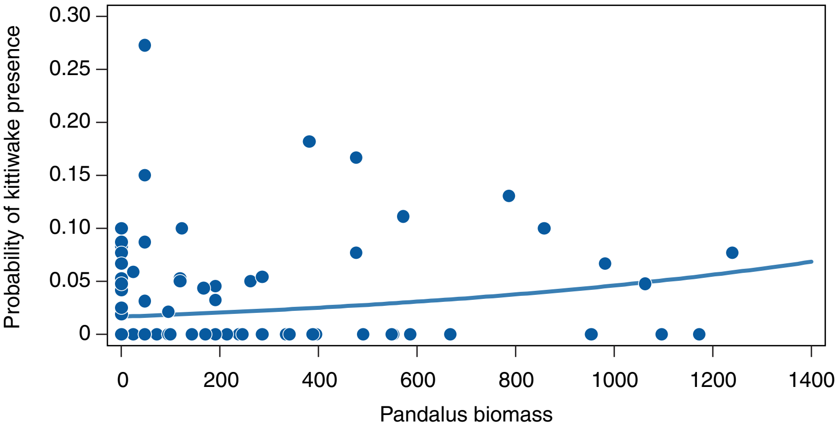


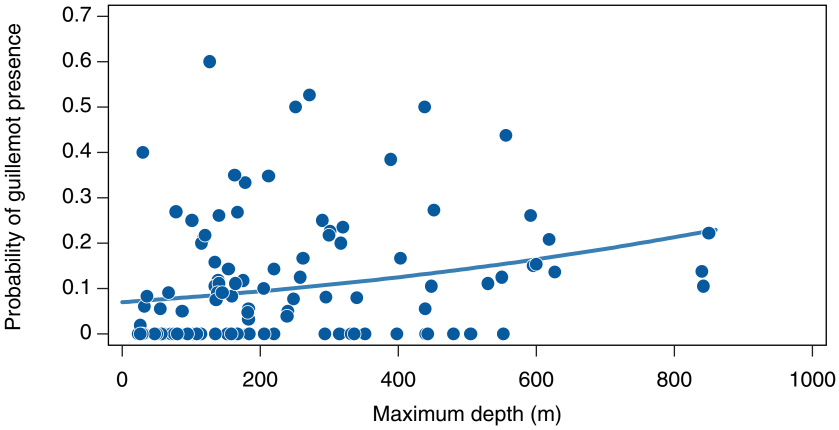
Figure 3.48. The relationship between the probability of observing black-legged kittiwake during a 2-minute interval and the biomass of *Pandalus* shrimp larvae at the associated oceanographic station.



Thick-billed murre

The final model included one covariate, depth ($\chi^2 = 6.71$, $P = 0.0096$, **Figure 3.49**). Thick-billed murres thus tended to occur mainly in relatively deep areas, although there was much unexplained variation.

Figure 3.49. The relationship between the probability of observing thick-billed murre during a 2-minute interval and depth at the associated oceanographic station.



Black guillemot

The final model included two covariates, Simpson index ($\chi^2 = 5.49$, $P = 0.0192$, **Figure 3.50**) and depth ($\chi^2 = 36.49$, $P < 0.0001$, **Figure 3.51**). Black guillemots thus strongly avoided deep areas and tended to occur where stratification was weak. Black guillemots are known to have two habitats: the shallow coastal waters where they forage on bottom-associated fauna, and (in winter) leads in dense ice where they forage on ice-associated fauna. Surprisingly, no association with ice cover was found here, and the reason is probably that the ship only marginally covered the habitat in dense ice. This bias will be corrected when we include aerial survey data in the analysis.

Figure 3.50. The relationship between the probability of observing black guillemot during a 2-minute interval and Simpson index at the associated oceanographic station.

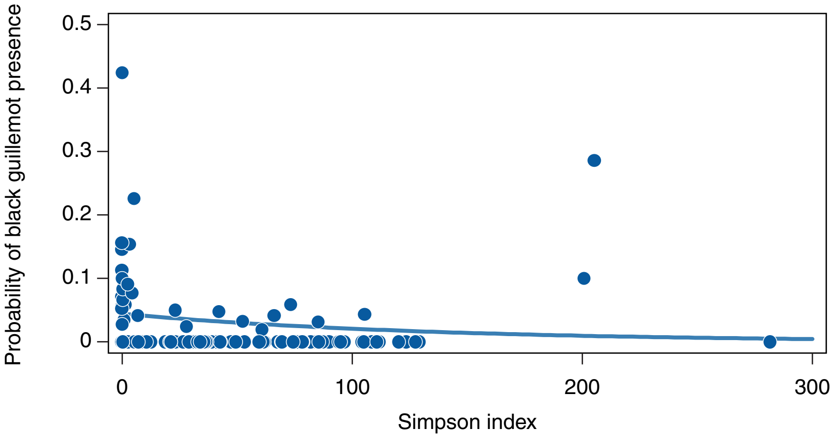
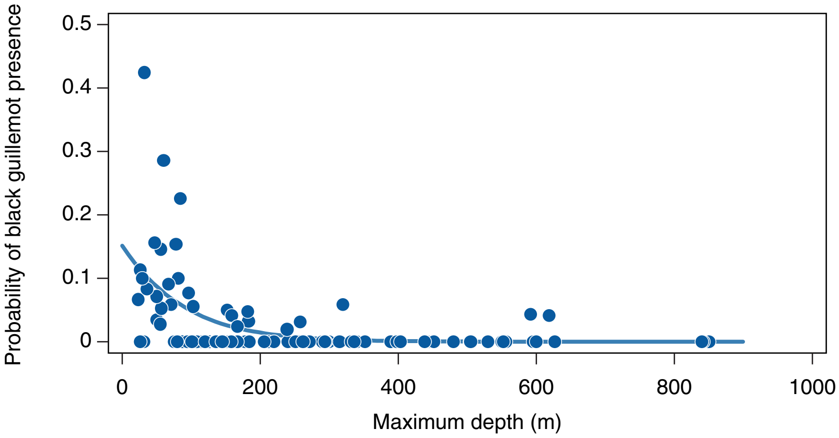


Figure 3.51. The relationship between the probability of observing black guillemot during a 2-minute interval and depth at the associated oceanographic station.



3.4.3 Thick-billed murre diet

24% of the birds had an empty stomach when they were caught, 61% of all stomachs contained invertebrates and 27% contained fish. **Table 3.6** summarises the diet items found in the stomachs as frequency of occurrence, number of individuals and wet weight. Crustaceans (mainly the amphipod *Parathemisto libellula*) were the most common and numerous prey, but in terms of biomass contributed little to murre diet. Capelin were only found in 3 stomachs (17 individuals), but made up 42% of the total wet weight. Similarly, very few individual squid (probably *Gonatus fabricii*; 5 individuals in 4 stomachs) made up 55% of total wet weight.

Table 3.6. Diet composition of thick-billed murres, expressed as frequency of occurrence, number of individuals, and biomass (estimated wet weight).

	n	%
Number of birds examined	49	
Number of empty stomachs	12	24
Frequency of occurrence of invertebrates	30	61
Frequency of occurrence of fish	13	27
FREQUENCY OF OCCURRENCE		
Fish	**7**	**19**
Gadidae undetermined	1	3
Capelin (*Mallotus villosus*)	3	8
Undetermined fish (otoliths)	3	8
Crustacea	**16**	**43**
Euphausiacea or Mysidacea undetermined	6	16
Gamarellus homari	1	3
Pandalus sp.	2	5
Parathemisto libellula	7	19
Other	**11**	**31**
Squid (*Gonatus fabricii*)	4	11
Polychaeta	1	3
Pteropod	1	3
Copepod	1	3
Stones	4	11
NUMBER OF INDIVIDUALS		
Fish	**26**	**16**
Gadidae undetermined	2	1
Capelin (*Mallotus villosus*)	17	11
Undetermined fish (otoliths)	7	4
Crustacea	**128**	**80**
Gamarellus homari	2	1
Pandalus sp.	2	1
Parathemisto libellula	124	78
Other	**6**	**3**
Squid (*Gonatus fabricii*)	5	3
Polychaeta	1	>1
ESTIMATED WET WEIGHT (g)		
Fish		
Capelin (*Mallotus villosus*)	213	42
Crustacea		
Gamarellus homari	< 1	
Parathemisto libellula	13	3
Other		
Squid (*Gonatus fabricii*)	276	55
Polychaeta	< 1	

3.5 Marine mammals

Table 3.7 shows marine and other mammals observed during the aerial and ship surveys. Nine species were observed. In addition to the species treated in detail below, a few harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*) and unidentified seals were observed. No polar bears were observed, but tracks were frequent in the drift ice, particularly along transects northwest of Disko Island (152-184). A single Arctic fox (*Alopex lagopus*) was observed (between transects) in the drift ice, but many tracks were seen.

Table 3.7. Marine mammals observed on and off survey transects.

Species	Aerial survey		Ship survey	
	On transect (6220 km)	Off transect	On transect (1782 km)	Off transect
Bowhead whale	31	1		7
Minke whale				1
Narwhal	36	2		
Beluga	154	1		
Walrus	64	4		
Ringed seal	243	8	4	4
Bearded seal	77		80	359
Harp seal	1			
Hooded seal	2		3	3
Unidentified seal	25		2	4

Abundance estimates based on the aerial survey could be calculated for a few species (**Table 3.8**).

Table 3.8. Estimated abundance of marine mammals in survey area in late April/Early May 2006. Based on pooled estimates from 17 strata. Estimates could not be corrected for submerged individuals because relevant time budget data were unavailable. For bowhead whale and beluga, sample sizes were below the recommended limit for estimating abundance.

Species	Estimate	95% C.I.
Bowhead whale	448	221 – 907
Beluga	1421	690 – 2928
Walrus (northern subarea)	46	
Walrus (southern subarea)	370	
Ringed seal	4603	2608 – 8124
Bearded seal	1225	693 – 2167

Bowhead whale (Balaena mysticetus)

Bowhead whales were primarily observed to the southwest of Disko Island, which is a well known concentration area in spring (Heide-Jørgensen et al. 2007). A few were also seen in inner Disko Bay and west of Uummannaq Fjord (**Figure 3.52** and **Figure 3.53**). A remarkable observation was made on 25 April, when a large bowhead whale was observed accompanied by a calf born this year on a position of app. 68° 12′ N and 56° 00′ W. It was seen between transects, so is not included on the map. The whales occurring in these areas in spring are presumed to be mainly resting, pregnant or senescent females (Heide-Jørgensen et al. 2007).

GINR surveyed a much larger region during the same spring and their abundance estimate was 1229 animals present in almost the same waters as we observed bowheads (Heide-Jørgensen et al. 2007). However, the abundance estimates are not directly comparable, as the GINR estimate is corrected for both submerged animals and observer bias.

Narwhal (Monodon monocerus)

Only few narwhals were observed (**Figure 3.54**), although important wintering grounds were surveyed (cf. Heide Jørgensen & Acquarone 2002, Heide-Jørgensen et al. 2003), and most had probably moved out of the region heading for their summering grounds. No abundance estimate was attempted for this species due to insufficient sample size.

Beluga (Delphinapterus leucas)

Belugas were primarily observed on the north-eastern corner of Store Hellefiskebanke, which is a well-known upwelling area (**Figure 3.55**). A few were seen here and there in the marginal ice zone, and two single individuals were found far inside the drift ice near the Canadian border, perhaps whales which had initiated spring migration towards the Canadian summer grounds. Based on the observations, the abundance was estimated at 1421 belugas in the whole study area. Regions 4C and 5C, which cover the northern part of Store Hellefiskebanke, were estimateed to contain 856 individuals.

Walrus (Odobenus rosmarus)

In total 68 walruses were observed on transect. They were distributed between two areas, both well known winter habitats for the species (Born et al. 1994). Most were observed on Store Hellefiskebanke and only a few off northwest Disko island (**Figure 3.56**). The abundance in these two areas was calculated applying separate strata. 370 walruses were estimated to be present in the southern stratum on Store Hellefiskebanke and 46 in the northern (not corrected for submerged animals). GINR surveyed marine mammals during the same season and estimated the total abundance between Nordre Strømfjord and Vaigat at 3100 individuals (corrected for submerged animals and observer bias) (Mosbech et al. 2007).

Ringed seal (*Phoca hispida*)

This common seal occurred dispersed in the drift ice areas. The only major concentration was seen along the eastern part of the northernmost transect (184), where they were resting at breathing holes on the fast ice (**Figure 3.57**). The abundance in the entire survey area was estimated at 4600 individuals (not corrected for submerged animals).

Bearded seal (Erignathus barbatus)

This species occurred dispersed in the drift ice, with some concentrations on the northern part of Store Hellefiskebanke (**Figure 3.58** and **Figure 3.59**). This area is well known for its concentrations of bearded seals in winter (Boertmann et al. 1998). The abundance in the entire survey area was estimated at 1225 individuals (not corrected for submerged animals).

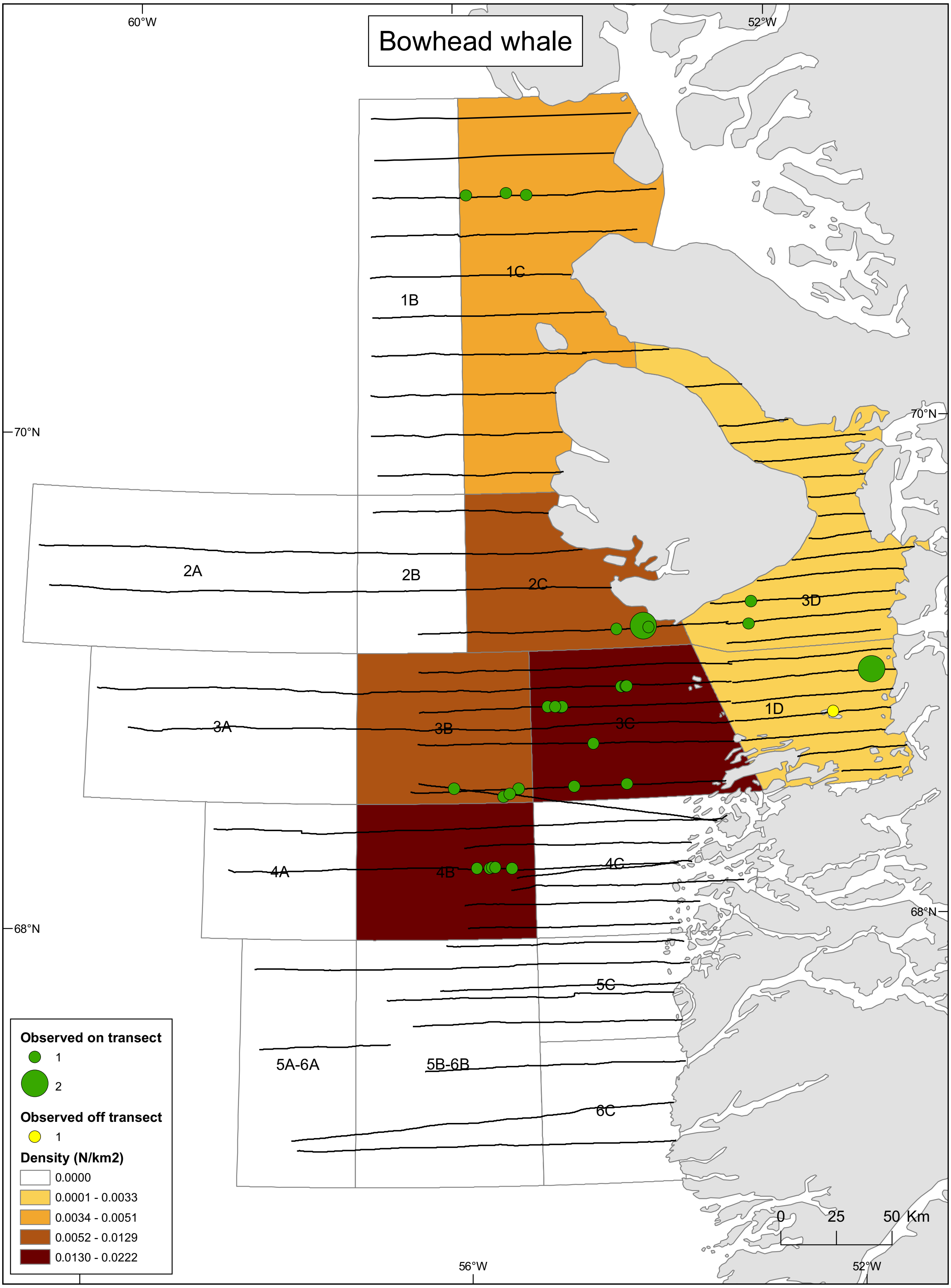


Figure 3.52. Distribution of bowhead whales (n = 32) observed on and off aerial transects in April and May 2006. Densities calculated in each of the 18 strata and shown in nuances of brown.

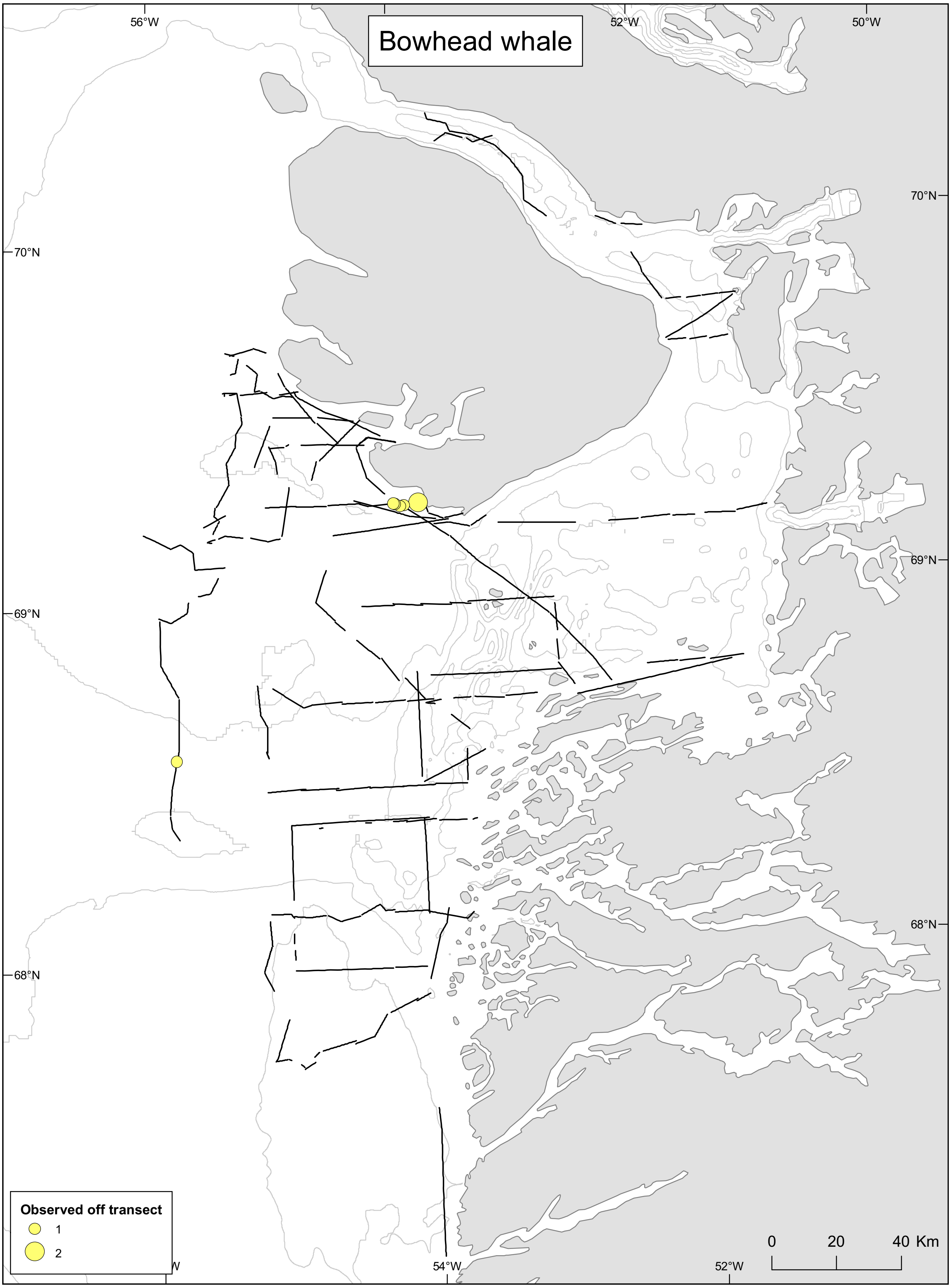


Figure 3.53. Distribution of bowhead whales (n = 11) observed off ship transects in April and May 2006.

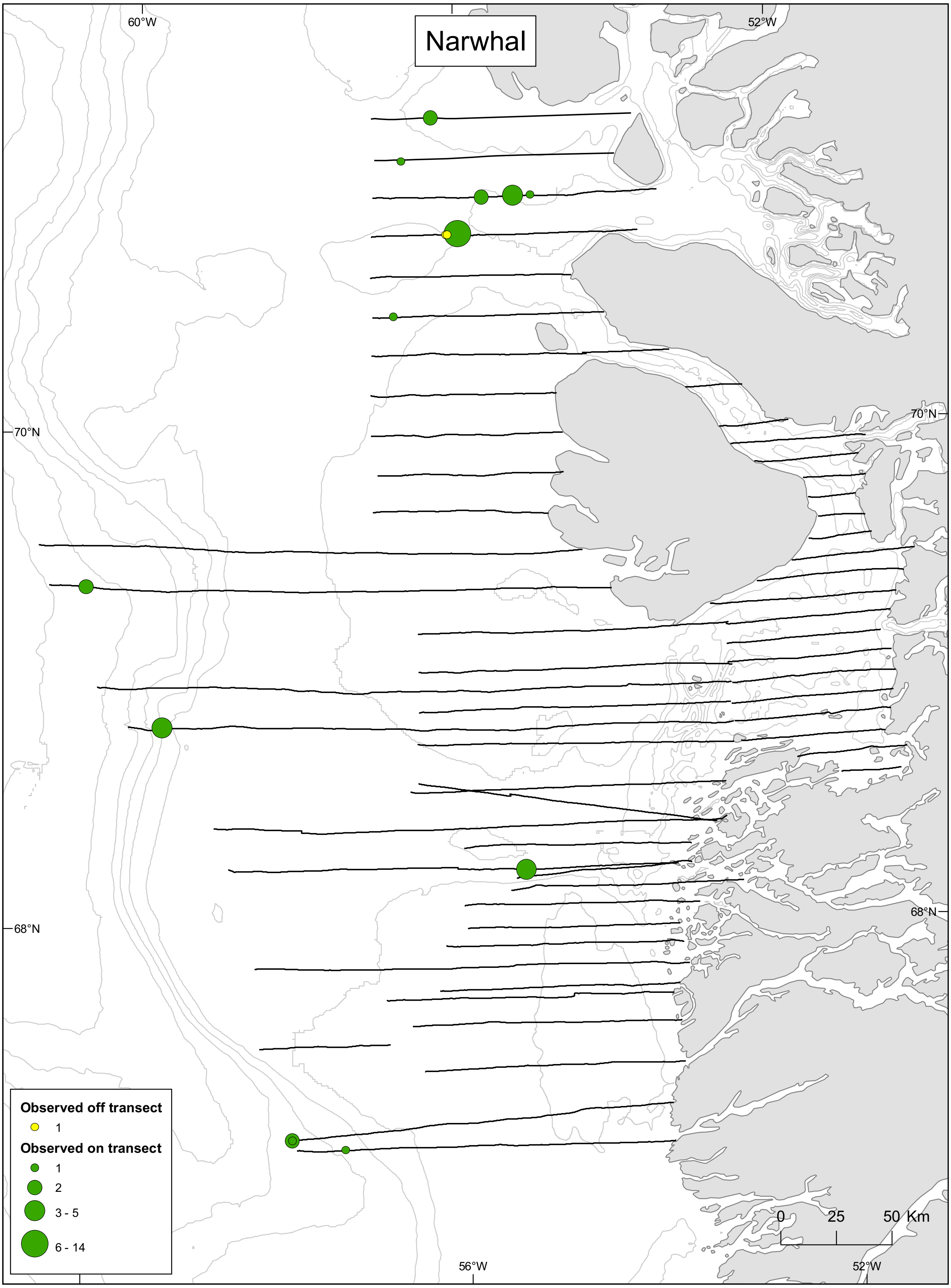


Figure 3.54. Distribution of narwhals (n = 38) observed on and off aerial transects in April and May 2006.

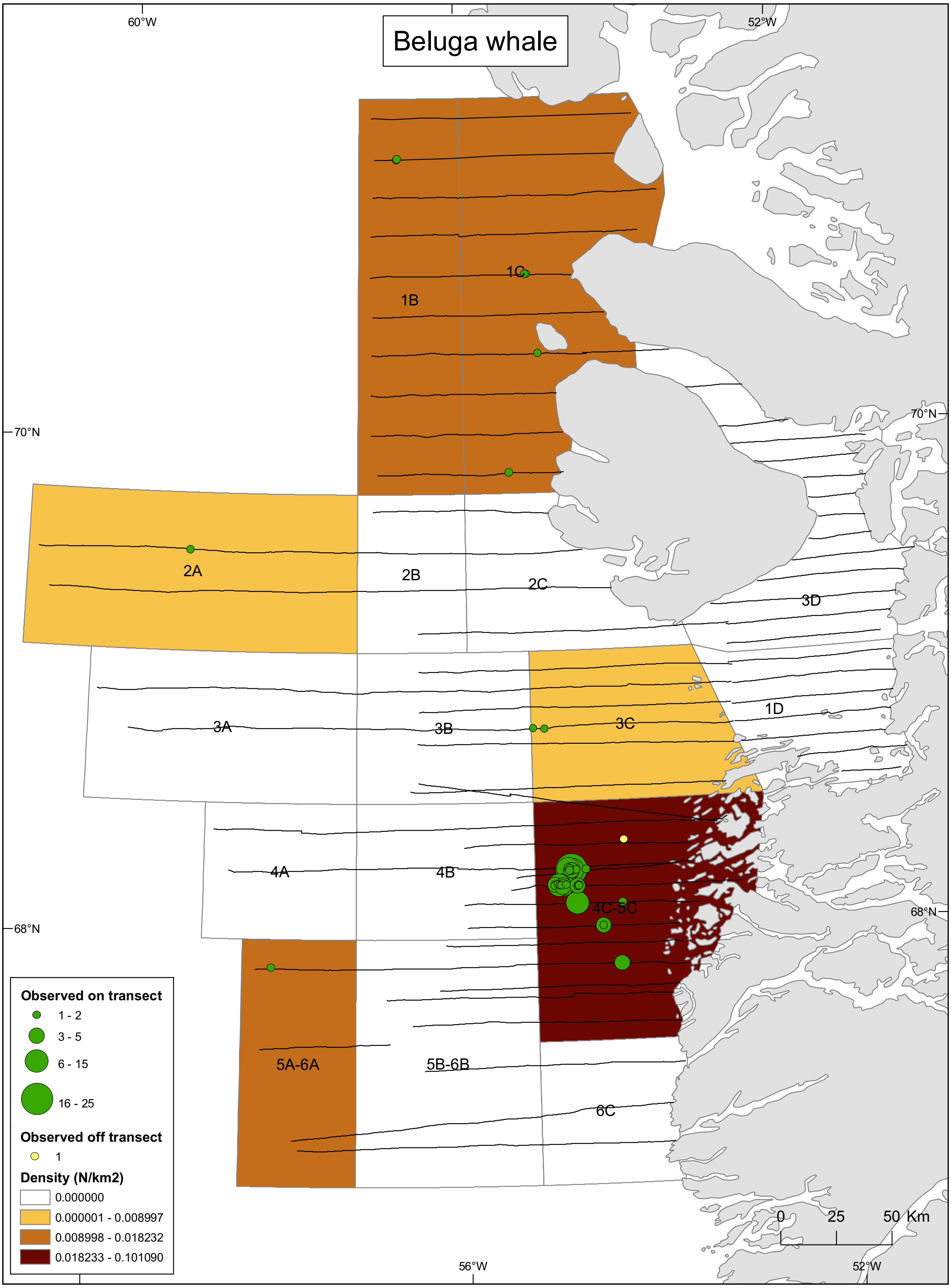


Figure 3.55. Distribution of belugas (n = 155) observed on and off aerial transects in April and May 2006. Densities calculated in each of the 18 strata and shown in nuances of brown.

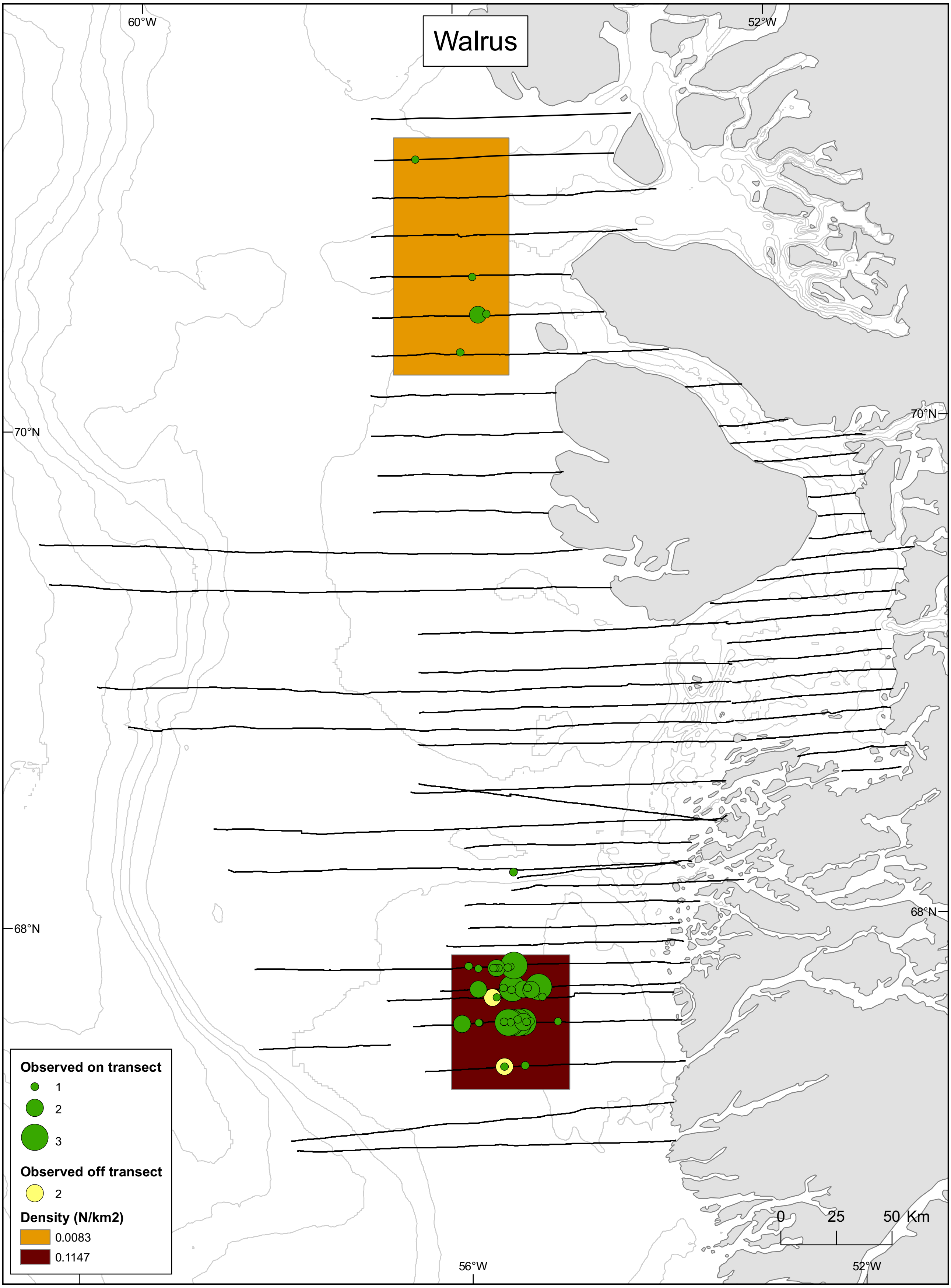


Figure 3.56. Distribution of walruses (n = 68) observed on and off aerial transects in April and May 2006. Densities calculated in 2 strata and shown in nuances of brown.

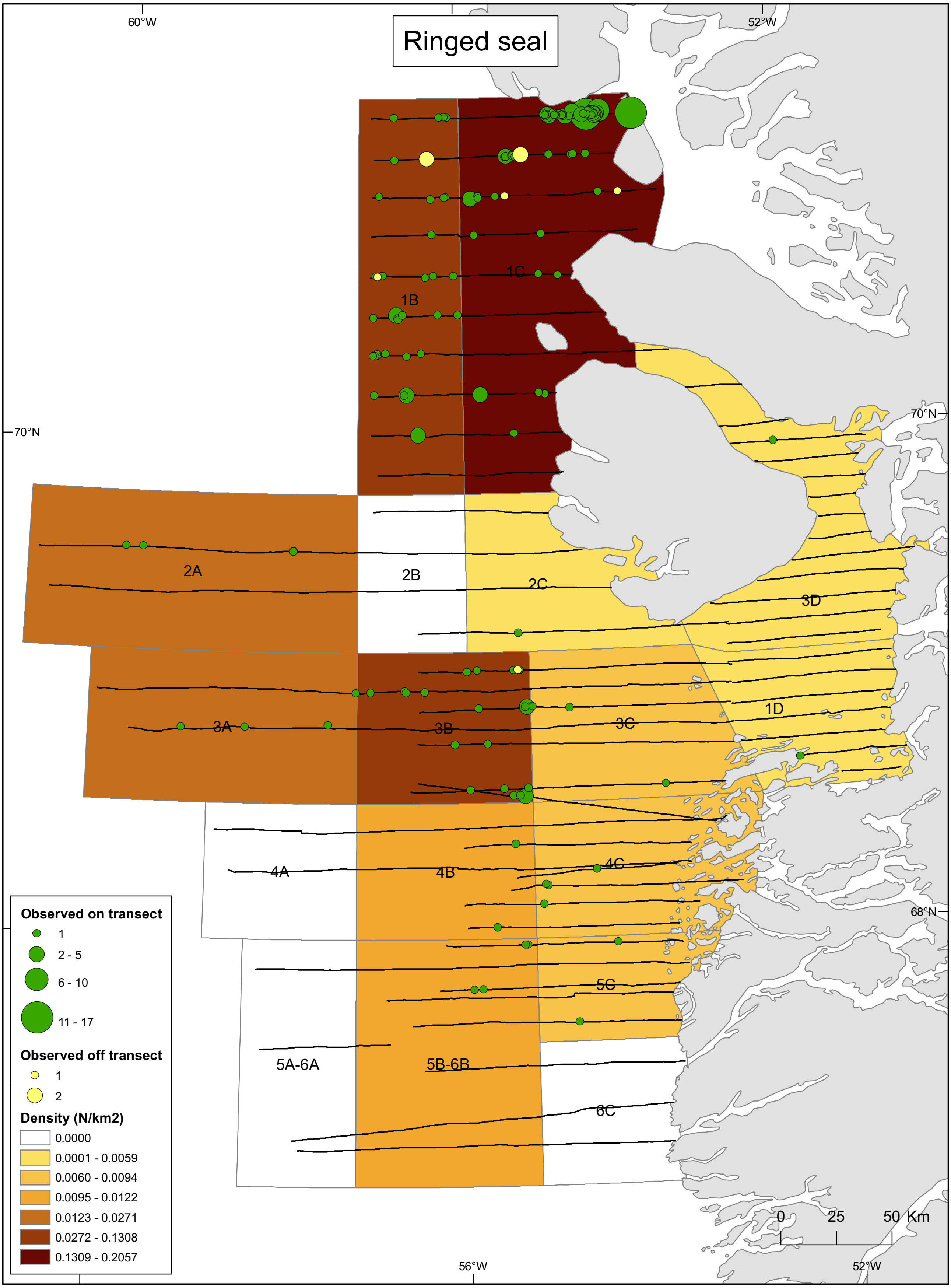


Figure 3.57. Distribution of ringed seals (n = 251) observed on and off aerial transects in April and May 2006. Densities calculated in each of the 18 strata and shown in nuances of brown.

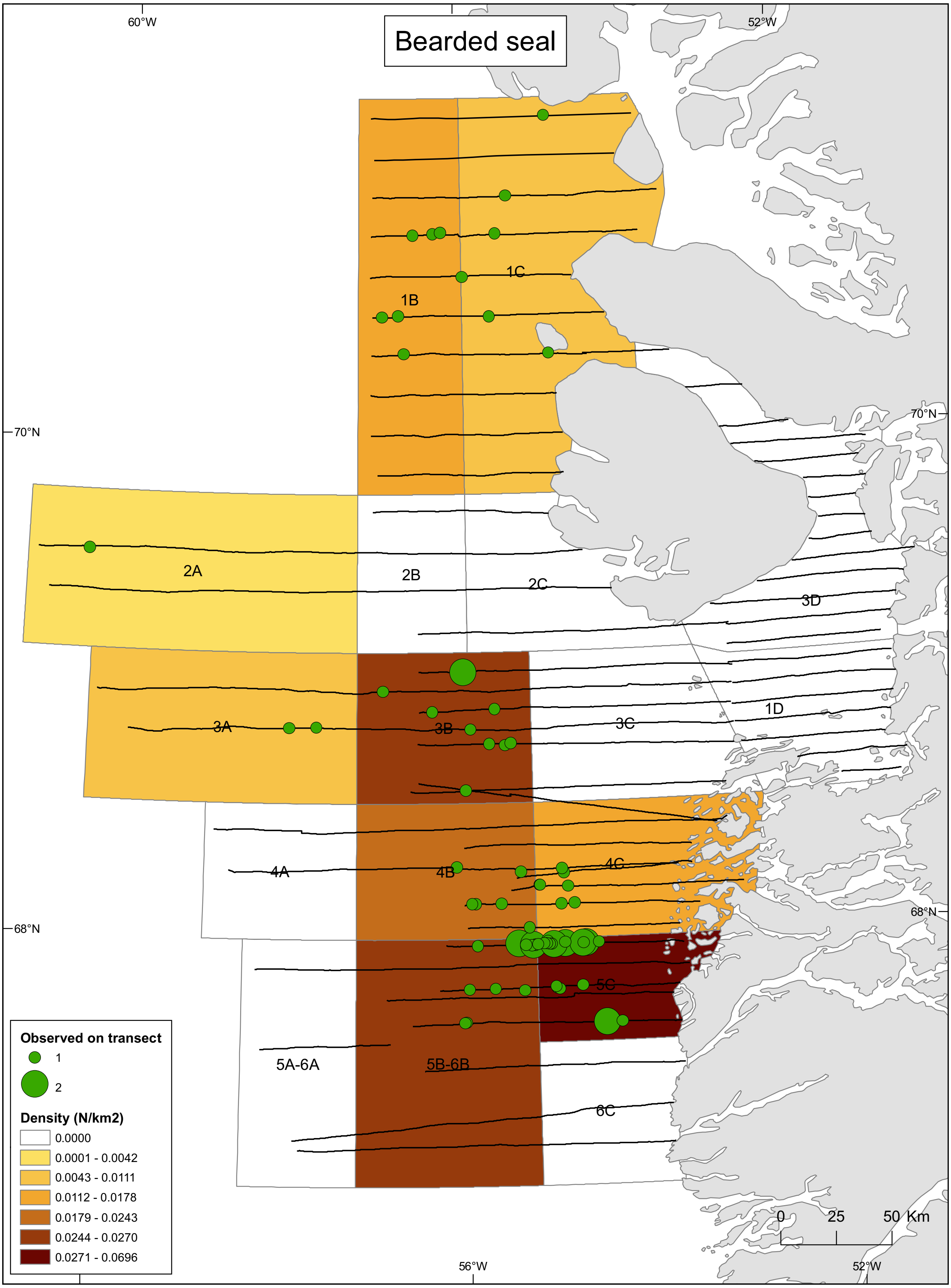


Figure 3.58. Distribution of bearded seals (n = 77) observed on aerial transects in April and May 2006. Densities calculated in each of the 18 strata and shown in nuances of brown.

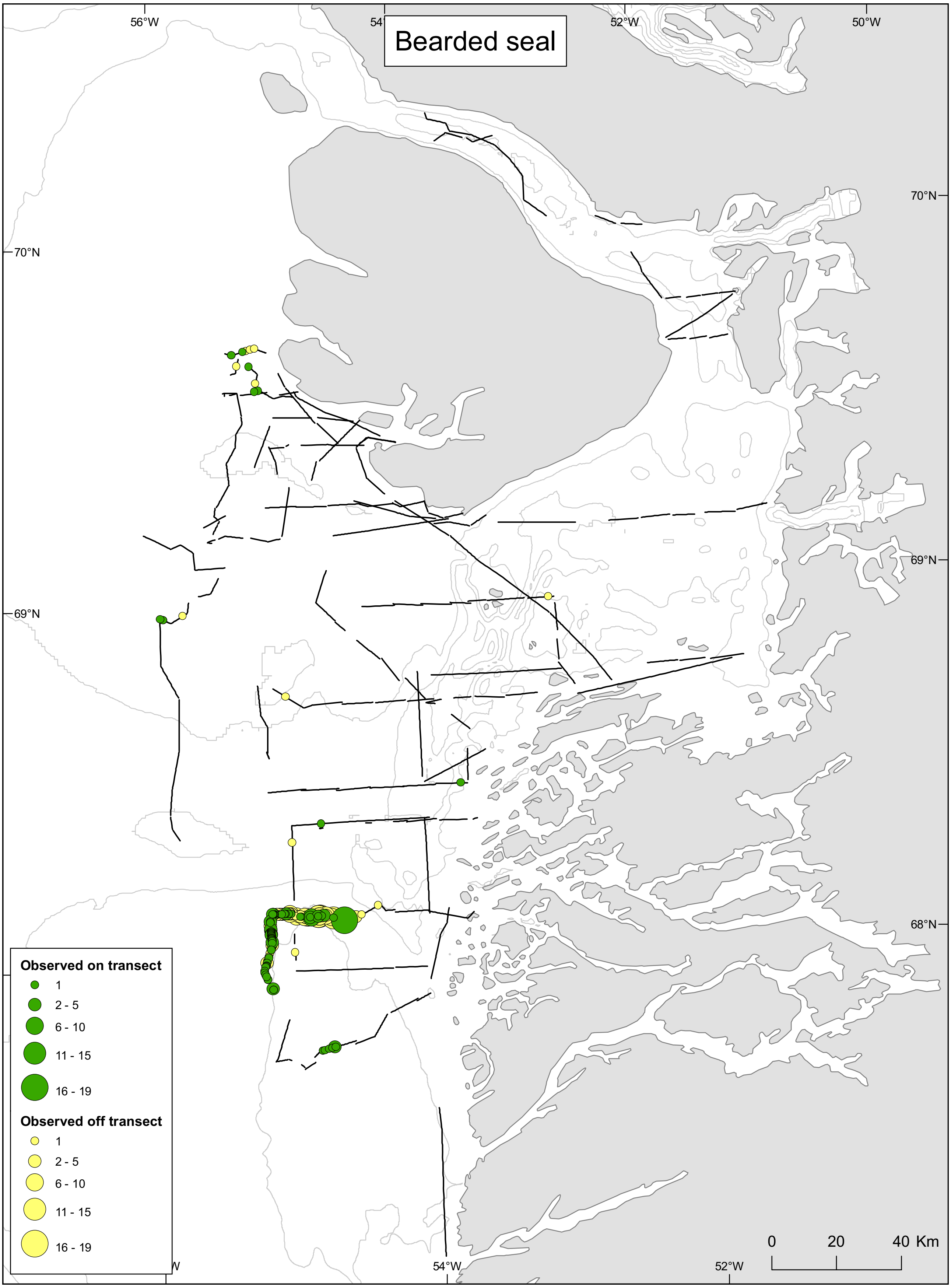


Figure 3.59. Distribution of bearded seals (n = 439) observed on ship transects in April and May 2006.

4 Discussion and conclusions

4.1 The spring phytoplankton bloom

Based on the preliminary results from observations north of Store Hellefiskebanke and the Disko Bay region from the period 18 April – 10 May, we conclude that there are at least two mechanisms for generating plankton in the region. In northern parts of Store Hellefiskebanke, the bloom starts earlier and is much stronger than observed elsewhere in the region. The plankton bloom probably starts when there is sufficient light for plankton to grow. The shallow banks keep the phytoplankton in the in the photic zone where net growth is possible. Strong tidal mixing may also feed the upper layers with nutrients, which boosts the bloom even more. In Disko Bay and west of Disko Island, the plankton bloom starts when stratification is strong enough to keep the plankton in the upper photic parts of the water column. However, Söderkvist et al. (2006) showed that only a weak stratification is needed to initiate the plankton bloom, which was generated by upwelling of warmer and more salty water from below. The first analysis of the time series at the permanent station during spring 2006 showed that the concentration of chlorophyll increased during an upwelling event in late April. The signal was not as clear as in 1997 and 2005 though, and more analyses are needed to identify the actual mechanism that initiated the plankton bloom in 2006. Vertical profiles of stratification and fluorescence along transects southwest of Disko Bay entrance do, however, illustrate the importance of vertical stratification for triggering plankton blooms.

4.2 Zooplankton distribution

The distribution pattern of the zooplankton was only weakly related to the water column structure and bloom development. In particular, it was unclear which factors were behind the large spatial variation in biomass of the quantitatively most important group, *Calanus* copepods, although biomass tended to be lower in areas where ice concentration was high. *Calanus* biomass was unusually low at Store Hellefiskebanke, perhaps because overwintering adults had not yet migrated into this relatively shallow area from deeper waters. Shrimp larvae also tended to be less abundant in areas with high ice concentrations, and showed a positive association with chlorophyll content, suggesting a link to a well-developed spring bloom. In contrast, barnacle nauplii strongly avoided stratified water and were common where ice concentration was high. In particular, they were extremely numerous at several shallow stations on Store Hellefiskebanke. This association with mixed waters and pre-bloom conditions may be explained by their benthic origin.

4.3 Seabird distribution

Seabird distribution is scale-dependent and patchy over a range of scales. At a regional scale (e.g. 300 km), it is evident from this and other studies that large numbers of seabirds each spring pass and stage in the surveyed area of south-eastern Baffin Bay, and that many species favour the eastern over the western Baffin Bay for their spring migration because of the earlier ice break-up (e.g. Mosbech and Johnson 1999). Spatial patterns of seabird distribution at the medium scale (e.g. 20 km), and the ecological factors underlying these patterns are generally complex (Fauchald et al. 2002). In this study, seabird densities and numbers generally were highest within 100 km of the coast, and for several species especially at or just north of Store Hellefiskebanke. The distribution pattern of the bottom-feeding seabirds was most clear, e.g. the distribution of king eiders confined to the shallow part of Store Hellefiskebanke was very clear and related to their maximum diving depth of 40 m. The king eider preference for the Bank area compared to the coastal areas and archipelagos is thought to be related to better forage conditions, less disturbance and a dynamic ice regime at the bank (Mosbech et al. 2006a). In contrast to the king eider, the common eider has a maximum diving depth of only 20 m, and accordingly it was distributed along coastlines and in archipelagos where ice had broken up so that foraging at shallow depth was possible.

For the pelagic-feeding seabirds, distribution patterns at the medium scale were less clear. Results from the aerial and ship-based surveys were not always in agreement, and although statistically significant associations were found between seabird distribution and aspects of the environment, the explanatory power of the preliminary models (based on ship-based data) was mostly fairly low. One problem contributing to this may be the relatively long sampling periods (23 days for the ship survey, 15 days for the aerial survey). In a highly dynamic system, where ice distribution changes rapidly over the study period and the spring phytoplankton bloom is in various stages of progress, seabird abundance and distribution are unlikely to be constant, which may cause extensive spatiotemporal heterogeneity in the observed association between seabirds and their environment. In addition, many important prey organisms for seabirds were not sampled well or at all during this survey, so that correlations had to be sought spanning at least two trophic levels, likely resulting in additional environmental noise and thus loss of statistical power. Finally, distance to land or nearest major colony was not included as a predictor of seabird distribution in these preliminary analyses. However, in some cases data from particularly the ship-based survey indicated that birds were more common and/or abundant near coasts and colonies, e.g. northern fulmars near colonies in Disko Fjord (**Figure 3.28**) and black guillemots along the SW coast of Disko Island (**Figure 3.44**). Further analyses will therefore consider distance to coast or colony as an additional predictor, which may help clarify ecologically important patterns.

In general, the patchiness, the temporal dynamics and the complexity of the marine environment make detailed predictions of pelagic seabird distribution very difficult. However, as data accumulate key areas with higher probability of high densities gradually emerge.

4.4 Marine mammal distribution

Bowhead whale, beluga, walrus and bearded seal were all patchily distributed with concentrations in areas previously known as aggregation areas for these species (Boertmann et al. 1998, Born et al. 1994, Heide-Jørgensen et al. 2007, Heide-Jørgensen & Acquarone 2002). Outside these aggregation areas, bowhead whales, walruses and bearded seals were found in low numbers in the northern part of the study area, and very few belugas were observed outside the concentration on Store Hellefiskebanke. Narwhals had probably initiated their spring migration and many may have left the area as only few were observed. Ringed seals were more evenly distributed in low densities throughout the drift ice, and the higher densities observed in the northernmost part of the study area was the result of high numbers of seals on the fast ice edge south of Svartenhuk peninsula.

4.5 Thick-billed murre diet

The proportion of empty stomachs seemed high (24%) given that the birds were caught when they were supposed to be actively feeding or resting after a meal, particularly compared to 3% empty stomachs obtained by Falk & Durinck (1993) in the same area in winter. The frequency of occurrence of fish (mainly capelin) was also lower in this study (27%) than found by Falk & Durinck (1993) (70%). These results suggest that birds found it difficult to catch large and energy-rich fish and instead had to resort to presumably less profitable invertebrate prey.

5 References

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This report describes the results of a coordinated aerial and ship-based survey of seabirds, marine mammals, and physical and biological oceanography in the Disko Bay and southeastern Baffin Bay in spring 2006. The main aim of the survey was to improve understanding of how top predators exploit the highly dynamic marginal ice zone during spring, when the ice is rapidly melting. The spatial distributions of primary production, zooplankton, seabirds and marine mammals are described, and preliminary results are presented from analyses aimed at understanding these distributions. Zooplankton biomass was dominated by *Calanus* copepods, shrimp larvae and barnacle nauplii, and the distribution of all three groups was related to ice concentration. The study area was estimated to be used by approx 1 million seabirds, including 430,000 thick-billed murres and 400,000 king eiders. King eiders were concentrated on the shallow Store Hellefiskebanke, whereas the distribution of most other seabirds was only weakly related to the physical and biological variables measured. Abundance of marine mammals was also estimated, including 1400 belugas and 450 bowhead whales.

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