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Baseline Surveys for Seabirds in the Labrador Sea

Relevés de référence sur les oiseaux marins dans la mer du Labrador

Canada

March 2016

Correct citation for this report is:

D. A. Fifield, A. Hedd, G. J. Robertson, S. Avery-Gomm, C. Gjerdrum, L. A. McFarlane Tranquilla, S. J. Duffy. 2016. Baseline Surveys for Seabirds in the Labrador Sea (201-08S). Environmental Studies Research Funds Report No. 206. St. John's. 69 pp.

Environmental Studies Research Funds

Baseline Surveys for Seabirds in the Labrador Sea (201-08S)

Final Report

Wildlife Research Division
Environment and Climate Change Canada
St. John's, Newfoundland

March 2016

Acknowledgements

We thank the Environmental Studies Research Funds (ESRF) for funding support and Dave Burley of the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) and Dave Taylor (ESRF Secretariat) for guidance and support throughout. Access to survey vessels was kindly provided in part by DFO chief scientists, and CCGS captains. Environment and Climate Change Canada (ECCC) management and administrative support was provided by Kevin Cash, Richard Elliot, François Fournier and Don Moncrieff. We thank Jack Lawson (DF0) for the opportunity to participate in aerial surveys and for fruitful discussion of survey and analysis methods. We thank the Nunatsiavut Government and NunatuKavut for support and participation in the observer training workshop. We also thank the many dedicated observers who spent long hours collecting data in often less than ideal weather conditions, and the captains and crews for their hospitality. Alejandro Buren, Francois Bolduc, Pat O'Hara, Rob Ronconi, Pierre Ryan, Sabina Wilhelm and Sarah Wong contributed to many discussions of survey techniques, analysis and mapping.

Table of Contents

List of Figures

List of Tables

1 Executive summary

The Labrador Sea is important to marine birds year-round, by supporting breeding seabird colonies during summer, and providing important staging, migration, and wintering habitat for seabirds from widespread colonies across the Atlantic. However, explicit local-scale spatial information on marine bird distribution has been limited by patchy marine survey coverage in the Labrador Sea, mostly due to logistical difficulties. To fill this gap, baseline data on seabird distribution were collected from vessels and aerial surveys in Labrador in 2013 and 2014. These data were combined with data from Environment and Climate Change Canada's Eastern Canada Seabirds At Sea (ECSAS) program, (funded in part by ESRF 2006-2009) to take advantage of new analysis methods in species distribution modeling to provide a richer description of seabird densities and distributions in the Labrador Sea.

From May 2006 to November 2014, ECSAS observers surveyed 13783.3 linear km (over 713 h) for seabirds within the Labrador Sea study area, with the most intensive effort occurring between 2012 and 2014. Surveys were conducted during all seasons, however, as survey platforms were largely ships of opportunity, effort was distributed unevenly across the study area through time. In total, ship surveys yielded 33,469 seabirds detected (12,379 flocks during 13783.3 km of transects, Table 6) in 4638 of 8392 (55%) survey segments, with dovekie, northern fulmar, black-legged kittiwake, and murres being most frequently observed. Average detection probability was 38% (CV=0.26) for all seabirds combined, ranging from a low of 31% (CV = 0.03) for dovekie to 54% (CV = 0.11) for Atlantic puffin. Density surface modelling efforts were generally successful, although depending on the species and season, reasonable predictions of seabird density were not possible for significant portions of the study area. Models explained between 21.7% and 68.3% of the deviance in the data, and position (latitude and longitude), sea surface temperature, sea surface height, bathymetry, distance to the shelf edge and eddy kinetic energy were important predictors in most models.

The Labrador Shelf and adjacent portions of the Labrador Sea were clearly important regions for seabirds, particularly during fall and winter, when average densities in areas of acceptable precision were 15.5 and 12.8 birds/km^2, respectively. During fall, relatively high densities were predicted throughout the Labrador Shelf, from the Saglek and Nain Banks south to the Labrador Trough, overlapping with areas of significant discovery licenses and coincident with southward migration of dovekies and murres from Arctic breeding colonies. Northern fulmars had the highest predicted densities in fall and winter (29.8 and 62.9 birds/km^2), followed by Black-legged Kittiwakes (13.8 and 20.6 birds/km^2), although confidence intervals were large for these species. Dovekies (17.1 and 14.8 birds/km^2) and murres (4.9 and 2.2 birds/km^2) were also numerous in fall and winter, and modeling efforts for these two species, especially murres, led to reasonable prediction throughout much of the study area. Gulls, Atlantic puffins and shearwaters were present in the study area at lower densities.

In conjunction with the DFO marine mammal surveys, four exploratory aerial surveys (2 in Oct-Nov 2013 and 2 in Aug 2014) were conducted to develop methods compatible with marine mammal observation protocols. 6,301 marine birds were counted in the 2013 surveys and 4,346 in the 2014 surveys. Northern fulmars were the most commonly detected seabird, followed by common eiders and unidentified alcids, with gulls making up the bulk of the remaining observations. The altitude of

these particular surveys (600 ft) was too high for reliable seabird observations, and many birds could not be identified to species, limiting the utility of them for seabirds.

On 13-14 November 2014 ECCC and DFO taught a Seabird and Marine Mammal Observer Training workshop in Happy-Valley Goose Bay. The workshop had 20 attendees from 6 communities (Port Hope Simpson, North West River, Happy Valley-Goose Bay, Hopedale, Makkovik and Nain) representing a diverse range of experience. Despite the diverse background of attendees (55% arrived with limited understanding of the subject), 90% reported that the workshop was extremely useful.

In consultation with researchers, C-NLOPB and industry, 21 existing seabird surveys occurring in the Labrador Sea were identified. Of these 9 were useable and imported into the ECSAS database. The others could or were not used for various reasons including survey protocol incompatibility (for industry surveys, because the ECSAS protocol was not published until 2012 and not provided to the C-NLOPB until the spring of 2015), and unavailability of data.

Overall, this program was successful in improving knowledge of seabird distribution and densities in the Labrador Sea. Although the density surface modeling proved very powerful in expanding the geographic scope of prediction beyond the available data, gaps in survey coverage remain, particularly off the continental shelf in fall and winter, and in the northern portion of the study area in all seasons. Future work should consider filling those seasonal and spatial gaps, and continuing to improve density surface modeling efforts, both in the Labrador Sea, in adjacent regions of interest to the offshore oil and gas industry.

The data analyzed in this report are available from Dave Fifield (dave.fifield@canada.ca) at Environment and Climate Change Canada.

Sommaire

La mer du Labrador est importante pour les oiseaux marins toute l'année : l'été, elle soutient les colonies reproductrices d'oiseaux marins et l'hiver, elle offre un habitat important d'escale, de migration et d'hivernage aux oiseaux marins de colonies répandues sur tout l'Atlantique. Or, il y a une lacune de données spatiales explicites à l'échelle locale sur la répartition des oiseaux marins en raison de la couverture irrégulière des relevés marins effectués dans la mer du Labrador, surtout à cause de difficultés logistiques. Pour combler cette lacune, des données de base sur la répartition des oiseaux marins ont donc été recueillies à partir de navires et de levés aériens au Labrador en 2013 et 2014. Ces données et des données du programme *Eastern Canada Seabirds at Sea* (oiseaux en mer dans l'est du Canada) ou ECSAS (partiellement financés par le Fonds pour l'étude de l'environnement de 2006 à 2009) ont été mises ensemble afin de profiter de nouvelles méthodes d'analyse dans la modélisation de la répartition des espèces pour avoir une description plus riche de la densité des oiseaux marins et de leur répartition dans la mer du Labrador.

De mai 2006 à novembre 2014, des observateurs du programme ECSAS ont effectué un relevé des oiseaux marins dans la zone d'étude de la mer du Labrador, couvrant 13 783,3 km linéaires (sur 713 heures), dont les efforts les plus intenses ont eu lieu entre 2012 et 2014. Les relevés ont été effectués pendant toutes les saisons, mais puisque ce sont des navires occasionnels qui servent

normalement de plateforme pour les relevés, pendant la période d’étude, la répartition des efforts était inégale dans l’ensemble de la zone d’étude. Les relevés des navires ont permis de détecter 33 469 oiseaux marins (12 379 bandes sur 13 783,3 km de transects; Tableau 6) dans 4 638 des

8 392 segments (55 %), dont les plus fréquemment observés étaient le mergule nain, le fulmar boréal, la mouette tridactyle et les guillemots. Pour l’ensemble des oiseaux de mer, la probabilité de détection moyenne était 38 % (CV=0,26), allant d’une faible probabilité de 31 % (CV = 0,03) pour le mergule nain à 54 % (CV = 0,11) pour le macareux moine. En général, les efforts de modélisation de la densité de surface ont été réussis. Toutefois, selon l’espèce et la saison, il n’était pas possible de faire des prévisions raisonnables quant à la densité des oiseaux marins dans des parties importantes de la zone d’étude. Les modèles ont expliqué de 21,7 à 68,3 % de l’écart dans les données, et dans la plupart des modèles, la position (latitude et longitude), la température de la surface de la mer, la hauteur de la mer, la bathymétrie, la distance jusqu’au bord du plateau continental et l’énergie de turbulence était des prédicteurs importants.

Le plateau continental du Labrador et les parties adjacentes de la mer du Labrador étaient manifestement des régions importantes pour les oiseaux marins et en particulier, à l’automne et l’hiver alors que les densités moyennes étaient de 15,5 et de 12,8 oiseaux/km^2, respectivement, dans les zones où la précision était acceptable. À l’automne, des densités relativement élevées ont été prévues pour l’ensemble du plateau continental du Labrador, des bancs Saglek et Nain vers le sud jusqu’à la fosse du Labrador, chevauchant des zones importantes de licence de découverte importante et coïncidant avec la migration vers le sud de populations de mergule nain et de guillemot de leurs colonies de reproduction dans l’Arctique. À l’automne et l’hiver, les densités prévues des fulmars boréaux étaient les plus élevées (29,8 et 62,9 oiseaux/km^2), suivies de celles des mouettes tridactyles (13,8 et 20,6 oiseaux/km^2), quoique les intervalles de confiance soient larges pour ces espèces. Les mergules nains (17,1 et 14,8 oiseaux/km^2) et les guillemots (4,9 et 2,2 oiseaux/km^2) étaient également nombreux à l’automne et l’hiver et les efforts de modélisation des deux espèces, surtout des guillemots, ont permis de faire des prévisions raisonnables pendant une grande partie de la zone d’étude. Les mouettes et les goélands, les macareux moines et les puffins étaient présents dans la zone d’étude à des densités plus faibles.

De pair avec les relevés de mammifères marins effectués par Pêches et Océans Canada, quatre levés aériens de reconnaissance (deux en octobre et novembre 2013 et deux en août 2014) ont été effectués afin d’élaborer des méthodes compatibles avec les protocoles d’observation des mammifères marins. Lors des relevés en 2013 et en 2014, 6 301 et 4 346 oiseaux marins ont été comptés, respectivement. L’oiseau marin le plus souvent détecté était les fulmars boréaux, suivis des eiders à duvet et des alcidés non identifiés. Les mouettes et goélands composaient les autres observations pour la plupart. L’altitude à laquelle ces relevés ont été effectués (600 pi) était trop haute pour faire des observations fiables sur les oiseaux marins et l’espèce de nombreux oiseaux n’a pu être identifiée, ce qui a rendu moins utiles ces observations.

Le 13 et 14 novembre 2014, Environnement et Changement climatique Canada et Pêches et Océans Canada ont tenu un atelier de formation sur l’observation d’oiseaux et de mammifères marins à Happy-Valley Goose Bay, au Labarador. L’atelier comptait 20 participants de six communautés (Port Hope Simpson, North West River, Happy Valley-Goose Bay, Hopedale, Makkovik et Nain), représentant une vaste gamme d’expérience. Malgré les antécédents divers des participants (55 % avaient une compréhension limitée du sujet de l’atelier), 90 % d’entre eux ont dit que l’atelier a été extrêmement utile.

En consultation avec des chercheurs, l'Office Canada-Terre-Neuve des hydrocarbures extracôtiers et l'industrie, 21 relevés d'oiseaux marins présents dans la mer du Labrador ont été trouvés. De ces relevés, neuf étaient utiles et ils ont été importés dans la base de données du programme ECSAS. Les autres relevés n'ont pas été utilisés pour diverses raisons, notamment l'incompatibilité du protocole d'enquête (pour les enquêtes de l'industrie, parce que le protocole ECSAS n'a été publié qu'en 2012 et non fourni à l'OCTLHE jusqu'au printemps 2015) et la non-disponibilité de données.

Globalement, ce programme a réussi à accroître les connaissances sur la répartition et les densités des oiseaux marins dans la mer du Labrador. La modélisation de la densité de surface s'est avérée très efficace pour élargir l'étendue géographique de prévision au-delà des données existantes, mais des écarts demeurent quant à la couverture des relevés et en particulier, au large du plateau continental à l'automne et l'hiver et dans la partie nord de la zone d'étude toute l'année. Pour les travaux à l'avenir, il est recommandé de considérer ce qui suit : combler les écarts saisonniers et spatiaux; continuer à améliorer les efforts de modélisation de la densité de surface, dans la mer du Labrador et dans les régions d'intérêt adjacentes à l'industrie pétrolière et gazière extracôtière. Pour consulter les données analysées dans le rapport ci-dessus, veuillez prendre contact avec Dave Fifield (dave.fifield@canada.ca) à Environnement et Changement climatique Canada.

2 Introduction

The Labrador Sea is important to marine birds year-round, by supporting breeding seabird colonies during summer, and providing important staging, migration, and wintering habitat for seabirds from widespread colonies internationally, including Canada, Greenland, Iceland, Svalbard, and the UK (Brown 1986, Huettmann and Diamond 2000, Bakken and Mehlum 2005, Frederiksen et al. 2012, Mosbech et al. 2012, Jessopp et al. 2013, Linnebjerg et al. 2013, Fort et al. 2013, McFarlane Tranquilla et al. 2013). However, explicit local-scale spatial information on marine bird distribution has been limited by patchy marine survey coverage in the Labrador Sea (Fifield et al. 2009), mostly due to logistical difficulties.

The Labrador Sea contains significant oil and gas reserves and has been a focus for resource exploration for decades (AMAP 2010). Yet, only recently has an increase in interest for offshore exploration in the Labrador Sea prompted a demand for better baseline biological data, currently sparse in this region (Fifield et al. 2009), required to support regional scale environmental assessments (C-NLOPB 2008). Seabirds are extremely vulnerable to the effects of oil at sea (Wiese and Robertson 2004, O'Hara and Morandin 2010), but determining the effect of an accidental hydrocarbon release in the marine environment is difficult when seabird densities in a particular area, and a particular season, are not known (Wilhelm et al. 2007).

Understanding the spatial and temporal extent of overlap of marine bird populations with offshore resource activities will be critical to the environmental assessment process (Camphuysen et al. 2004, Fifield et al. 2009), and to understanding potential risks to marine birds.

Since 2006 Environment and Climate Change Canada (ECCC) has developed a rigorous seabird at sea monitoring program for eastern Canada, known as the ECSAS (Eastern Canada Seabirds At Sea) program. This program has developed standardized protocols, a sophisticated data entry and management system, an inventory of required equipment (field-ready laptops and optics), training materials, a pool of qualified seabird observers with necessary safety training and analytical expertise in survey data analysis (with a specific focus on DISTANCE sampling). Previously funded ESRF projects, specifically the Offshore Seabird Monitoring Program (ESRF Report Number of 183; Fifield et al. 2009), which focused on areas of current production in Atlantic Canada, helped to move forward on many of these program components. All of these resources were available and required to initiate this study of seabird distributions in the Labrador Sea.

To portray seabird densities across Atlantic Canada waters, Fifield et al. (2009) presented means and variances for each species-group in 1° blocks of latitude and longitude. Although valid, this approach has some drawbacks, including the possibility of limited data in each block, the lack of any relationship in densities between adjacent blocks and the lack of use of any oceanographic or biological data that may help to understand drivers of seabird distributions and densities. Recent statistical advances in species distribution modeling (SDM), or density surface modeling (DSM), are providing an emerging framework that overcomes many of the constraints of the previous analysis (Miller et al 2013). Survey data are used directly to examine relationships between environmental covariates (generally collected by remote sensing) and seabird densities. Once these relationships are understood, predictions of seabird densities to areas of comparable environmental conditions are possible – even when there is no survey coverage in the immediate area (although predictions do become weaker as environmental conditions and distance from the surveyed area increases). These statistical approaches are an active area of research (Miller et al. 2013, Hedley et al. 2004), but all are based on advanced techniques and extensive experience and training are required.

This report, supported by ESRF, details the collection of baseline data on seabird distributions in the Labrador Sea that could be affected by offshore activities. We take advantage of new analysis methods in species distribution modeling to provide a richer description of seabird densities and distributions in the Labrador Sea. These methods include distance sampling analysis (Miller 2015, Buckland et al. 2001) of data collected with an appropriate protocol (Gjerdrum et al. 2012) coupled with density surface modelling of abundance (Miller et al. 2015, Miller 2013). See also the companion report, Lawson et al. (2016), for a similar modelling exercise of marine mammal occurrence in the Labrador Sea.

3 Objectives

As stated in the MOU, this project supports baseline surveys of seabirds in the Labrador Sea, in order to provide information that will support regulatory decision-making regarding mitigation of the effects of oil and gas production activities in the Labrador Sea (Figure 1).

The specific objectives of this study are to :

1. Conduct baseline surveys of seabirds in the Labrador Sea in support of ongoing oil and gas exploration and future oil and gas development;

2. To identify, collate, and integrate any existing data relevant to pelagic seabird distributions in the Labrador Sea;

3. To provide fundamental information on the distribution and species population densities of the seabirds in the study area;

4. To involve, train, and transfer expertise to local and in particular, indigenous individuals, the technical skills involved in conducting such surveys whenever possible;

5. To maintain positive control of the scientific methodology and quality of the data gathered during the surveys;

6. To ensure safety of any in-field study operations

4 Methods

4.1 Study Area

The study area is aligned with the Labrador Shelf Strategic Environmental Assessment (SEA) Area (C-NLOPB 2008), defined using NAFO regions (2G, 2H, 2J) within the Canadian EEZ.

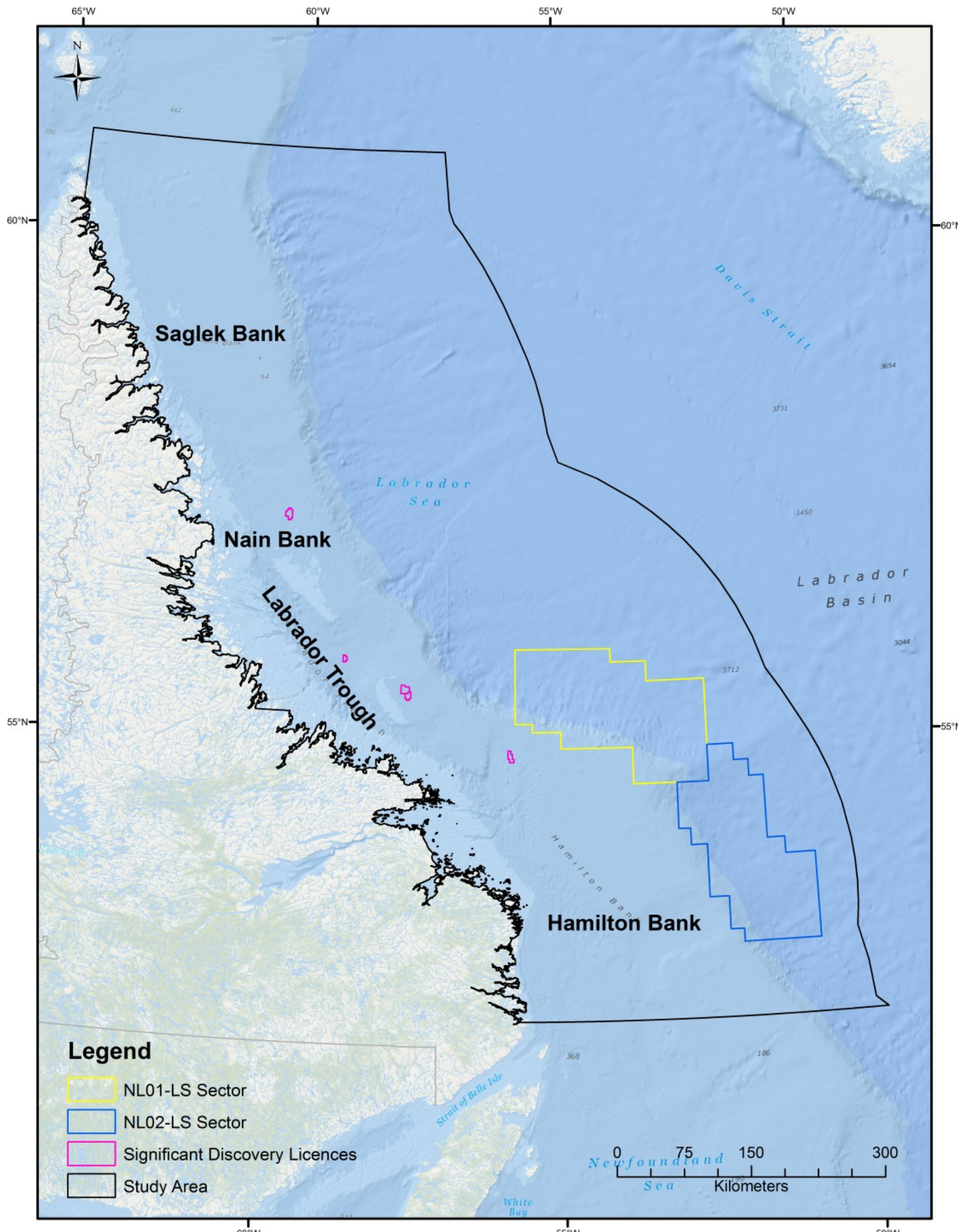


Figure 1. Labrador Sea study area, which encompasses the area of the Labrador Sea delineated by NAFO regions 2G, 2H, 2J, out to the Canadian EEZ (Exclusive Economic Zone). Significant discovery licenses and active C-NLOPB land issuance sectors in the Labrador Sea are also indicated.

4.2 Ship-based surveys

Surveys were conducted within the purview of Canadian Wildlife Service's ongoing Eastern Canada Seabirds At Sea (ECSAS) program (Gjerdrum et al. 2012), benefitting from access to a pool of experienced observers, established logistical support, and the strength of an ongoing database archive. Ship-based surveys were conducted following a standardized protocol that incorporates Distance Sampling methods (Gjerdrum et al. 2012, Buckland et al. 2001).

Observers were placed on ships of opportunity, except for four surveys that were contracted directly with funds from ESRF. Three were in the Labrador Sea; two in 2013 and 2014 aboard the F/V *What's Happening* from Nain, Labrador, captained by Mr. Joey Agnatok and one trip in 2015 aboard the F/V *Labrador Venture* from L'Anse au Loup, Labrador, captained by Mr. Lloyd Normore. These cruises were primarily intended to deploy and retrieve hydroacoustic recorders at two points on the Labrador Shelf to detect marine mammals (in collaboration with Dr. Jack Lawson, DFO; see MOU *"Mid-Labrador Marine Megafauna and Acoustic Surveys on the Labrador Coast (2010-07S)"* and associated report). The fourth survey was part of an Arctic Biodiversity Survey aboard the *M/V Cape Race* led by the University of New Brunswick. This cruise steamed from Qikiqtarjuaq, Nunavut south along the entire Labrador coast, to St. Pierre et Miquelon in September of 2014. The vessel charter was cost-shared with the University of New Brunswick, University of Guelph, Université de Laval, University of Toronto, University of Rhode Island, the Smithsonian, and Parks Canada.

Ship-based surveys were conducted using distance sampling (Buckland et al. 2001) according to the ECSAS protocol (Gjerdrum et al. 2012) and are explained more fully in Fifield et al. (2009). Briefly, surveys consisted of nominally 5-minute observation periods (called *segments*) along a continuous transect line. Coordinates at the beginning and end of each segment were recorded using ship-based navigation systems, puck-style GPS's, or with hand-held GPS units. Environmental variables were collected and updated at the beginning of each segment (Table 1; see also Gjerdrum et al. 2012). We recorded birds on the water continuously along each segment, but we used a snapshot approach for flying birds (Tasker et al. 1984, Gjerdrum et al. 2012). Distance categories (see Table 2) were assigned by measuring the perpendicular distance to each individual bird (or the centroid of each group of birds) with the help of a pre-marked custom ruler constructed for each observer-vessel combination (Gjerdrum et al. 2012). Data was either entered directly into the ECSAS Microsoft Access database using voice recognition software, or recorded on datasheets and entered into the database later (see full details in Fifield et al. 2009).

Table 1. Environmental variables collected during ship-based surveys.

Variable Name
Visibility (km)
Weather code
Glare conditions code
Sea state code
Wave height (m)
True wind speed (knots) OR Beaufort scale
True wind direction (deg)
Ice type code
Ice concentration code

4.3 Aerial surveys

The existence of aerial marine mammal surveys in the Labrador Sea (*"Mid-Labrador Marine Megafauna and Acoustic Surveys on the Labrador Coast (2010-07S)"*(Lawson et al. 2016), led by Dr. Jack Lawson, DFO) gave us the opportunity to collaborate and attempt to survey marine birds in 2013 and 2014. The survey route, altitude, and speed were pre-determined by the marine mammal survey protocol and we developed a specific aerial survey protocol in this context. Surveys were flown at a nominal flight speed of 100 knots at an altitude of 600 feet using a Twin Otter aircraft operated by Air Labrador based out of Happy Valley-Goose Bay, Newfoundland and Labrador. Cross-shelf transects were designed to capture variation in marine mammal (and seabird) distribution across a variety of depths and to ensure survey coverage beyond the shelf edge. Flight path and direction were chosen to ensure proximity to airstrips and fuel throughout the duration of the survey for logistical and safety considerations.

In 2013, data were collected by two seabird observers from both the port and starboard sides simultaneously, with observers switching positions at regular intervals during replicate 1 and remaining on the same side during the entirety of replicate 2 (see Results). In 2014, both seabird observers were seated on the port side. Two types of window (bubble and flat) were tested. Bubble windows allowed observers to see directly below the aircraft while flat windows occlude this part of the transect. In 2013, the port observer used a bubble window while a flat window was used on the starboard side. In 2014, the front observer was equipped with a large bubble window and a smaller one was used in the rear of the aircraft.

Aerial surveys were conducted using distance sampling where perpendicular distance is measured from the survey line to detected animals. This allows for the estimation and correction during analysis of imperfect animal detection (see Section 4.4.2, and Buckland et al. 2001, Gjerdrum et al. 2012). Similar to ship-based surveys, birds were assigned to distance categories consisting of bands of defined width running parallel to the survey line (Table 2, Gjerdrum et al. 2012; Camphuysen et al. 2004). The distance category for a flock containing multiple individuals was defined by the location of the centroid of the flock.

Distance categories were delimited by marking their boundaries on the observer window using a dry erase marker and a SUUNTO clinometer to measure angles down from the horizon (Table 2). In 2013, two different transect widths and distance category systems were used while in 2014, the wider transect width was used (Table 2). For replicate 1 (2013), categories were lettered A, B, C, D, and E and corresponded to the same distance ranges used in the ship-based survey (Gjerdrum et al. 2012; Table 2). During replicate 1 (2013), there was a large blind spot on the starboard side due to the flat window. Also, due to the flight altitude, the distance bands appeared very narrow to the observer. To remedy this, during replicate 2 (2013) and in 2014, the distance bands were widened and the blind spot was accounted for. The new bands were lettered Z , A, B, C, D, and E, and corresponded to distance ranges 0-100, 100-200, 200-300, 300-500, 500-700, and > 700 metres respectively (Table 2). Distance band Z was only visible to observers with a bubble window. Clinometer angles (Table 2), corresponding to desired distances were calculated using an arc distance formula, which takes into account the curvature of the earth (Lerczak and Hobbs 1998).

For replicate 1 (2013) and all surveys in 2014, observers recorded data by dictating observations into a digital voice recorder and recorded flight track information using a Garmin GPSmap 62s handheld GPS. For replicate 2 (2013), the starboard side observer used this same equipment, but the port side observer used a Panasonic Toughbook laptop linked to a Garmin GPSmap 78s handheld GPS and a Plantronics Digital DSP 400 headset with microphone connected to the computer. Recordings were captured using United States Fish and Wildlife Service (USFWS) VoiceGPS software. For replicate 1 (2013), data were recorded to the nearest minute, with time read from the voice recorder display. For replicate 2 (2013), data were recorded to the nearest second, with time automatically recorded with the computerized system and manually recorded from a stopwatch with the voice recorder system (observations from replicate 2 were subsequently binned into one-minute segments during data analyses to ensure similar count units across both replicates). Recordings from voice recorders and the USFWS VoiceGPS system were saved to a .wav file for backup and transcribed to a Microsoft Excel file (.xls). Coordinate information for each observation was interpolated by matching the time dictated into the voice recording or captured by the software with the time in the track file recorded from the handheld GPS.

Environmental data (Table 1) were also collected for the aerial surveys.

Table 2. Distance categories for aerial and ship-based surveys, and clinometer angles used for aerial surveys for aircraft flying at a nominal 600’.

Aerial Replicate 1 (2013 only) and Ship-based Surveys		
Distance category	**Distance band (m)**	**Clinometer angle of top of band (aerial)**
A	0-50	74.8
B	50-100	61.5
C	100-200	42.7
D	200-300	31.6
E	> 300	N/A

Aerial Replicate 2 (2013) and all 2014 surveys		
Distance category	**Distance band (m)**	**Clinometer angle of top of band (aerial)**
Z	0-100	61.5
A	100-200	42.7
B	200-300	31.6
C	300-500	20.2
D	500-700	14.8
E	> 700	N/A

4.4 Ship-based data analysis

4.4.1 Data extraction and filtering

All survey data within the study area collected using distance sampling with perpendicular distances (2006-2008, 2011-2014, Gjerdrum et al. 2012) were extracted from the ECSAS database version 3.38. However, data collected 2009-2010 under the ECSAS programme differed in its distance sampling methodology and therefore were not used in this analysis. Only data collected from moving vessels whose speed exceed 4 knots were included (Gjerdrum et al. 2012). Certain taxa (i.e., gulls, Northern fulmar, shearwaters, and black-legged kittiwake) are known to be attracted to fishing vessels, which can artificially inflate densities of these birds around such vessels. Therefore, observations of these taxa during DFO trawl surveys (10 of 35 trips) were removed prior to analysis.

4.4.2 Modeling approach

We produced separate analyses for eight species guilds, each consisting of a single species or a group of similar species (Table 3). For each guild, a seasonal spatial predictive model was constructed in R 3.2.3 (R Core Team 2014) following a two-stage density surface modeling approach (Miller et al. 2013) using the Distance v. 0.9.4 (Miller 2015) and dsm v. 2.2.9 (Miller et al. 2015) R packages.

Table 3. List of eight seabird guilds analyzed for this report.

Taxon	Common name	Scientific name
Atlantic puffin	Atlantic puffin	*Fratercula arctica*
Black-legged kittiwake	Black-legged kittiwake	*Rissa tridactyla*
Dovekie	Dovekie	*Alle alle*
Gulls	Herring gull	*Larus argentatus*
	Iceland gull	*Larus glaucoides*
	Glaucous gull	*Larus hyperboreus*
	Great black-backed gull	*Larus marinus*
	Lesser black-backed gull	*Larus fuscus*
	Sabine's gull	*Xema sabini*
	Unidentified gull	
Murres	Common murre	*Uria aalge*
	Thick-billed murre	*Uria lomvia*
	Unidentified murre	
Northern fulmar	Northern Fulmar	*Fulmarus glacialis*
Shearwaters	Great shearwater	*Puffinus gravis*
	Manx shearwater	*Puffinus puffinus*
	Sooty shearwater	*Puffinus griseus*
	Unidentified shearwater	
All seabirds	All of the above plus:	
	Arctic tern	*Sterna paradisaea*
	Black guillemot	*Cepphus grille*
	Great skua	*Stercorarius skua*
	Leach's storm-petrel	*Oceanodroma leucorhoa*
	Long-tailed jaeger	*Stercorarius longicaudus*
	Northern gannet	*Morus bassanus*
	Parasitic jaeger	*Stercorarius parasiticus*
	Pomarine jaeger	*Stercorarius pomarinus*
	Razorbill	*Alca torda*
	Red phalarope	*Phalaropus fulicaria*

Red-necked phalarope	*Phalaropus lobatus*
South polar skua	*Stercorarius maccormicki*
Unidentified storm-petrel	
Unidentified alcid	
Unidentified tern	
Unidentified skua	
Unidentified jaeger	
Unidentified phalarope	
Wilson's storm-petrel	*Oceanites oceanicus*

Stage 1. The first stage, detection function fitting, accounts for the fact that some birds are unavoidably missed during surveys (Buckland et al. 2001). For each guild, a detection function was fitted modeling guild detectability as a function of distance from the observer and other covariates including observer identity flock size, wind speed, wave height, season, and bird behavior: flying versus swimming (Thomas et al. 2010, Marques et al. 2007). The process of fitting a detection function to the histogram of observed distances consists of fitting a variety of smooth curve shapes to the histogram and selecting the one with the best fit (Figure 2). The mathematical properties of the chosen curve are then used estimate detectability, also known as the detection probability. The suite of curves fitted to the histogram is generated by one of two basic curve shape family equations (also known as *key functions*): the half-normal and the hazard-rate functions. These basic key function curve shapes are modified by the values of the covariates. This process can be envisioned as using the covariate values to induce extra "bendiness" and/or "stretching/shrinking" to the basic curve shape to make it fit the histogram better, thereby providing a highly flexible facility to fit a smooth detection function curve to the histogram of distances (Marques et al. 2007).

Best models for each guild were selected using Akaike Information Criteria (AIC)[1], and model fit was assessed using plots of model fit to distance histograms, and through χ^2 goodness-of-fit tests. The resulting detection function was then used to estimate the density of birds in each survey segment (Hedley et al. 2004).

[1] The **Akaike information criterion** (**AIC**) is a measure of the relative quality of statistical models for a given set of data. Given a collection of models for the data, AIC estimates the quality of each model, relative to each of the other models. Hence, AIC provides a means for model selection.
Source: https://en.wikipedia.org/wiki/Akaike_information_criterion

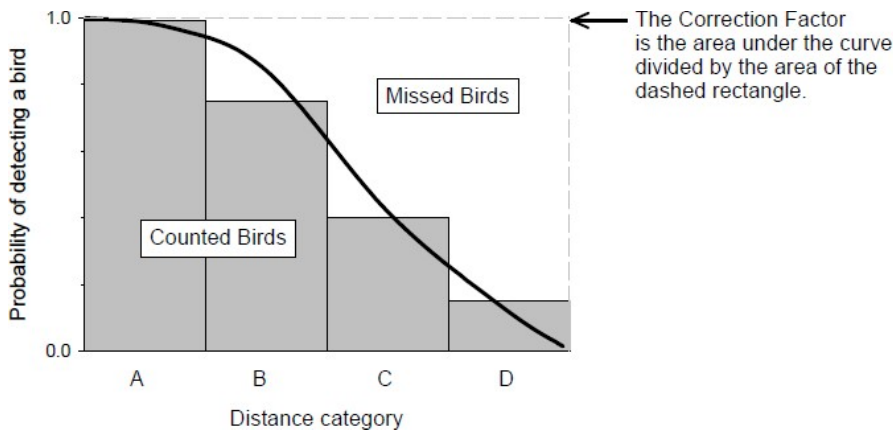


Figure 2. Typical histogram of observed distances with fitted detection function (smooth black curve). For our study the distance categories were A: 0-50m, B: 50-100m, C:100-200m, D:200-300m. The detection probability, labeled "Correction Factor" here is computed as the area under the curve divided by the area of the dashed rectangle. Adapted from Gjerdrum et al. (2012).

Stage 2. In the second stage, we constructed seasonal Generalized Additive Models (GAMs, Wood 2006) of the per-segment densities as a function of environmental covariates (see Section 4.4.2.1) in order to understand potential drivers of bird density in areas that we surveyed. A GAM can be envisioned as linear model constructed from an additive combination of parametric terms (modeling linear relationships) and smooth functions ("smooths" hereafter) of some predictor variables (Figure 3). Each smooth can be thought of as a "wiggly" curve fit to the data. The smooth curves are constructed from thin-plate regression splines and the extent of "wiggly-ness" required to fit the data is computed automatically by a statistical algorithm.

GAMs were fitted to the per-segment density data using both negative binomial and Tweedie response distributions. For each distribution, separate main effects and seasonal interaction models were fitted yielding four separate initial full models containing all environmental covariates. Main effects models contained smooths to model the additive effect of each environmental covariate, but the shape of these smooths was constrained to be constant across seasons. Seasonal interaction models differed only in that a separate smooth was fitted for each covariate in each season allowing the nature of the relationship to vary seasonally. A parametric (i.e., non-smooth) term for each season was also initially included in all models.

Model refinement progressed by backwards selection of each of the four initial models by refining all smooth terms first, followed by parametric terms.

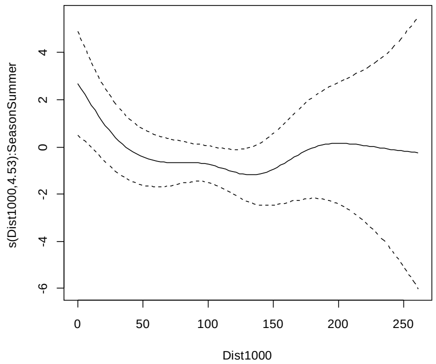
Refinement of smooth terms consisted of either replacing a smooth term by a parametric one (if warranted), or by removing the term, and then refitting the model and repeating the process until all terms had been considered. At each step, the smooth term with the lowest estimated degrees of freedom (EDF – a measure of "wiggly-ness") was considered. Only those with terms with EDF less than 1.5 were considered for replacement or removal. Such a low EDF is indicative of a smooth that has very little "wiggly-ness" and thus doesn't really require a smooth term at all since it can be represented by a parametric (linear relationship) term. Such smooth terms were replaced by parametric terms, but only if the slope of the relationship was significantly different from 0 (i.e., if its p-value was ≤ 0.01) and were removed otherwise (Figure 3). When replacing smooth terms with parametric terms in seasonal interaction models (where the shape of the smooth curve for a term was allowed to differ across seasons), the newly inserted parametric term included an interaction with season to allow the slope of the linear relationship to vary by season.

Refinement of parametric terms consisted of removing those whose p-value was ≥ 0.01, and interactions were removed before main effects.

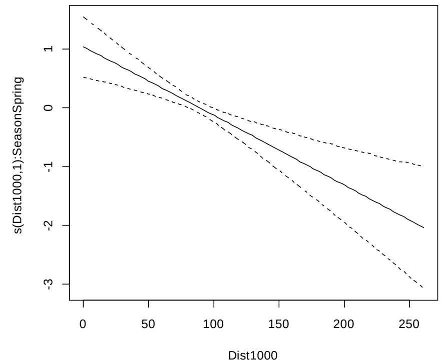
QQ-plots of the four models obtained through this backward selection process plus the original four full models before backward selection (for a total of eight candidate models) were compared in order to select a single “best” model. When two or more models had equally good QQ-plots, the model with the best AIC and percentage of deviance explained was selected.

Finally, we used the best fitted model for each guild to predict to areas we did not survey producing a map of predicted density in each 2km x 2km cell of the entire study area for which the same environmental covariates were available. Maps of model uncertainty depicting coefficient of variation (CV) were produced at a resolution 6 km x 6 km due to computer memory constraints.

A.



B.



C.

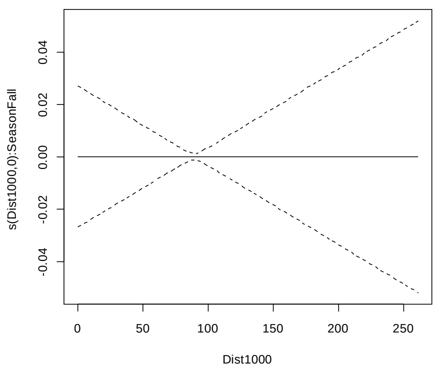


Figure 3. Example plots of 3 smooth terms employed in a Generalized Additive Model (GAM) that show the seasonal effect of distance to the 1000 m isobath on bird density that were A) retained in the model (Atlantic puffin), B) replaced with a parametric term (gulls), and C) removed from the model (gulls).

4.4.2.1 Environmental covariates used in modeling

To model the density (or equivalently, abundance) of seabirds in the Labrador Sea, we used a suite of environmental variables (Table 4) that have either been demonstrated or could be expected to correlate with the distribution or abundance of seabirds at sea (Louzao et al. 2006, 2011; Wakefield et al. 2009; Oppel et al. 2012). Marine Geospatial Ecology Tools (MGET; Roberts et al. 2010), which run as a toolbox inside ArcGIS, were used to extract (or interpolate) values for the dynamic and most of the static variables associated with the starting position of each segment (Table 4). Values of sea surface temperature (SST) (JPL MUR MEaSUREs Project 2010), and anomalies in both sea surface height (SSH), and eddy kinetic energy (EKE) (AVISO 2015) were extracted directly using MGET Data Products tools. To estimate spatial gradients in SST (SSTG), monthly rasters of SST climatology were first created, and gradients subsequently estimated as a proportional change (PC) within a surrounding 3x3 grid cell moving window as follows: PC = [(SST maximum value-SST minimum value) x 100]/(SST maximum value). SST minimum and maximum rasters were created from the monthly climatologies using the Focal Statistics tool, with subsequent algebra executed using the Raster Calculator, both found within the ArcGIS Spatial Analyst toolset. Static environmental variables (bathymetry and its derivatives) were determined from ETOPO2 grids (National Geophysical Data Center 2006) which is based on satellite altimetry and shipborne ground-truthing measurements. The spatial gradient in bathymetry (BathyG) was estimated as indicated above for the gradient in SST, and distance to the continental shelf break (Dist1000, defined as the 1000 m contour) was calculated using the Near tool within ArcGIS Analysis toolset.

Table 4. List of environmental variables used to model the density of seabirds within the Labrador Sea.

Variable	Product/Dataset	Spatial resolution	Temporal resolution	Description
Dynamic variables				
Sea surface temperature (SST, °C)	GHRSST L4/ JPL-L4UHfnd-GLOB-MUR	0.01°	Daily	L4 interpolated sea surface temperature
SST gradient (SSTG)	Derived from GHRSST L4/ JPL-L4UHfnd-GLOB-MUR	0.01°	Monthly	Spatial gradient in sea surface temperature, derived from monthly climatologies
Sea surface height anomaly (SSH, m)	AVISO	0.25°	Monthly	Anomaly in sea surface height
Eddy kinetic energy (EKE, m^2/s^2)	AVISO	0.25°	Monthly	Anomaly in eddy kinetic energy
Static variables				
Bathymetry (m)	ETOPO2	0.03°	-	Water depth
Bathymetry gradient (BathyG)	Derived from ETOPO2	0.03°	-	Spatial gradient (slope) in water depth
Distance to 1000 m contour (Dist1000)	Derived from ETOPO2	-	-	Distance to the 1000 m depth contour

Environmental data used to predict seabird abundance or density
One of our main objectives was to provide spatially explicit estimates (or predictions) of seabird density throughout the study region within the Labrador Sea, throughout the year. As seabird density distribution is known to vary seasonally, following our modeling efforts for each guild, we generated seasonal predictions across the study region using a 2 km x 2 km prediction grid. The spatial resolution of this grid was chosen to match the segment length, which was approximately 2 km. Each square within the prediction grid was populated with the static variables listed in Table 4, along with seasonally averaged values for the dynamic covariates recorded over the past 10 years (2005-2014). To generate these dynamic covariate layers, we first used MGET Data Products tools to create monthly rasters for the period January 2005 to December 2014, and then the ArcGIS Raster calculator tool (Spatial Analyst toolset) to create averages based upon the following seasonal categorizations - Summer: June-August, Fall: September-October, Winter: November-March, and Spring: April-May. Seasonal spatial gradients in SST were calculated as indicated above for the modeling step, but using the seasonally averaged SST rasters as input. Values for the prediction grid were obtained using an MGET Spatial and Temporal Analysis tool (“Project Raster to Template”), which projected each environmental raster to the coordinate system, cell size and extent of the prediction grid.

Ice coverage within the study area
To estimate the portion of the study area that may be ice covered, and therefore unavailable as habitat for seabirds, we obtained ArcGIS shapefiles containing weekly climatologies of median ice concentration for the East Coast and Northern Canadian Waters for the period 1981-2010, as compiled by the Canadian Ice Service (http://ec.gc.ca/glaces-ice/). As we were interested in the *maximum* seasonal median ice extent where ice concentrations exceeded 9-9+ (i.e., waters that were > 90% ice covered), we first selected these concentrations and then used the ArcGIS Merge tool (Data Management Tools) to create a single polygon for each season.

4.4.3 Mapping of results

Two seasonal maps were produced for each of the 8 guilds: the first showing estimated density at a resolution of 2 km x 2 km, and the second showing the uncertainty in the density estimates at a resolution of 6 km x 6 km (see Appendix 1).

4.4.4 Seasonal density estimates

For each seabird guild, seasonal density estimates (birds/km^2) were produced for areas where acceptable density surface model precision was achieved. Estimates were considered to have acceptable precision if their associated CVs were ≤ 2 and predictions were generated using values inside the range of our sampled covariates. These area varied by guild and season (see maps in Appendix 1).

5 Results

*5.1 **Objective 1.** Conduct baseline surveys of seabirds in the Labrador Sea in support of ongoing oil and gas exploration and future oil and gas development*

5.1.1 Ship-based Surveys

From May 2006 to November 2014, ECSAS observers surveyed 13,783.4 linear km (over 713 h) for seabirds within the Labrador Sea study area (Table 5, Table 6, Figure 4), with the most intensive effort occurring between 2012 and 2014. In total, 34,469 seabirds were counted, with dovekie, northern fulmar, black-legged kittiwake, and murres being most frequently observed. Surveys were conducted during all seasons; however, as survey platforms were largely ships of opportunity, effort was distributed unevenly across the study area through time (Figure 5). The most complete spatial coverage was achieved in summer, when surveys were conducted from Saglek Bank in the north to Hamilton Bank in the south, both on and off the Labrador Shelf, while the poorest spatial coverage occurred in winter when most surveys were concentrated in the south in the vicinity of Hamilton Bank (Figure 5). Effort was most intense in fall, with shelf waters south of and including the Nain Bank being well surveyed. Seasonal differences in the spatial distribution and intensity of survey effort have implications for the precision of seabird density estimates, as demonstrated below.

Table 5. Details of 35 survey trips whose data are analyzed in this report. Surveys supported by the ESRF during this study (or previously) are highlighted in bold.

Start date	End date	Observer	Vessel	Survey time (hours)	Survey length (km)	Birds counted
20-Jul-2012	02-Aug-2012	Wong, Sarah	Louis St Laurent	14.0	413.1	312
18-Nov-2013	07-Dec-2013	Toms, Brad	Hudson	5.7	128	145
19-Nov-2006	**04-Dec-2006**	**Fifield, David Donaldson, Garry**	**Hudson**	**3.0**	**59.7**	**56**
24-May-2006	08-Jun-2006	Gjerdrum, Carina	Hudson	11.0	265.7	1831
10-May-2007	27-May-2007	Gjerdrum, Carina	Hudson	21.0	490.0	369
25-Jun-2007	07-Jul-2007	Bolduc, Francois	Des Groseilliers	5.2	131.9	107
04-Jul-2007	20-Jul-2007	Wells, John	Louis St Laurent	7.2	189.4	28
20-May-2008	03-Jun-2008	Ronconi, Rob	Hudson	14.2	349.4	310
21-Nov-2011	10-Dec-2011	Ryan, Pierre	Hudson	6.0	135.9	273
13-May-2012	06-Jun-2012	Duffy, Steve	Maria S. Merian	57.1	1192.1	628
03-Oct-2012	16-Oct-2012	Mallam, Peter	Teleost	33.1	512.7	352
30-Oct-2012	13-Nov-2012	Wells, Regina	Teleost	32.9	519.0	299
14-Nov-2012	27-Nov-2012	Mallam, Peter	Teleost	7.2	106.0	46
19-Nov-2012	09-Dec-2012	Ryan, Pierre	Hudson	6.6	147.5	280
07-May-2013	28-May-2013	Maftei, Mark	Hudson	26.0	540.8	1192
09-Jul-2013	28-Jul-2013	Ludkin, Rick	Teleost	33.8	611.0	647
19-Jul-2013	01-Aug-2013	Wong, Sarah	Louis St Laurent	8.2	203.8	252
14-Aug-2013	**17-Sep-2013**	**Ludkin, Rick**	**Hudson**	**58.9**	**1152.9**	**4281**
17-Oct-2013	**20-Oct-2013**	**Avery-Gomm, Stephanie**	**What's Happening**	**13.1**	**187.6**	**879**
04-Oct-2013	**15-Oct-2013**	**Boucher, Megan**	**Teleost**	**16.2**	**273**	**430**
16-Oct-2013	**28-Oct-2013**	**Wells, Regina**	**Teleost**	**50.4**	**825.4**	**3012**
13-Nov-2013	18-Nov-2013	Wong, Sarah	Louis St Laurent	10.9	302.2	424
13-Nov-2013	**26-Nov-2013**	**Ludkin, Rick**	**Teleost**	**19.2**	**326.1**	**287**
02-May-2014	**24-May-2014**	**Duffy, Steve**	**Hudson**	**34.0**	**737.3**	**1229**

30-Jun-2014	14-Jul-2014	Loch, John	Hudson	3.3	71.6	80
09-Jul-2014	28-Jul-2014	Davidson, Elizabeth	Teleost	37.6	749.7	1733
23-Jul-2014	**27-Jul-2014**	**Avery-Gomm, Stephanie**	**What's Happening**	**4.8**	**69.5**	**36**
07-Aug-2014	**18-Aug-2014**	**Winkel, Jeannine**	**Des Groseilliers**	**13.3**	**303.3**	**201**
01-Sep-2014	**16-Sep-2014**	**Gjerdrum, Carina**	**Cape Race**	**34.5**	**495.1**	**1123**
10-Sep-2014	12-Oct-2014	Maftei, Mark	Amundsen	13.9	389.1	4256
04-Oct-2014	**14-Oct-2014**	**Avery-Gomm, Stephanie**	**Teleost**	**32.1**	**620.4**	**5497**
16-Oct-2014	**27-Oct-2014**	**Wells, Regina**	**Teleost**	**36.5**	**569.4**	**1252**
29-Oct-2014	**11-Nov-2014**	**Loch, John**	**Teleost**	**29.3**	**471.6**	**1504**
12-Nov-2014	25-Nov-2014	Ludkin, Rick	Teleost	4.1	81.8	41
16-Nov-2014	07-Dec-2014	Hogan, Holly	Hudson	9.1	161.2	77
Total				**713.6**	**13783.3**	**33469**

Table 6. Vessel-survey effort and data used for density surface models of seabirds within the Labrador Sea, summarized by collection year, season and program.

	No. of Survey trips	No. of segments	Survey time (h)	Survey length (km)	No. of birds counted
			Year		
2006	2	83	14.0	325.4	1887
2007	3	245	33.5	811.3	504
2008	1	171	14.2	349.4	310
2009		0	0	0	
2010		0	0	0	
2011	1	72	6.0	135.9	273
2012	6	1857	150.8	2890.4	1917
2013	10	2880	242.6	4550.9	11549
2014	12	3084	252.5	4720.1	17029
			Season		
Spring	8	1758	161.2	3529.4	3861
Summer	6	2020	170.2	3519.4	8316
Fall	10	3099	256.5	4426.0	18204
Winter	11	1515	125.7	2308.6	3088
			Program		
ECSAS	22	4263	368.1	7692.0	13682
ESRF	13	4129	345.5	6091.3	19787
Total	**35**	**8392**	**713.6**	**13783.3**	**33469**

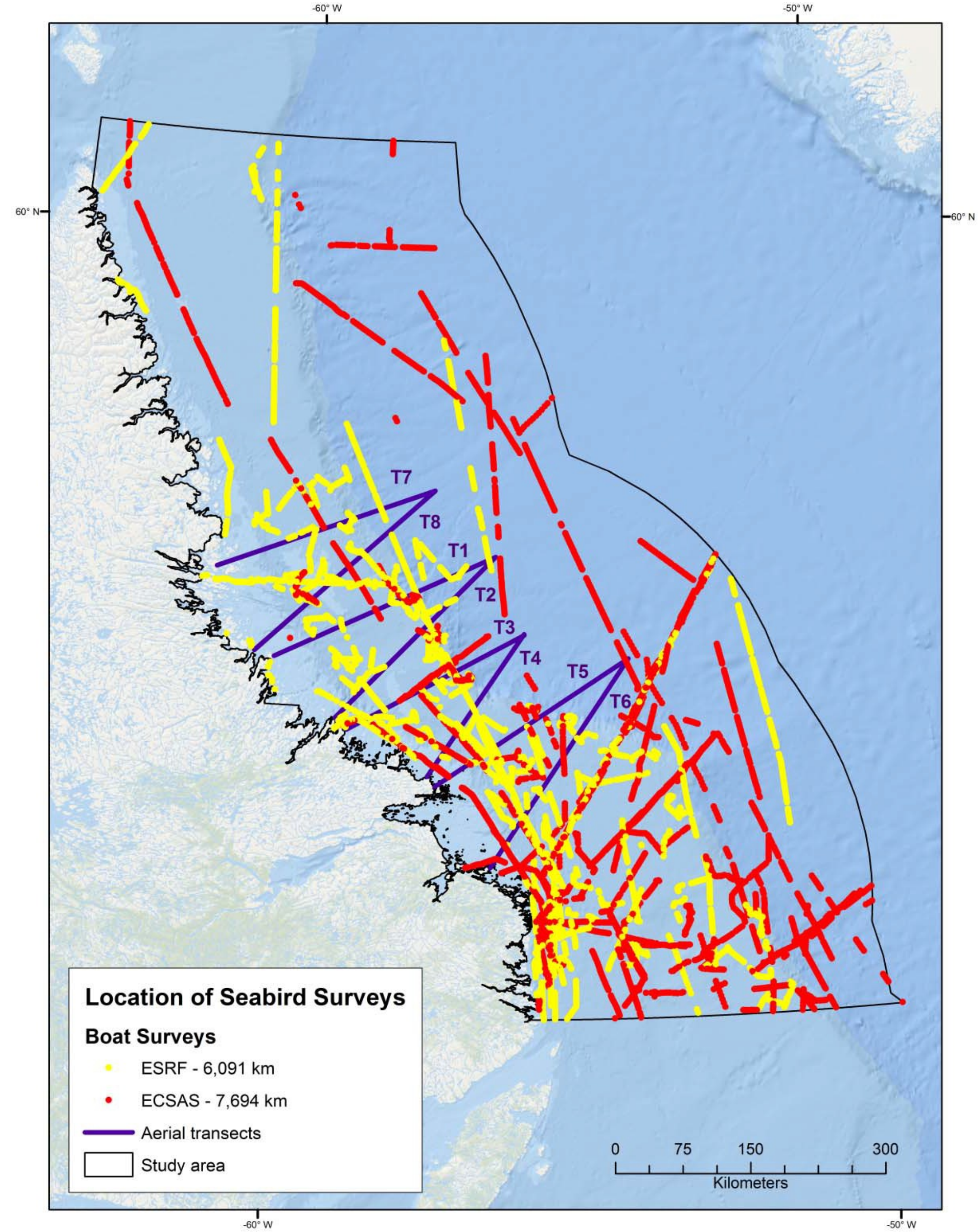


Figure 4. Survey effort (2006-2008, 2011-2014) including ECSAS surveys (red), and those supported by ESRF during this study or previously (yellow) that were completed specifically to address the data gap in the Labrador Sea.

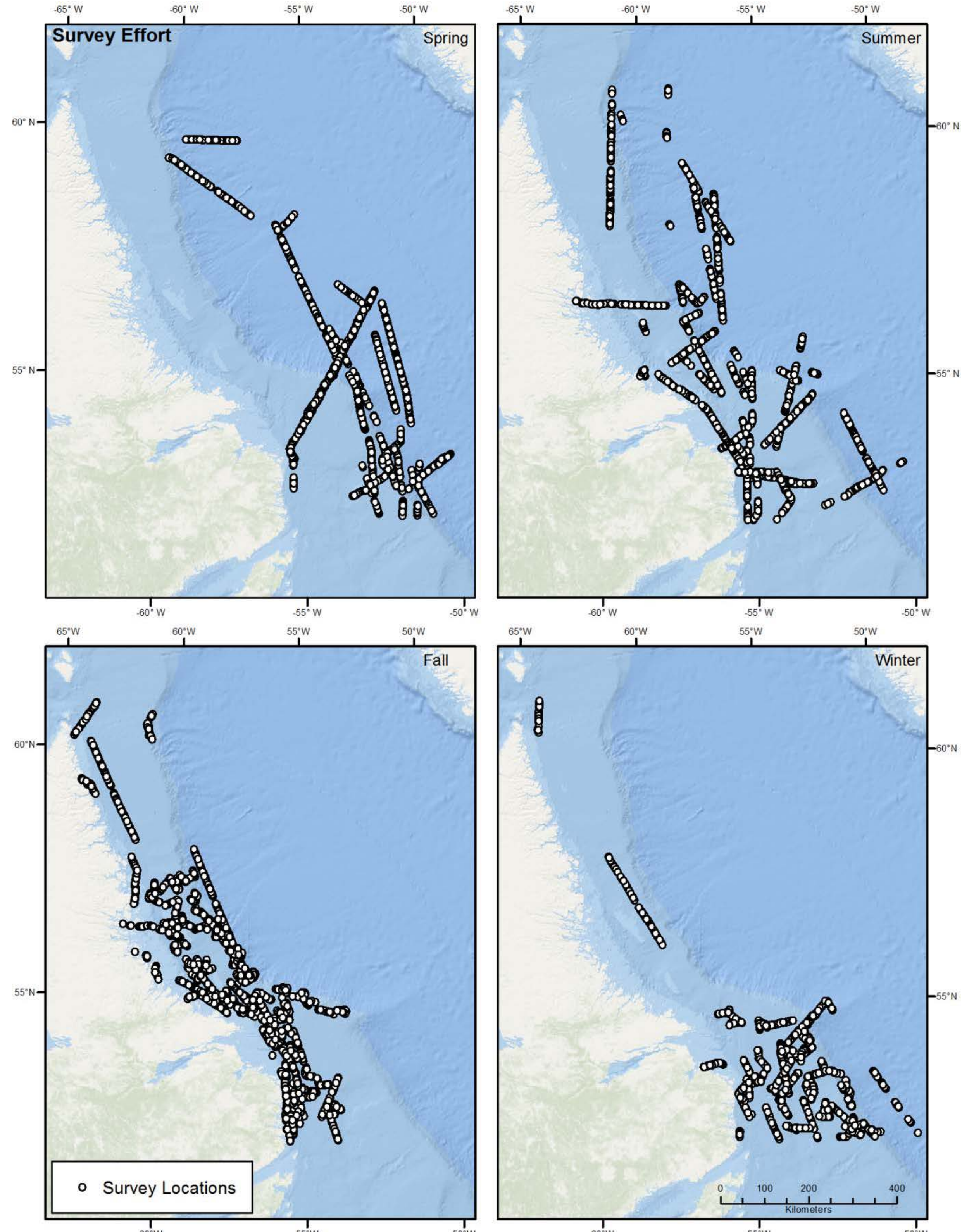


Figure 5. Seasonal ship-based survey effort (2006-2008, 2011-2014) in Labrador Sea.

5.1.2 Aerial Surveys

Aerial Surveys

In 2013, aerial surveys were conducted along six transect lines (T1 – T6, Figure 4). The first survey occurred on 16 October but due to poor weather it was only a partial survey (part of T1 and T2 only); the first full replicate (a complete survey of all 6 lines) was on 17 October. A second full replicate (all 6 lines) was completed on 2 November. In 2014, an additional two transect lines (T7 and T8) were added, north of line T1 (Figure 4) to provide extra coverage. The first survey occurred on 25 August (T3 – T6) followed by T1, T2, T7 and T8 on 26 August. A full replicate of all 8 lines was conducted on 28 August.

In 2013, two complete aerial surveys of lines T1 – T6 were conducted on the Labrador Shelf, and 6,301 marine birds were counted (Table 7). By far the most frequent observations were of northern fulmar (58%), followed by common eider (14%), large alcids (likely thick-billed murre, common murre and razorbill; 14%), and unidentified white-winged gull (potentially including kittiwakes, Iceland gull and glaucous gull; 13%). The remainder of the sightings (<1%) consisted of 4 great black-backed gull, 1 dovekie, 1 glaucous gull, and 45 birds that could not be identified (Table 7).

In 2014, two complete surveys were again conducted, covering lines T1 – T8. Despite the increased survey coverage relative to 2013, fewer marine birds were recorded (number of bird sightings = 4,346). Similar to 2013, northern fulmar was the species most frequently observed (64%), followed by large alcids (19%), unidentified white-winged gull (10%), and eider (6%). The remainder of the sightings (<2%) consisted of 43 great black-backed gulls, 7 geese, and 7 birds that could not be identified (Table 8).

Table 7. Summary of species sighted from Labrador Sea aerial surveys, from 16-17 October and 7 November, 2013.

Family	**Species sighted**	**Scientific name**	**No. of detections**	**No. of days detected**	**Total count**
Procellariidae	Northern fulmar	*Fulmaris glacialis*	1121	3	3,664
Alcidae	Unidentified alcid	Alcidae	227	3	856
	Dovekie	*Alle alle*	1	1	1
Laridae	Great black-backed gull	*Larus marinus*	4	2	4
	Unidentified white-winged gull	Laridae	513	3	825
	Unidentified gull	Laridae	3	1	7
	Glaucous gull	*Larus hyperboreus*	1	1	1
Anatidae	Common eider	*Somateria mollissima*	4	1	905
	Unidentified bird	Aves	14	3	38
Total					**6,301**

Table 8. Summary of species sighted from Labrador Sea aerial surveys, from 25, 26, and 28 August, 2014.

Family	**Species sighted**	**Scientific name**	**No. of detections**	**No. of days detected**	**Total count**
Procellariidae	Northern fulmar	*Fulmaris glacialis*	1867	3	2,780
Alcidae	Unidentified alcid	Alcidae	234	3	823
Laridae	Great black-backed gull	*Larus marinus*	6	2	43
	Unidentified white-winged gull	Laridae	164	3	435
Anatidae	Canada goose	*Branta canadensis*	1	1	3
	Unidentified goose	Anatidae	1	1	4
	Common eider	*Somateria mollissima*	4	2	126
	Unidentified eider	*Somateria*	2	1	125
	Unidentified bird	Aves	4	2	7
Total					**4,346**

5.2 ***Objective 2.*** *To identify, collate, and integrate any existing data relevant to pelagic seabird distributions in the Labrador Sea*

This work was contracted out to Scope Ecological (Scope Ecological 2014).

In consultation with researchers, C-NLOPB and industry, 21 existing seabird surveys occurring in the Labrador Sea were identified. Of these 9 were useable and imported into the ECSAS database. The others could or were not used for various reasons including survey protocol incompatibility (for industry surveys, because the ECSAS protocol was not published until 2012; and, its supporting software was not made available to the C-NLOPB for distribution to operators until the spring of 2015), and unavailability of data (Scope Ecological 2014).

5.3 ***Objective 3.*** *To provide fundamental information on the distribution and population densities of the seabirds in the study area*

5.3.1 Raw results

In total, ship surveys yielded 33,469 seabirds detected (12,379 flocks during 13783.3 km of transects, Table 6) in 4638 of 8392 (55%) segments.

5.3.2 Detection function models

The detection function models best explaining the data for each guild are listed in Table 9. Hazard-rate key functions were chosen as the base model for all guilds except the gulls, and all detection function models included covariates. Only dovekies included enough observations by all observers to include observer as a covariate. Average detection probability, out to a distance of 300m, was 38% (CV=0.26) for all seabirds combined, ranging from a low of 31% (CV = 0.03) for dovekie to 54% (CV = 0.11) for Atlantic puffin. Therefore, failing to use distance sampling methodology would have underestimated bird densities by 2-3 times.

5.3.3 Densities

Density surface models
A negative binomial distribution for the response provided the best fit to the data for all species groups modeled except Atlantic puffin, where it was outperformed by the tweedie distribution (Table 10). For 5 of the 8 guilds, full models (i.e., without backward selection) containing season as a parametric term, seasonal bivariate spatial smooths of x and y (projected longitude and latitude, respectively), plus seasonal smooths of all 6 environmental covariates were selected (Table 10). Bathymetry gradient was a nonsignificant term and was removed from the black-legged kittiwake model. For the gulls, EKE, bathymetry gradient and SST gradient were all nonsignificant terms and were removed from the model, while SSH, distance to the 1000 m isobath and an interaction between Season*SSH were included as parametric terms. The dispersion parameter (larger means less dispersion) for the negative binomial models ranged from 0.084 for the murres to 0.375 for the model including all seabirds. The Atlantic puffin model contained season and bathymetry gradient

as parametric terms, seasonal bivariate spatial smooths of x and y, plus seasonal smooths of SST, EKE and distance to the 1000 m isobath. All other terms were nonsignificant and were dropped from the model.

Table 9. Detection function models for each guild.

Species	N observations	Key function	Covariates	Average detection probability (CV)
All seabirds	12379	Hazard-rate	Taxon + Wind + Swell + FlySwim + Season + Size	0.38 (0.26)
Atlantic puffin	364	Hazard-rate	Size	0.54 (0.11)
Black-legged kittiwake	683	Hazard-rate	Size + Wind + Swell + FlySwim	0.47 (0.06)
Dovekie	3886	Hazard-rate	Wind + Swell + FlySwim + Season + Observer	0.31 (0.03)
Gulls	486	Half-normal	Swell + Season	0.43 (0.04)
Murres	2647	Hazard-rate	Size + Season	0.37 (0.03)
Northern fulmar	3179	Hazard-rate	Wind + Swell	0.46 (0.03)
Shearwaters	926	Hazard-rate	Wind + Swell + FlySwim + Season	0.45 (0.05)

Table 10. Density surface models for each guild.

Taxon	Response distribution (parameter)	Model terms	Deviance explained	Estimated average density - birds/km^2 (CV), 95% Cis[1] Spring	Summer	Fall	Winter
All seabirds	Negative binomial (0.375)	Smooth: (x,y), SST, SSH, EKE, BathyG, SSTG, Dist1000 Parametric: Season	33.2%	3.49 (0.31) 1.91 – 6.36	8.01 (0.31) 4.46 – 14.38	15.54 (0.28) 9.03 – 26.74	12.76 (0.43) 5.70 – 28.58
Atlantic puffin	Tweedie (p=1.109)	Smooth: (x,y), SST, EKE, Dist1000 Parametric: Season, BathyG	66.6%	0.10 (0.71) 0.03 – 0.34	0.13 (0.24) 0.08 – 0.21	0.14 (0.47) 0.06 – 0.33	0.04 (0.71) 0.01 – 0.15
Black-legged kittiwake	Negative binomial (0.057)	Smooth: (x,y), SST, SSH, EKE, SSTG, Dist1000 Parametric: Season	41.8%	0.13 (0.13) 0.11 – 0.17	0.76 (0.28) 0.44 – 1.32	13.8 (1.35) 1.88 – 101.63	20.61 (1.57) 2.31 – 183.67
Dovekie	Negative binomial (0.157)	Smooth: (x,y), SST, SSH, EKE, BathyG, SSTG, Dist1000 Parametric: Season	68.3%	21.48 (1.25) 3.20 – 144.15		17.07 (0.17) 12.30 – 23.70	14.81 (0.77) 3.89 – 56.40
Gulls	Negative binomial (0.026)	Smooth: (x,y), SST Parametric: Season, SSH, Dist1000, Season*SSH	25.1%	0.71 (0.21) 0.47 – 1.08	0.14 (0.29) 0.08 – 0.24	0.08 (0.31) 0.05 – 0.15	0.24 (0.78) 0.06 – 0.91
Murres	Negative binomial (0.084)	Smooth: (x,y), SST, SSH, EKE, BathyG, SSTG, Dist1000 Parametric: Season	21.7%	1.21 (0.20) 0.82 – 1.79	0.95 (0.37) 0.47 – 1.92	4.89 (0.12) 3.84 – 6.21	2.19 (0.33) 1.17 – 4.08
Northern fulmar	Negative binomial (0.146)	Smooth: (x,y), SST, SSH, EKE, BathyG, SSTG, Dist1000 Parametric: Season	47.1%	6.30 (0.32) 3.43 – 11.57	6.79 (0.16) 4.99 – 9.23	29.79 (1.13) 5.01 – 177.13	62.86 (1.22) 9.64 – 410.05
Shearwaters	Negative binomial (0.071)	Smooth: (x,y), SST, SSH, EKE, BathyG, SSTG, Dist1000 Parametric: Season	63.1%		1.84 (0.59) 0.63 – 5.40	0.57 (0.23) 0.36 – 0.90	0.34 (0.79) 0.09 – 1.34

[1]Note that seasonal estimated densities for individual guilds may exceed those for all seabirds because the area of acceptable precision over which density is calculated differs for each guild, and because areas of high predicted abundance at the fringe of poor-precision areas are included for some guilds (see maps in Appendix 1).

5.3.3.1 All seabirds

This group captures all seabirds observed during vessel surveys, including species for which there was insufficient data for individual modeling, as well as taxa that could not be fully resolved. In addition to the guilds modeled separately, this group involved the following ECSAS species group designations – storm petrels, other alcids, terns, skuas, jaegars, northern gannet, and phalaropes.

The Labrador Shelf and adjacent portions of the Labrador Sea are clearly important regions for seabirds, particularly during Fall and Winter, when average densities in areas of acceptable precision were 15.54 and 12.76 birds/km^2, respectively (Table 10 and Figure 7). During Fall, relatively high densities were predicted throughout the Labrador Shelf, from the Saglek and Nain Banks south to the Labrador Trough, coincident with southward migration of dovekies and murres from Arctic breeding colonies. Predicted densities in a substantial portion of the Saglek Bank and Labrador Trough exceeded 50-75 birds/km^2 in Fall. Seabird hotspots in Fall overlapped with several significant hydrocarbon discoveries on the Labrador Shelf. Relatively lower bird densities were predicted in offshore regions in Fall, however, the lack of survey coverage in these areas lowers confidence in the predictions. During Winter, the model predicted high densities (>25 birds/km^2) all along the continental shelf break, while during Summer, discrete regions along the Saglek/Nain Banks in the north and along the Hamilton Bank in the south had densities exceeding 50 birds/km^2. Predicted densities were lower overall during Spring, and averaged 3.5 birds/km^2 in areas of acceptable precision.

5.3.3.2 Atlantic puffin

In the Northwest Atlantic, the bulk of the Atlantic puffin population (~400,000 pairs) breeds in a few large colonies off eastern Newfoundland, with smaller colonies occurring from the eastern Arctic to the Gulf of Maine (Lowther et al. 2002). The winter distribution of Atlantic puffins is poorly known. Observations of Atlantic puffins within the study area occurred mainly during Summer and Fall when birds were largely restricted to southern areas (Figure 10). There were very few observations of puffins in Winter and Spring. Predicted seasonal densities of Atlantic puffins were low overall (0.04 – 0.14 birds/km^2), with highest densities predicted in nearshore waters off the southern Labrador coast, in the vicinity of the Gannet Islands breeding colony in Summer (Figure 9).

5.3.3.3 Black-legged Kittiwake

Black-legged kittiwakes are a small pelagic gull species, with an estimated eastern Canadian breeding population of 525,000 individuals (Baird 1994); breeding colonies range from Barrow Strait in the north to the Gulf of St. Lawrence in the south. Recent year-round tracking of birds from colonies throughout the North Atlantic indicates that during winter the Grand Bank, Labrador Shelf and adjacent pelagic waters of the Labrador Sea are heavily used (Frederiksen et al. 2012). Kittiwakes were observed throughout the study area, and throughout the year (Figure 12). As expected, predicted densities were relatively low during Spring (0.13 birds/km^2) and Summer (0.76 birds/km^2), and relatively high in Fall (13.8 birds/km^2) and Winter (20.6 birds/km^2) , however, with CVs exceeding 1, predictions for the latter seasons were not very precise. Predicted densities were relatively high along the northern Labrador coast in Summer and along the southern Labrador coast in Fall (Figure 11). In Winter, predicted densities were relatively high over Hamilton Bank (Figure 11).

5.3.3.4 Dovekie

Dovekies breed in Greenland, Svalbard and the Russian arctic (population > 40 million pairs; Montevecchi & Stenhouse 2002) and winter between the northern Labrador Sea and Cape Hatteras, with the Grand Bank being a notably important wintering site (Brown 1986, Fifield et al. 2009, Fort et al. 2013). Consistent with known annual movement patterns, dovekies occurred within the study region in all seasons, however, they were observed most frequently in Fall and Winter. In Fall, predicted densities averaged 17.1 birds/km^2 and were high throughout much of the Labrador Shelf region from Saglek Bank south to the Labrador Trough. Winter densities in areas of acceptable precision averaged 14.8 birds/km^2, and as birds continued migrating, highest predicted densities occurred near the continental shelf break off southern Hamilton Bank. Hotspots for dovekie within the study region in Fall and Winter overlap with significant hydrocarbon discoveries on the Labrador Shelf and large parcels that are within the early stages of exploration in the region of Hamilton Bank. As expected, fewer observations of dovekies were made in the study area during Spring and Summer, as birds moved toward their Arctic breeding grounds.

5.3.3.5 Gulls

This group includes all large gulls occurring in the study area; herring, Iceland, glaucous, great black-backed, lesser black-backed, Sabine's and unidentified gull species. Herring and great black-backed gulls breed and occur throughout the study region year-round (Brown 1986, Fifield et al. 2009), and their populations number in the tens of thousands (Pierotti and Good 1994, Good 1998). Iceland, glaucous, and Sabine's gulls are largely Arctic breeders that occur within the study area in winter (Snell 2002, Weiser and Gilchrist 2012), and lesser black-backed gulls are European visitors. Large gulls were observed in relatively low numbers throughout the study area, throughout the year (Figure 16). Highest predicted densities occurred in Spring (0.71 birds/km^2), largely in association with the continental shelf break and slope (Figure 15), while lowest predicted densities occurred in Fall (0.08 birds/km^2). During Winter, highest predicted densities occurred in the northern portion of the study region, over Saglek Bank. Overall, the gull DSMs performed well, evidenced by the relatively low CV for predictions year round (Figure 16 and Table 10).

5.3.3.6 Murres

Often being indistinguishable at sea, and sharing similar vulnerability to oil pollution, thick-billed and common murres are grouped here. Thick-billed murres breed throughout the Arctic while, in the North-west Atlantic, common murres breed in low-Arctic regions to north 56°N. Large numbers of Murres winter on the Grand Bank, within the Labrador Sea and off the west coast of Greenland, with some as far south as the Gulf of Maine (Gaston & Hipfner 2000, Ainley et al. 2002, McFarlane Tranquilla et al. 2015). Total Atlantic population for both species combined has been estimated to be 16 – 25 million breeding birds (Gaston and Jones 1998). Murres were observed throughout the study region, throughout the year (Figure 18). Highest predicted densities occurred over the

Labrador Shelf in Fall, at a time of year when thick-billed murres in particular are moving south, migrating from Arctic breeding colonies to winter at lower latitudes. Densities in areas of acceptable precision in Fall averaged 4.9 birds/km^2, and were particularly high throughout continental shelf waters between Saglek Bank and the Labrador Trough. Several significant hydrocarbon discoveries on the Labrador Shelf overlap with hotspots for murres during this time. Relatively high murre densities were also predicted along the continental shelf edge in northern portions of the study area in Winter. During Summer, high densities (>10 murres/km^2) were predicted in nearshore waters off southern Labrador, which is in the vicinity of the Gannet Islands breeding colony. Murres were found in lower densities throughout the study area in Spring (average 1.2 birds/km^2). Overall, the murre DSMs performed well, evidenced by the relatively low CV for predictions year round (Figure 18 and Table 10).

5.3.3.7 Northern Fulmar

The majority of eastern Canadian Northern fulmars (174,000 pairs; Gaston et al. 2012) breed in the Arctic, with a few small colonies occurring in Newfoundland and Labrador (Mallory et al. 2012). Large numbers of fulmars, which likely include birds of European origin, occur in southern regions in winter as far south as Cape Hatteras, with major concentrations observed on the Grand Bank (Fifield et al. 2009, Mallory et al. 2012). Fulmars were observed throughout the study region in all seasons (Figure 20). Predicted densities in areas with acceptable precision averaged 6.3 and 6.8 birds/km^2 in Spring and Summer, respectively, with hotspots predicted in the vicinity of the shelf break, slope and adjacent pelagic waters in northern and southern portions of the study area (Figure 19). In line with known seasonal movement patterns, predicted fulmar densities were also high during Fall and Winter, however, with CVs exceeding 1, the predictions are not very precise.

5.3.3.8 Shearwaters

The shearwater group includes great, sooty, manx and unidentified shearwater species. Great shearwaters breed only at a few sites in the central south Atlantic, while sooty shearwaters breed in both the south Atlantic and the south Pacific. Both southern hemisphere species are trans-equatorial migrants, with large numbers known to spend their non-breeding period in the northwest Atlantic (Brown 1986, Fifield et al. 2009, Hedd et al. 2012). Very small numbers of manx shearwaters breed at the Middle Lawn Island colony, off Newfoundland's Burin Peninsula, the only known breeding site for this species in North America (Robertson 2002). Shearwaters were most frequently observed in the study area during Summer and Fall, some observations occurred during Winter and they were largely absent in Spring (Figure 22). As expected based upon known seasonal movement patterns, highest predicted densities occurred during Summer (1.84 birds/km^2) when hotspots occurred in central and southern portions of the Labrador Sea and in Fall (0.57 birds/km^2) when predicted densities were highest near the shelf break (Figure 21).

*5.4 **Objective 4.** To involve, train, and transfer expertise to local and in particular, indigenous individuals, the technical skills involved in conducting such surveys whenever possible*

As identified in Fifield et al. (2009), training a pool of skilled observers is critical to conducting effective at-sea seabird surveys over a broad geographic area. Six observers were trained in 2013 for the ECSAS program. As well, two at-sea survey training workshops were conducted (January 2013 (NS) and October 2013 (NL)) to review seabird identification and provide instruction for data recording and management. These workshops were followed by ship-board training with an experienced observer in 5 cases.

One of the ships we surveyed from was the F/V *What's Happening*, a 65ft Inuit-owned crab fishing boat belonging to Joey Agnatok from Nain, Labrador. The vessel was comfortable, with a port indoor observation station and starboard outdoor observation station, and the captain and crew were proficient, knowledgeable, interested in the research, and expressed an interest in future work. It is recommended that this local connection be continued, and may present an excellent platform for training local and indigenous individuals in the future.

On 13 – 14 November 2014 Environment Canada and DFO taught a Seabird and Marine Mammal Observer Training workshop in Happy-Valley Goose Bay. The workshop had 20 attendees from 6 communities (Port Hope Simpson, North West River, Happy Valley-Goose Bay, Hopedale, Makkovik and Nain) representing a diverse range of experience. It was an excellent opportunity to train Labradoreans (100%), particularly indigenous people (~70%), and to build capacity in the north. Coordination with the Nunatsiavut Government facilitated attendance of 9 Nunatsiavut beneficiaries, and we enjoyed a strong NunatuKavut presence, as well as individuals from Parks Canada, the Torngat Secretariat, Carleton University and Memorial University. Despite the diverse background of attendees (55% arrived with limited understanding of the subject), 90% reported that the workshop was extremely useful. Following the workshop, participants received a certificate of participation and materials to aid them in future related work (hard copy of the Eastern Canada Seabird at Sea Protocol, bird and marine mammal field guide books). There were multiple inquiries about certifications but neither ECCC nor DFO have accreditation programs for observers at this time. Although at-sea survey efforts in the Labrador Sea are winding down, these individuals are now primed for the field-based training opportunities and following that, employment opportunities (e.g., aboard seismic vessels) and to date at least one individual has found employment as an observer.

Figure 6. Participants in the Seabird and Marine Mammal Observer Training workshop in Happy-Valley Goose Bay 13-14 November 2014.

5.5 ***Objective 5.*** *To maintain positive control of the scientific methodology and quality of the data gathered during the surveys*

All data collected were under the purview of the ECSAS program, therefore all QA/QC measures of that program were in place. As a result, all observers were trained in seabird identification, the ECSAS protocol, distance sampling techniques and how to use the database to record their data. All data were examined by Carina Gjerdrum before final importation into the ECSAS database. The ECSAS program uses the latest methods for ship-board seabird surveys, with detailed instruction on how to record each possible type of bird detection (Gjerdrum et al. 2012).

To increase the utility of data collected by industries operating on the Labrador Sea, a seabird observation protocol was developed that could be incorporated by marine mammal observers operating on seismic vessels. This consultation was undertaken with Danish authorities, as wildlife observers on seismic vessels in Greenlandic waters are required to collect both marine mammal and seabird data (in Canada they are only required to sight marine mammals, although ECCC, through C-NLOPB, requests that all seismic vessels collect seabird data). These protocols were adapted to meet the requirements of the marine mammal observers and provided to C-NLOPB for use. The success of these modified protocols will be assessed as they are used.

5.6 Objective 6. To ensure safety of any in-field study operations

EC staff were required to read and sign off on relevant Task Hazard Analysis and Safe Working Practices. In the field, all observers were equipped with first aid, communications, navigation, and safety gear as appropriate for the survey platform (more equipment was provided to aerial observers in a Twin Otter, compared to observers on CCG vessels). Safe in-field operations were additionally supported through Small Vessel Operator's Proficiency (SVOP), Marine Emergencies Duties - A1, Basic Safety Training, and Wilderness and Remote First Aid training for observers and field personnel. Contractors were required to meet the minimum training requirement of vessels they were on, and all contractors had comprehensive liability insurance. Offshore aerial surveys also required life vests with attached oxygen reserve.

6 Discussion and Recommendations

6.1 Importance of the Labrador Sea

High seabird densities in fall confirm that the Labrador Sea is a critical migration pathway for seabirds breeding in Greenland and the Canadian Arctic. This is particularly true for dovekie and murres migrating south to overwintering grounds on the Grand Banks east of Newfoundland.

Winter densities are also relatively high. Arctic breeding fulmar and a significant proportion of the global kittiwake population overwinter in the Labrador Sea, alongside smaller populations of dovekie, murres and large gulls.

Spring densities may be driven by seabirds migrating north to their breeding colonies. Densities are lower than in fall, perhaps because sea ice precludes migration over part of the Labrador Shelf or because sampling efforts failed to capture the rapid return migration. In summer, densities likely represent immature birds, non-breeding adults, nearby breeders, or over-wintering southern hemisphere shearwaters taking advantage of seasonally abundant prey.

6.2 Use of predictive density surface modeling

Predictive density surface models were successfully applied to produce spatially explicit density estimates for seabirds in the Labrador Sea. This model-based approach incorporates the relationship between density (or equivalently abundance) and environmental covariates and allows for population level inference from samples collected from ships of opportunity, as opposed to a random sample design (Miller et al. 2013, Williams et al. 2006). Advantages of this approach include the ability to predict density in areas not surveyed, and in arbitrary sub-regions of the study area such as regions with good prediction precision (see Table 10). Another advantage is the provision of insight into the ecological factors correlated with density. However, density surface models are not a panacea. They are data-hungry and unbiased estimates depend upon model correctness which is never perfectly achievable since all models are approximations of reality. Predictions from density surface models can be validated using approaches including k-fold cross-validation to estimate predictive accuracy, and seabird tracking studies (e.g., McFarlane Tranquilla et al. 2013, 2015 , Frederiksen 2012, Fort et al. 2013) to validate areas of intense usage.

Other modeling approaches exist in addition to GAMs for modeling the relationship between observed seabird counts and environmental covariates. These include generalized linear models, and machine learning techniques (e.g. random forests, boosted regression trees and maximum entropy). Oppel et al. (2012) found that an ensemble approach combining predictions from several model types was superior when predicting areas of importance to marine birds, and that individual models fared more poorly when attempting to predict spatial patterns of absolute abundance (see also Lieske et al. 2014).

> ***Recommendation 1****: Density surface models should be further validated using cross-validation and tracking studies.*

> ***Recommendation 2:*** *Further development of modeling approaches should consider a wide range of model types and ensembles methods.*

Although our study area was large, it represents only a subset the larger oceanic context involving large-scale oceanographic processes that likely shape patterns of seabird abundance. The acquisition of existing seabird abundance data in adjoining areas of the Davis Strait/Baffin Bay and the Northeast Newfoundland Shelf integrated using density surface modeling approaches will inform seabird abundance in Canadian waters and provide a more holistic view of areas important to seabirds and industry in the larger oceanographic context.

> ***Recommendation 3:*** *Expand modeling exercise to incorporate existing seabird data from adjacent oceanographic regions to provide a more holistic view of important seabird areas.*

6.3 Remaining gaps

The data analyzed here represent a substantial improvement in spatial and temporal coverage in the study area relative to that previously available (Fifield et al. 2009). Nonetheless, gaps remain with coverage tending to be better in the south and poorer in the northern portion of the study area year-round. The best spatial coverage occurred in summer, but in spring, more coverage is required in any ice-free portion of the continental shelf and more deep-water coverage is needed in the north. The deep off-shelf waters during winter (northern portion only) and fall require more effort and these areas are of particular concern since tracking studies show them to be important during these times (McFarlane et al. 2013, 2015, Frederiksen et al. 2012, Fort et al. 2013), and the southern deep off-shelf region is subject to ongoing and upcoming oil and gas land issuance processes (see Figure 1). Capturing seasonal variation in seabird densities in these areas will be very important to appropriately estimate risk to seabirds in the case of an accidental hydrocarbon release (Fifield et al. 2009).

> ***Recommendation 4:*** *Continue to fill data gaps for the Labrador Sea, especially to address seasonal patterns. In particular, spring and winter surveys (when there are fewer surveys in general) and off-shelf coverage in areas of land issuance require survey effort.*

6.4 Aerial surveys

Aerial survey transects were designed to quantify the abundance and distribution of marine mammals across the Labrador Shelf, but also provided the opportunity to survey seabirds. Aerial surveys for seabirds are quick and relatively inexpensive compared to ship-based surveys, but do result in data with lower resolution as species are more difficult to identify from the faster moving aircraft compared to the slower-moving ship. This was especially true for the aerial surveys conducted in this study as the flight altitude was much higher than is typical for seabird surveys (surveys were designed for marine mammals and flown at an altitude of 600 feet compared to an altitude of 200-300 feet typically flown for aerial surveys designed for seabirds; Buckland et al. 2012).

Despite the limitations and challenges of surveying birds from the air at this high altitude, these results suggest that the method yields important information that can complement data collected from ships. First, a large amount of area was covered in a short amount of time and over 10,000 individuals from 4 families were identified across the two survey years. The survey method was particularly useful for northern fulmar, a species known to be particularly attracted ships, thereby biasing density estimates. The distribution of northern fulmar obtained from aerial survey data is therefore likely more representative than that derived from ship-based surveys. Second, this project provided the opportunity to develop and test an aerial survey protocol using distance sampling. Specifically, the inclusion of surveys with both observers on the same side of the airplane (2014) will allow for the use of double-observer analysis methods to test the assumption that all birds at distance 0 are detected (Buckland et al. 2001). This analysis is not yet complete, but results will help determine whether combining marine mammal and seabird surveys is practical in the future. The use of digital survey methods (video and stills) were not explored in this study but should be considered, particularly when the aircraft is flying at much higher altitudes than is typical for seabird surveys (> 300 feet). Although the technology is still being developed, digital methods can provide better estimates of abundance compared to visual surveys, fewer unidentified species, and a means to validate the data through archived images (Buckland et al. 2012).

> **Recommendation *5:*** Continue to *develop techniques for aerial surveys including the use of digital methods, and formalize the methodology to compute detection functions and densities.*

6.5 Integration of industry collected data

Efforts to identify, assess and, include industry and researcher collected data met with modest success. Twenty-one (21) surveys were identified in the Labrador Sea. While nine of the 21 were used the rest were not useable for a variety of reasons. Data sharing agreements could not be reached with one company, and some surveys were not conducted using the ECSAS or comparable protocol.

The C-NLOPB requires that marine mammal observers on seismic vessels collect seabird survey data, however, data from very few seismic cruises were made available for importation in to the ECSAS database. The main reason for data not making its way to the ECSAS database appears to be related to the fact that the ECSAS protocol wasn’t formally published until 2012 and its supporting software did not become available to the C-NOLPB from ECCC for distribution to operators until 2015 in the context of the Environmental Assessment process.

Given the cost and effort of obtaining data in the Labrador Sea, continued effort is needed to ensure industry collected data continue to follow established distance sampling protocols and continues to be transferred to ECCC, and integrated into the ECSAS database in a timely manner. These appear to be recurring problems as similar issues were noted by Fifield et al. (2009).

> **Recommendation 6***: Industry, C-NLOPB and ECCC continue to work together to ensure that any seabird survey data collected by industry follows established protocols, including the use of distance sampling, and continues to be submitted to C-NLOPB and ECCC and integrated into the ECSAS database in a timely manner.*

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8 Appendices

8.1 Appendix 1. Seabird density maps

This appendix presents two seasonal maps for each guild listed in Table 3. The first map shows predicted distribution and density (at 2 km x 2 km resolution), while the second indicates the estimated uncertainty in these densities (at 6 km x 6 km resolution) indicated by coefficient of variation (CV). Hatched portions of the maps indicate areas of low prediction precision (CVs > 2 or predictions beyond the range of our sampled covariates), and should be interpreted with extreme caution.

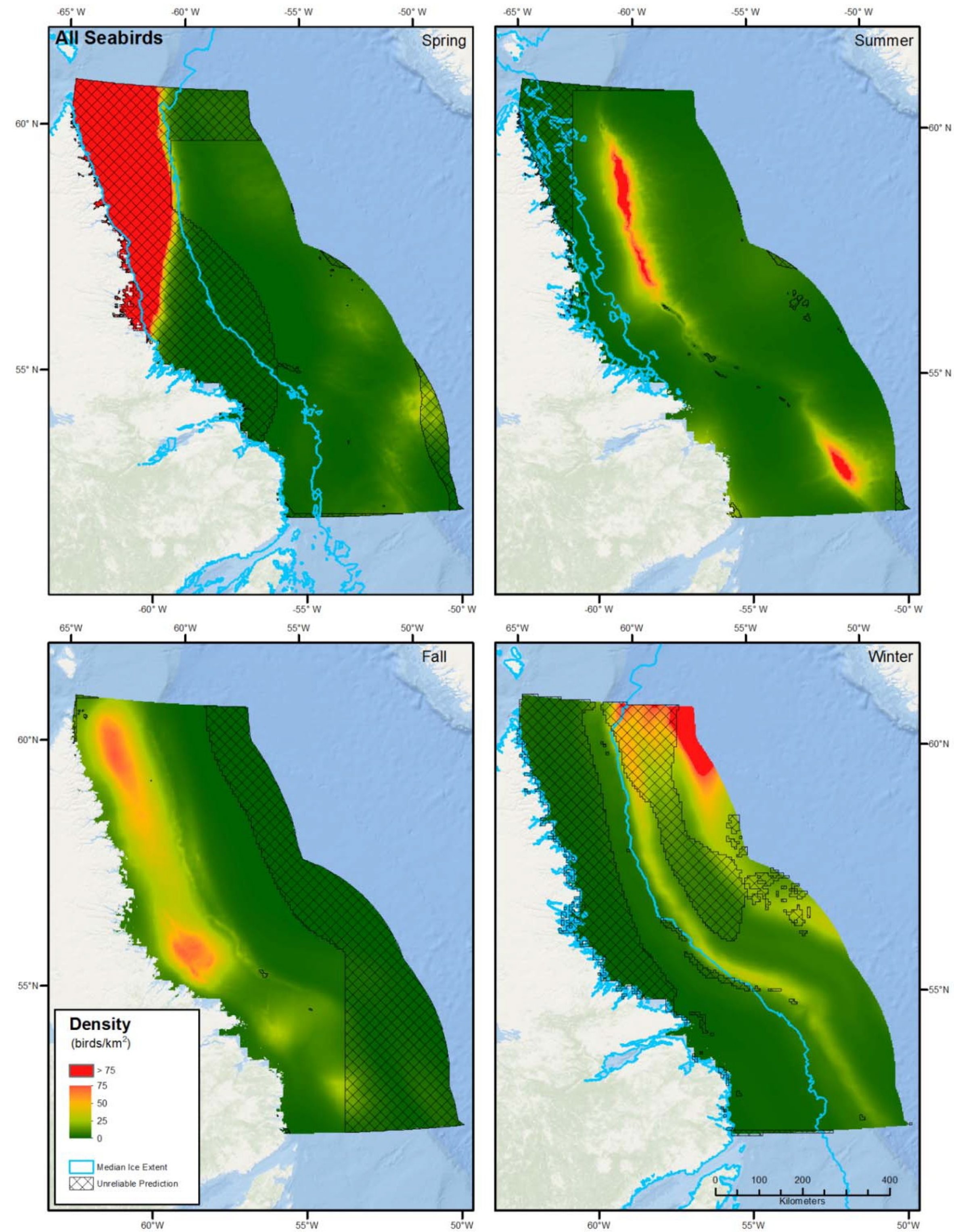

Figure 7. Seasonal predicted densities (2 km x 2 km grid) of all seabirds based on Generalized Additive Models (GAMs).

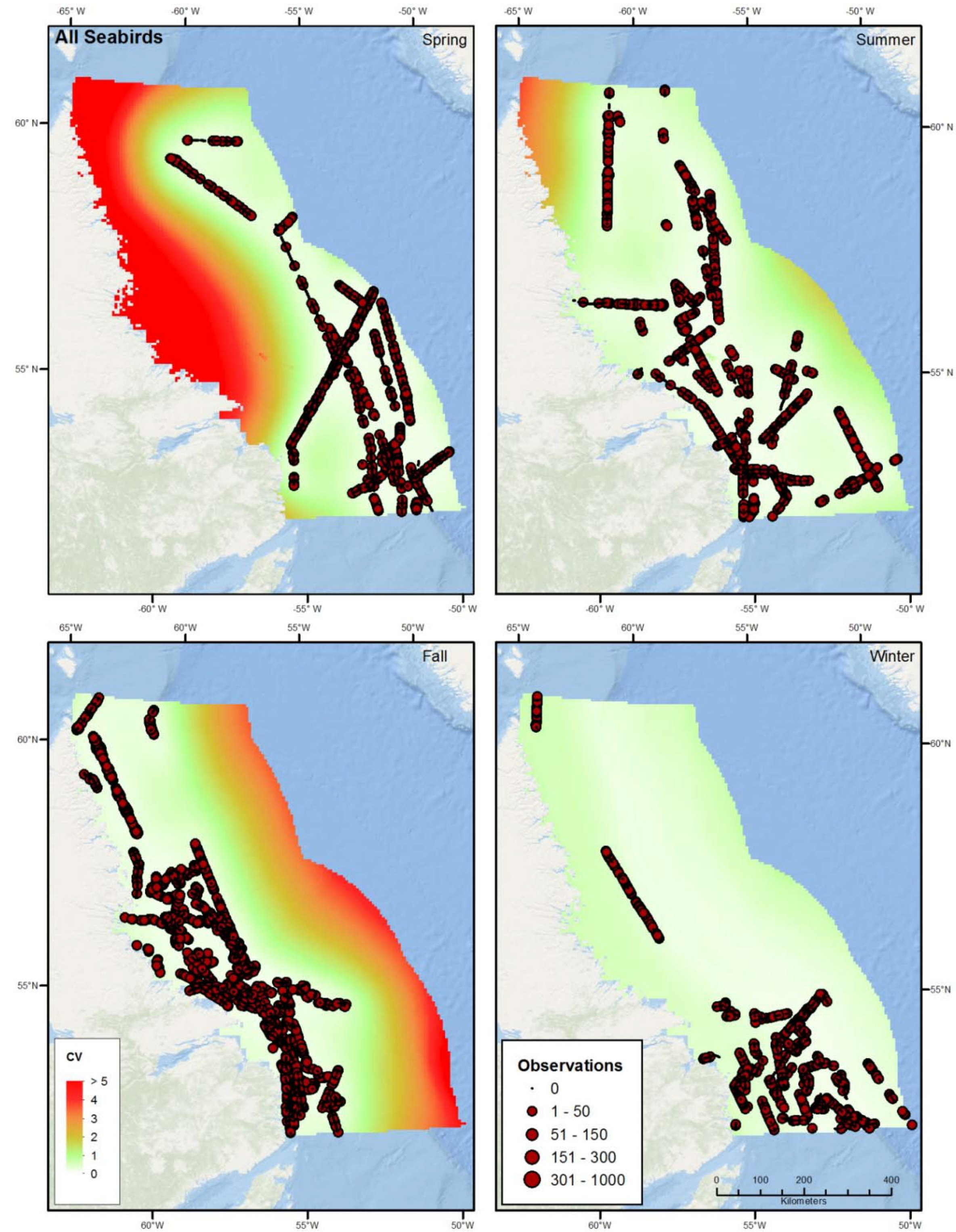

Figure 8. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of all seabirds based on Generalized Additive Models (GAMs).

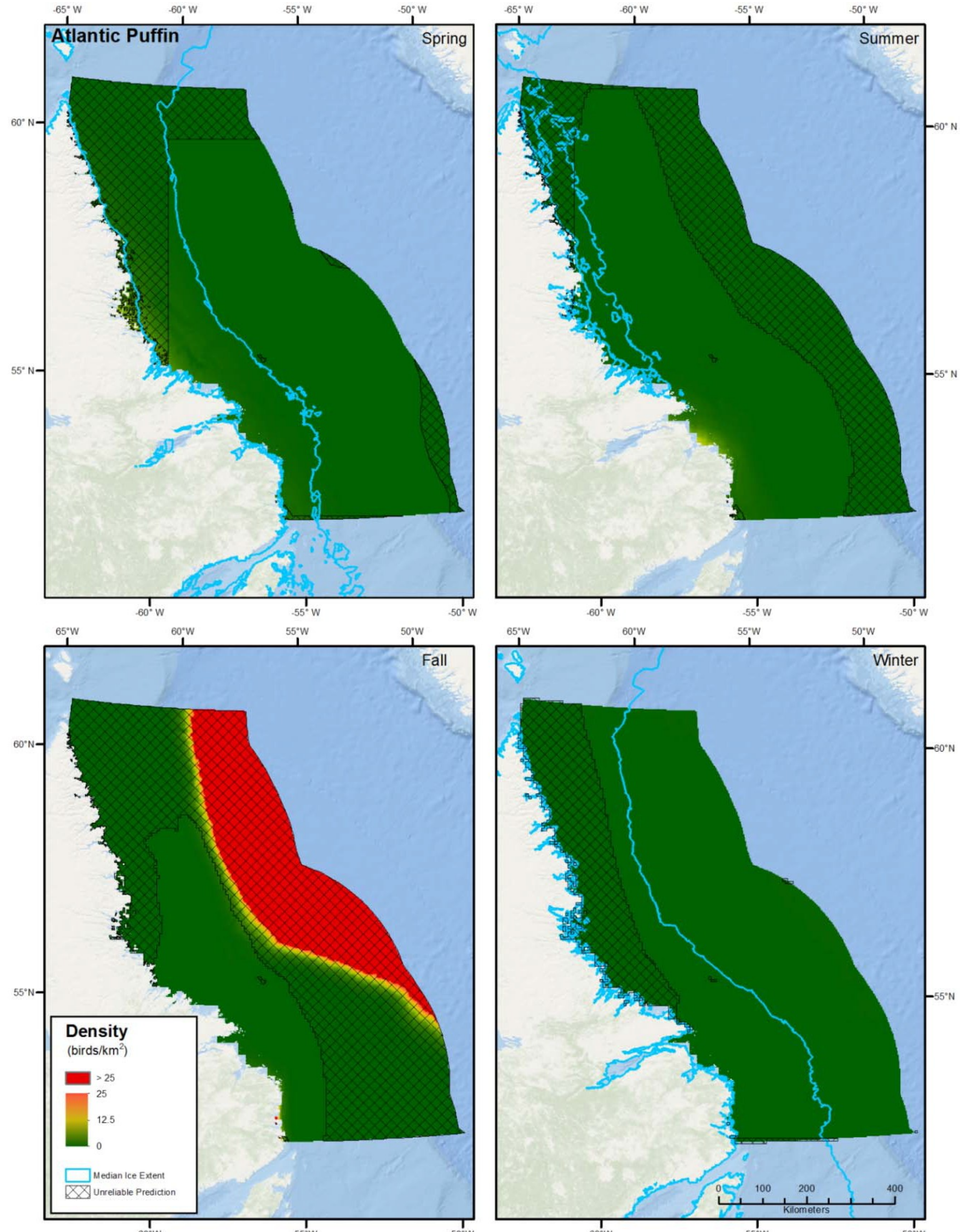

Figure 9. Seasonal predicted densities (2 km x 2 km grid) of Atlantic puffin based on Generalized Additive Models (GAMs).

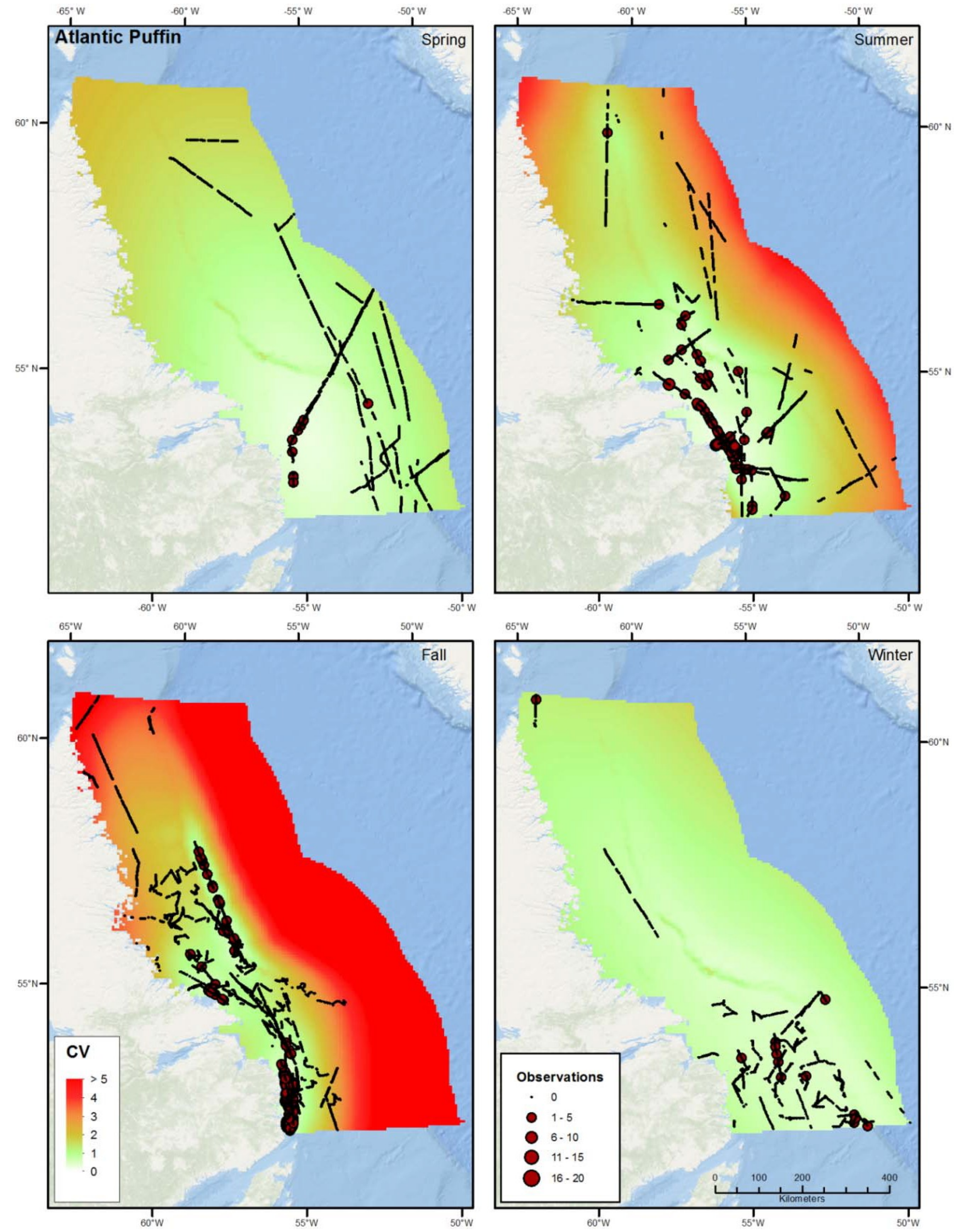

Figure 10. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of Atlantic puffin based on Generalized Additive Models (GAMs).

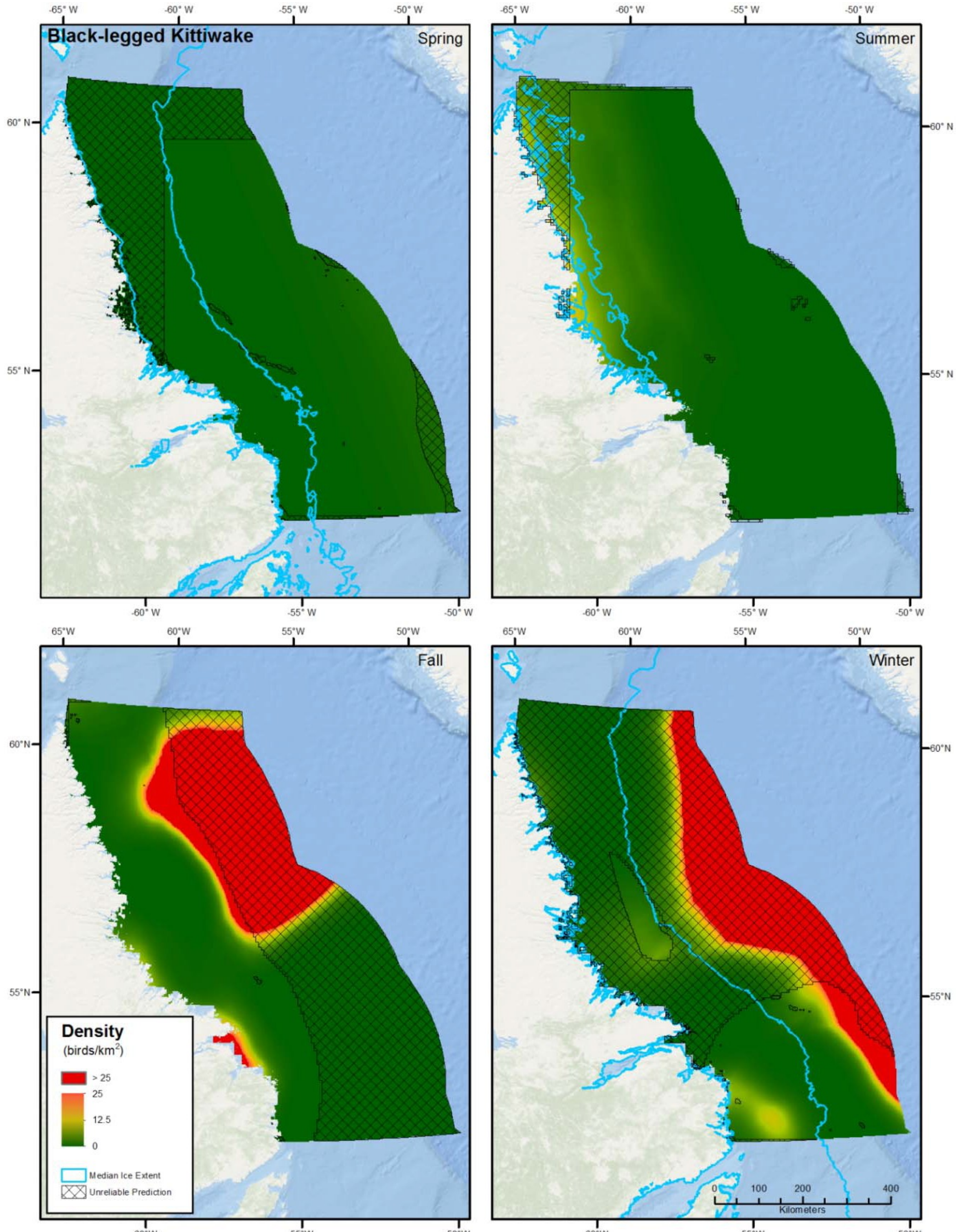

Figure 11. Seasonal predicted densities (2 km x 2 km grid) of Black-legged kittiwake based on Generalized Additive Models (GAMs).

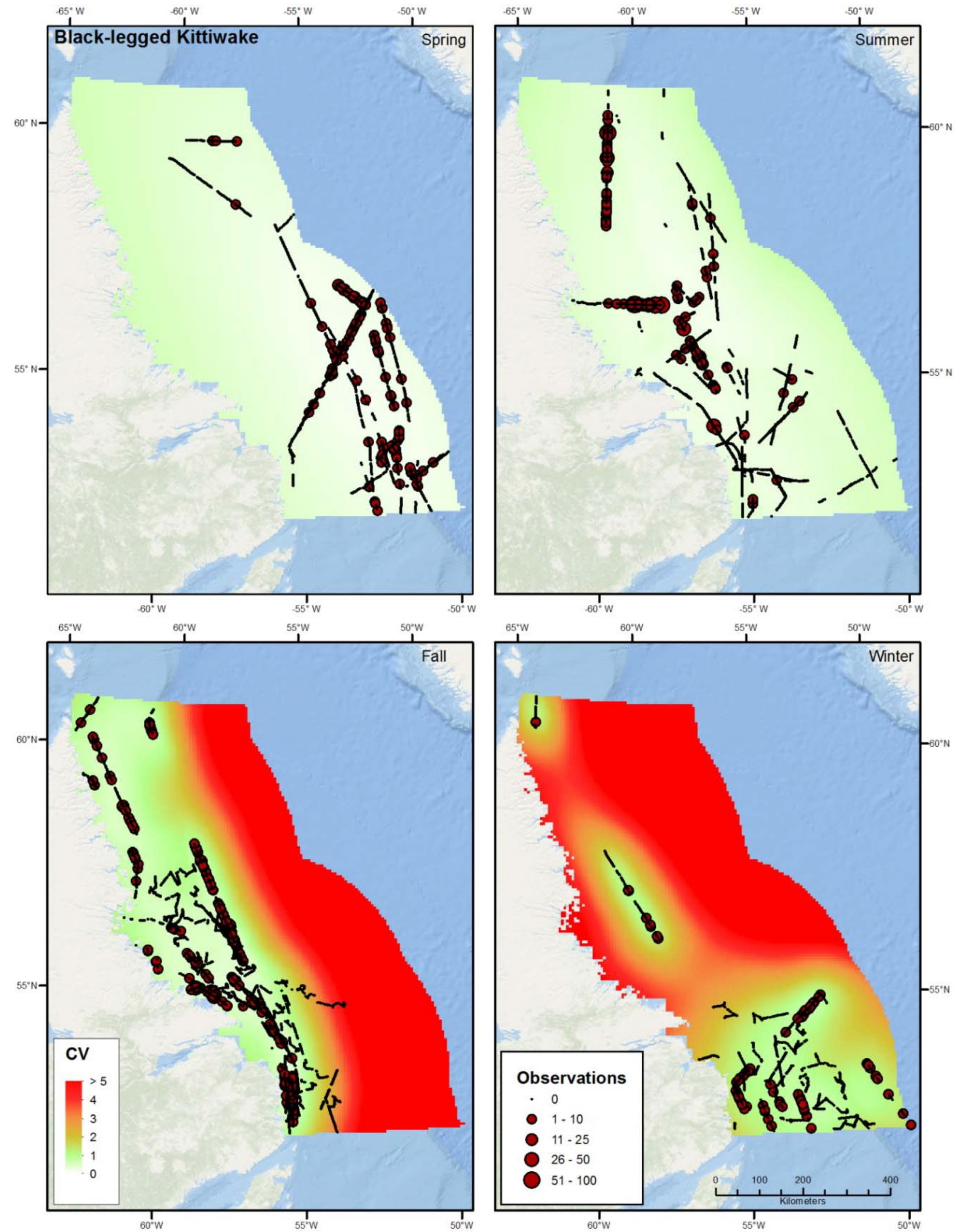

Figure 12. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of Black-legged kittiwake based on Generalized Additive Models (GAMs).

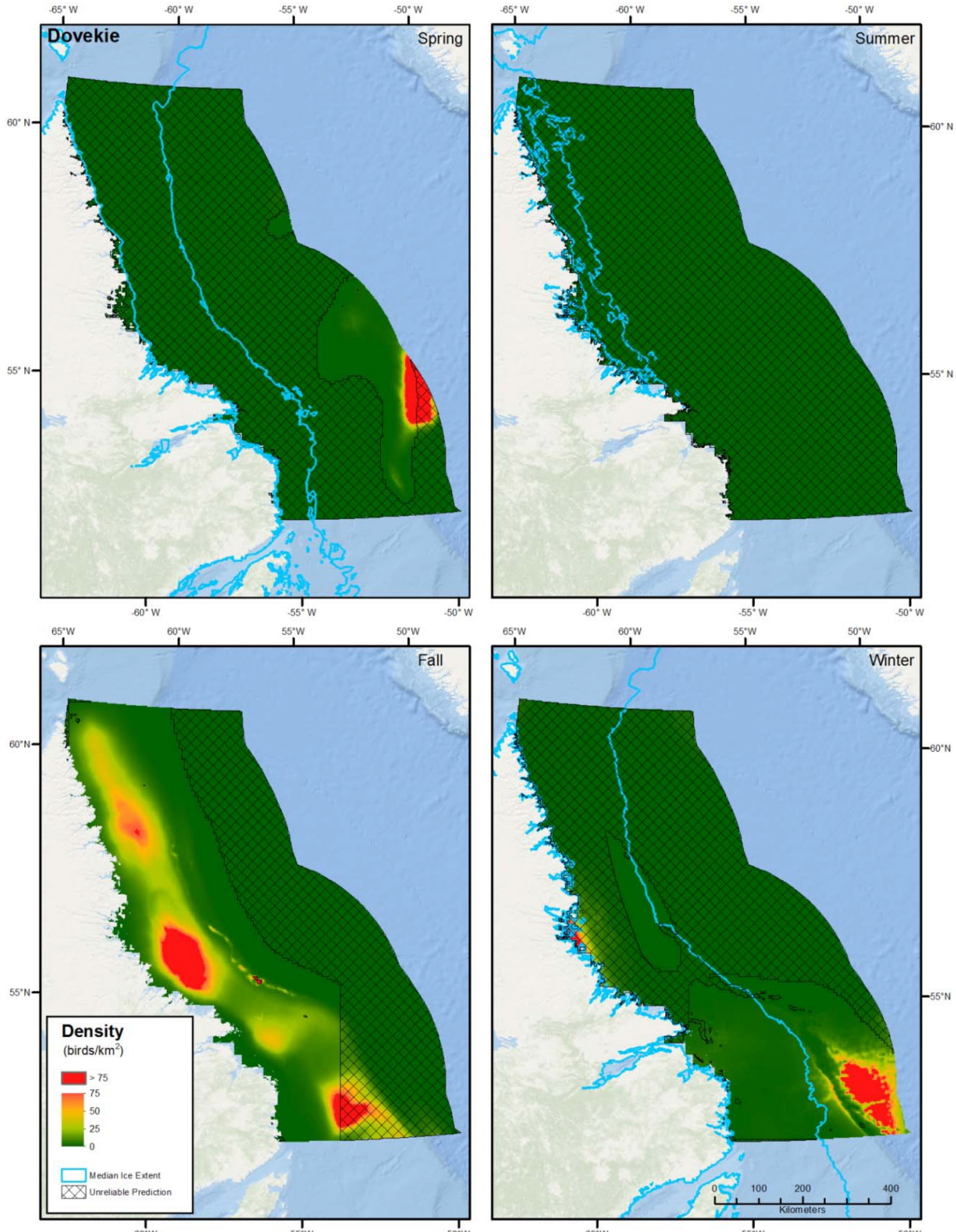

Figure 13. Seasonal predicted densities (2 km x 2 km grid) of dovekie based on Generalized Additive Models (GAMs).

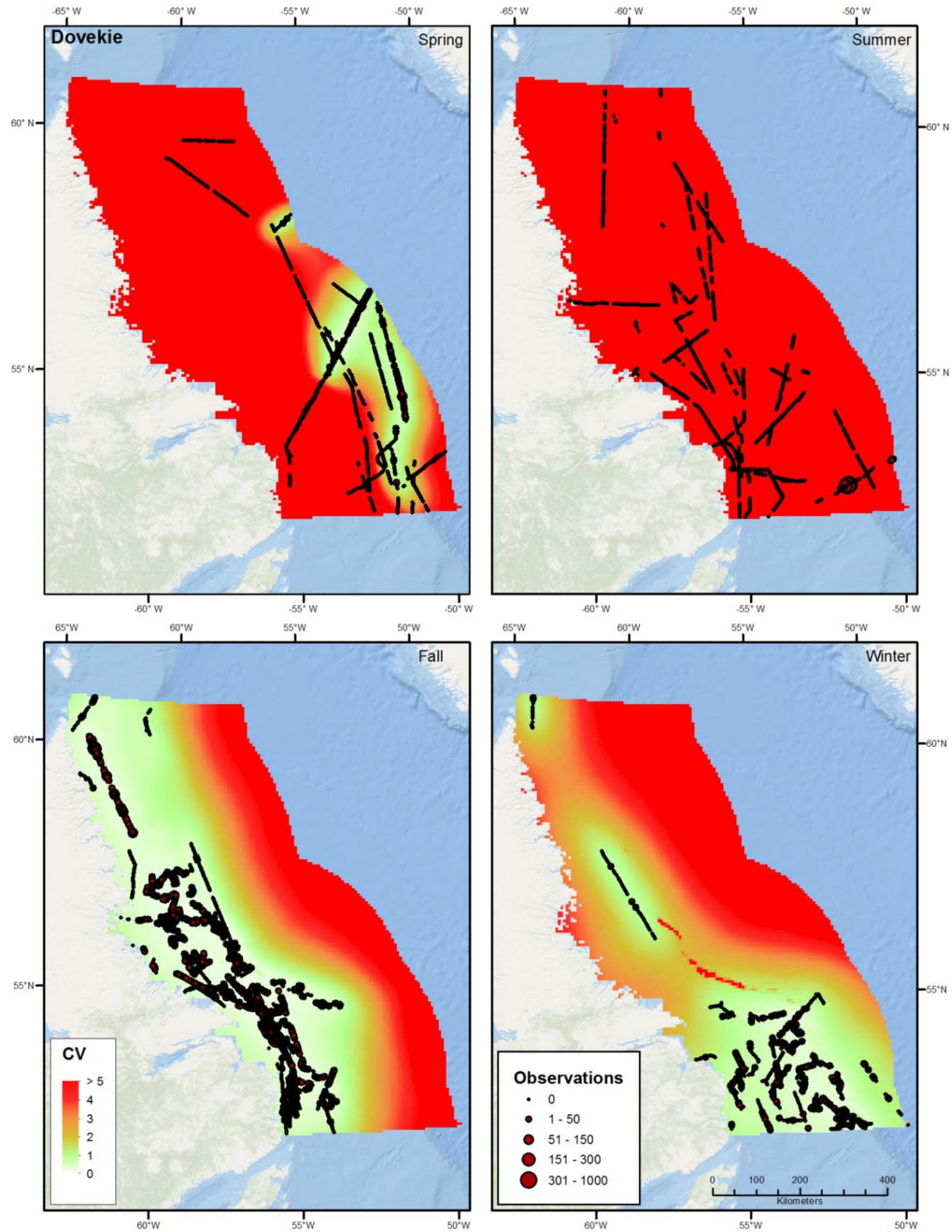

Figure 14. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of dovekie based on Generalized Additive Models (GAMs).

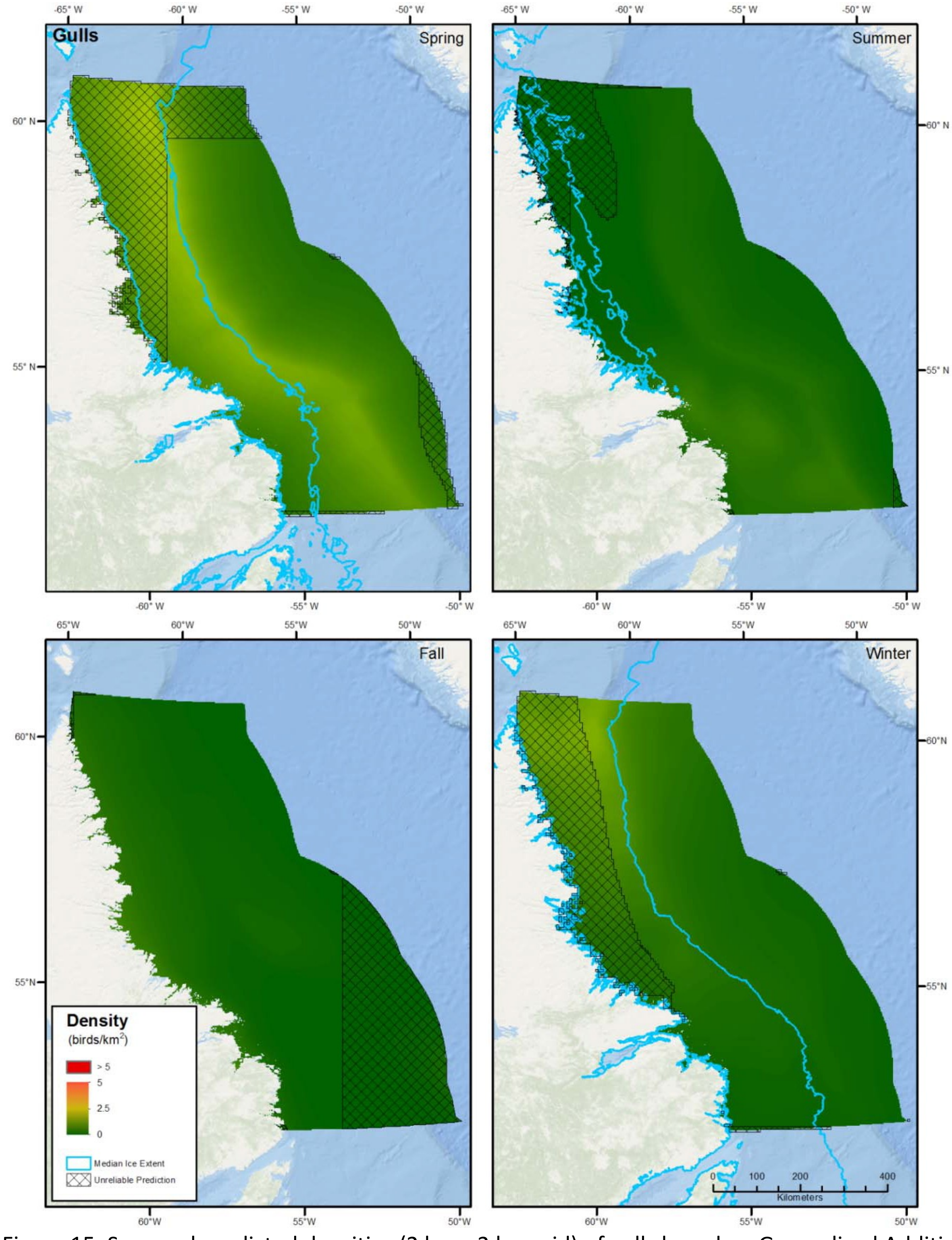

Figure 15. Seasonal predicted densities (2 km x 2 km grid) of gulls based on Generalized Additive Models (GAMs).

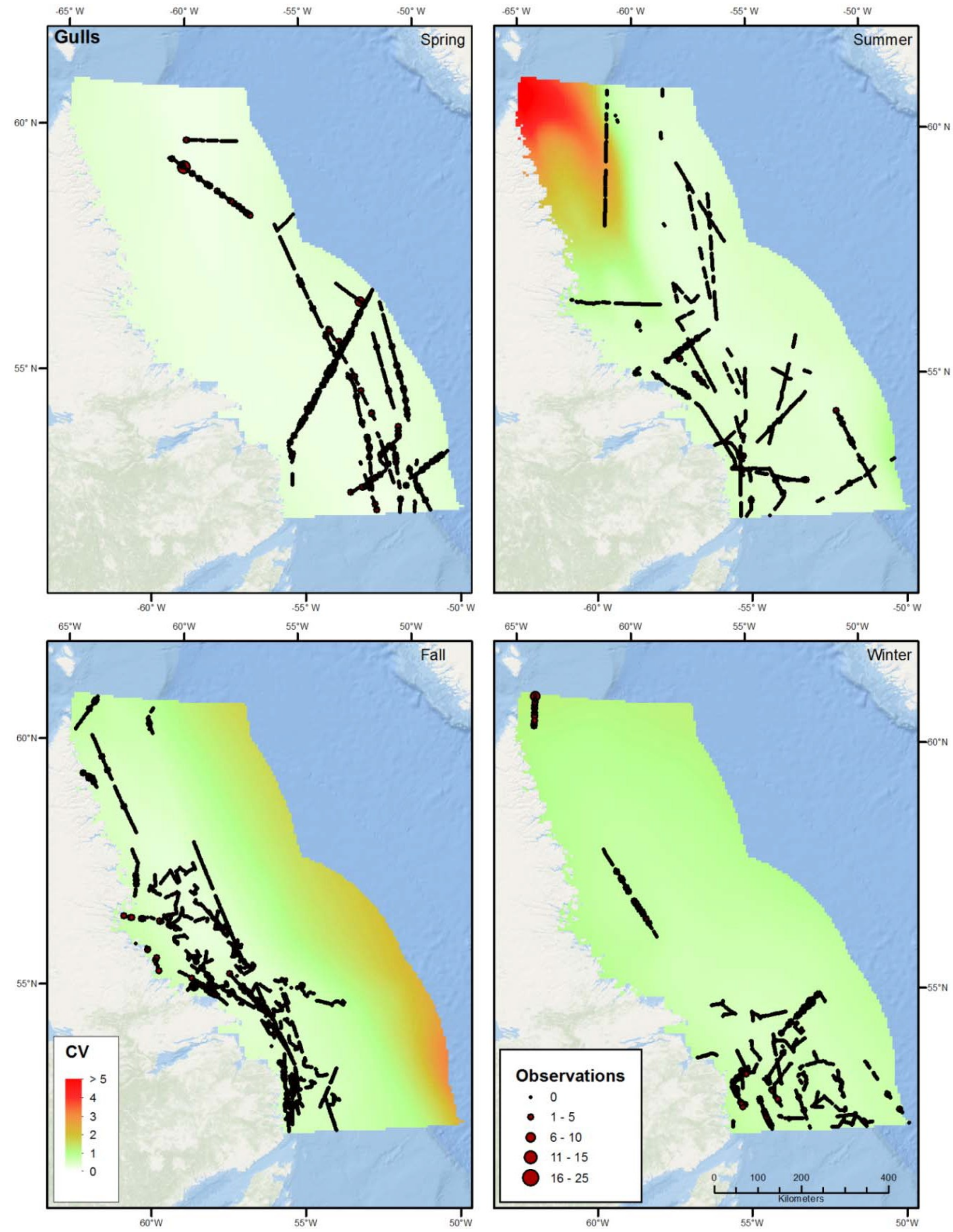

Figure 16. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of gulls based on Generalized Additive Models (GAMs)

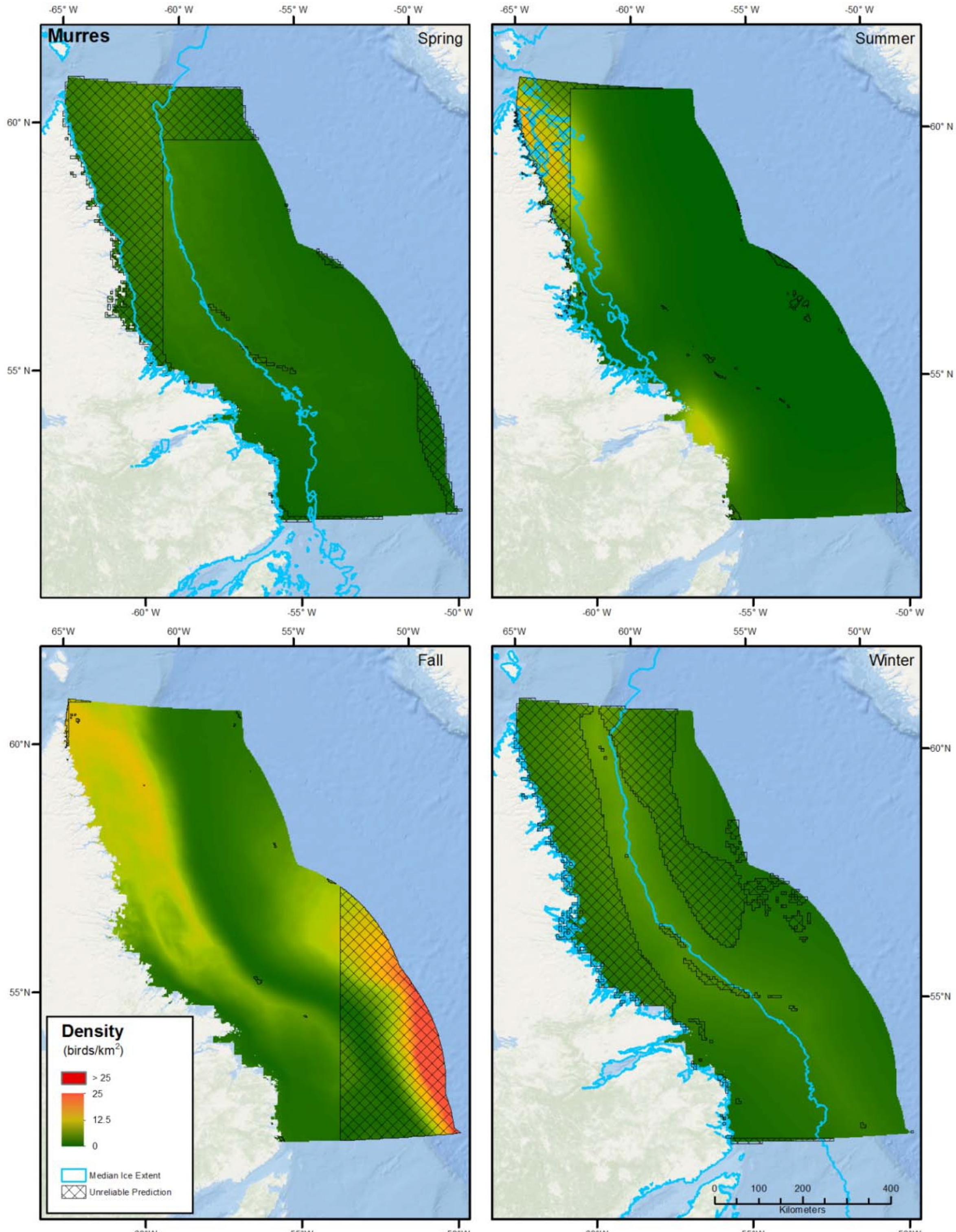

Figure 17. Seasonal predicted densities (2 km x 2 km grid) of murres based on Generalized Additive Models (GAMs).

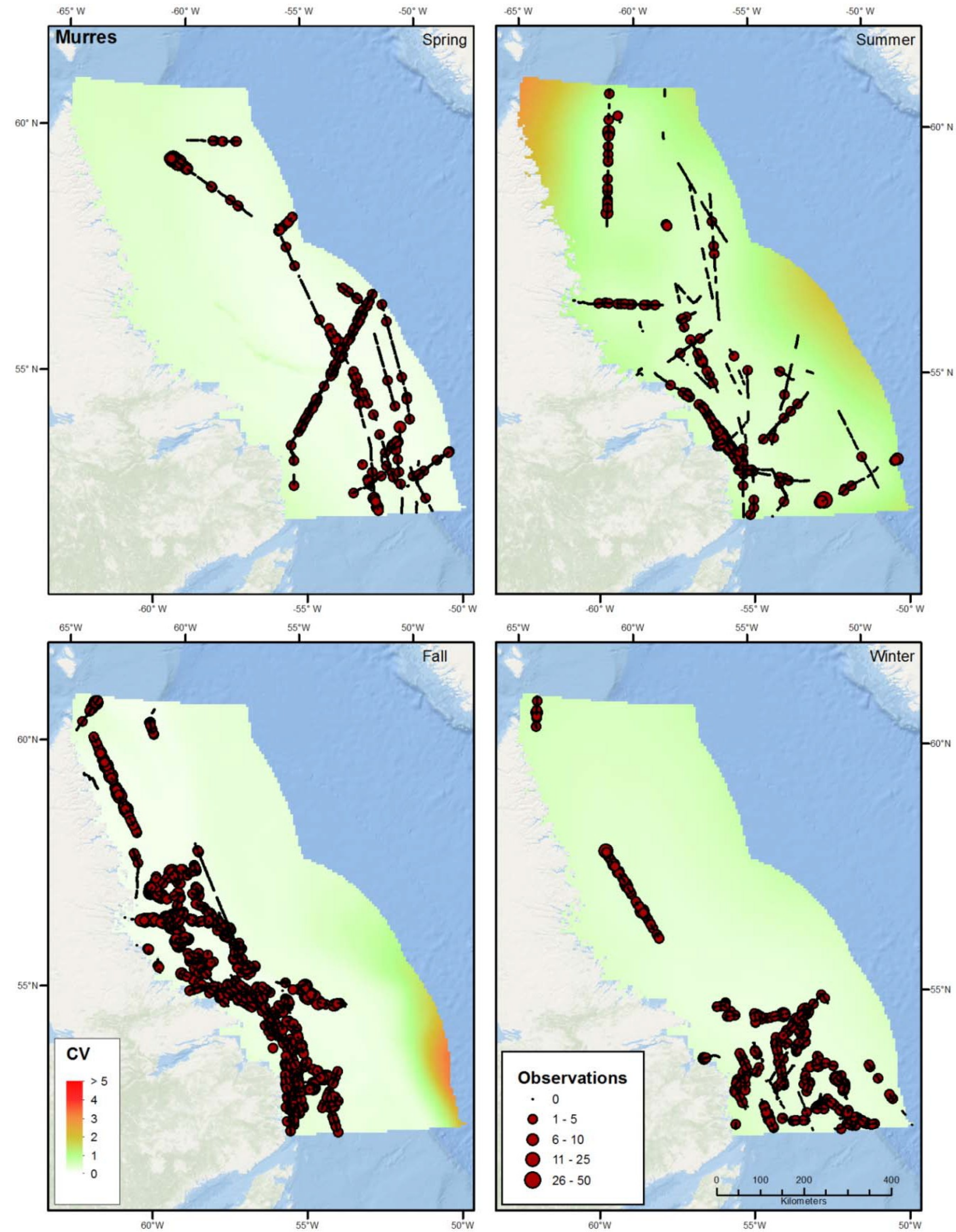

Figure 18. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of murres based on Generalized Additive Models (GAMs).

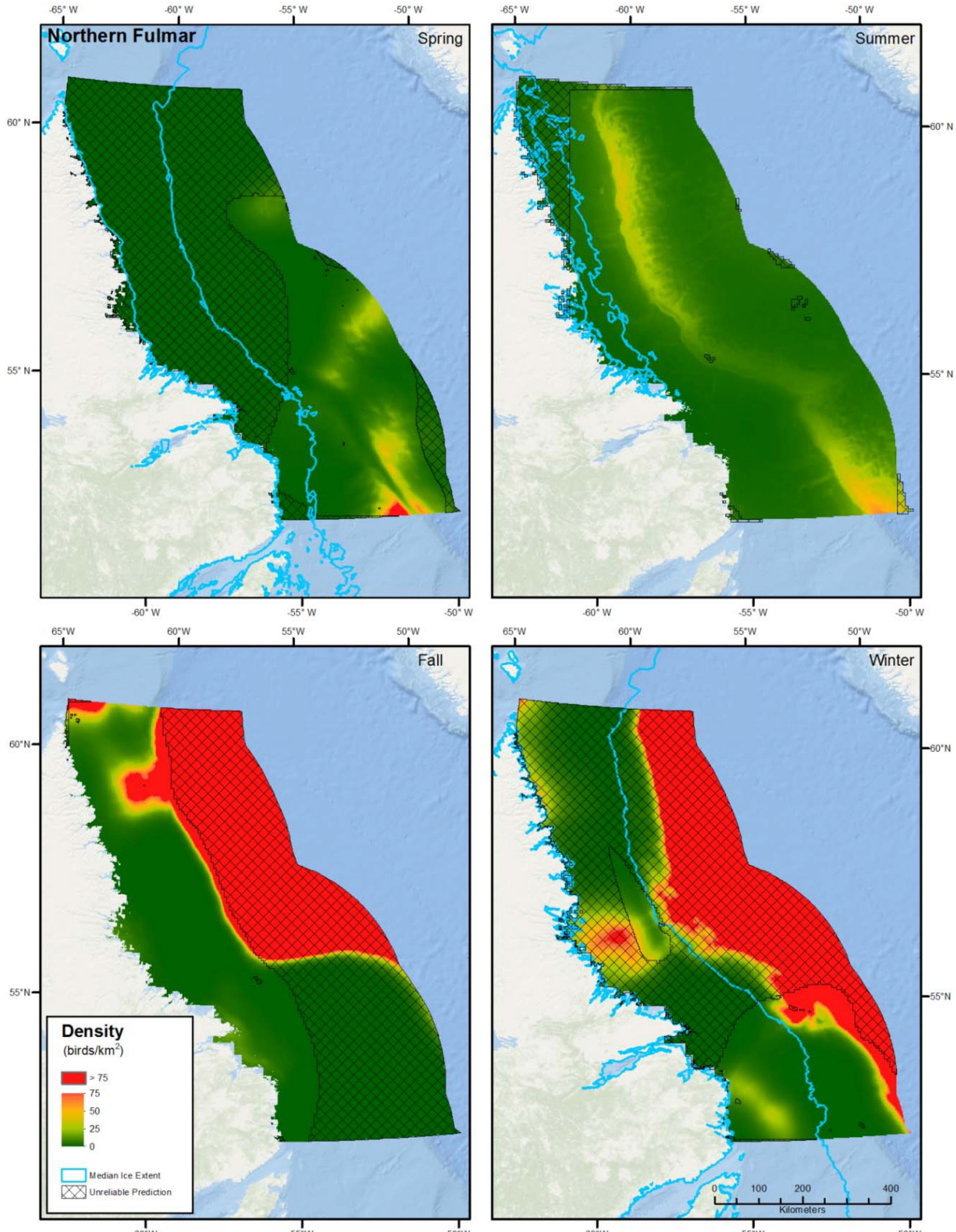

Figure 19. Seasonal predicted densities (2 km x 2 km grid) of Northern fulmar based on Generalized Additive Models (GAMs).

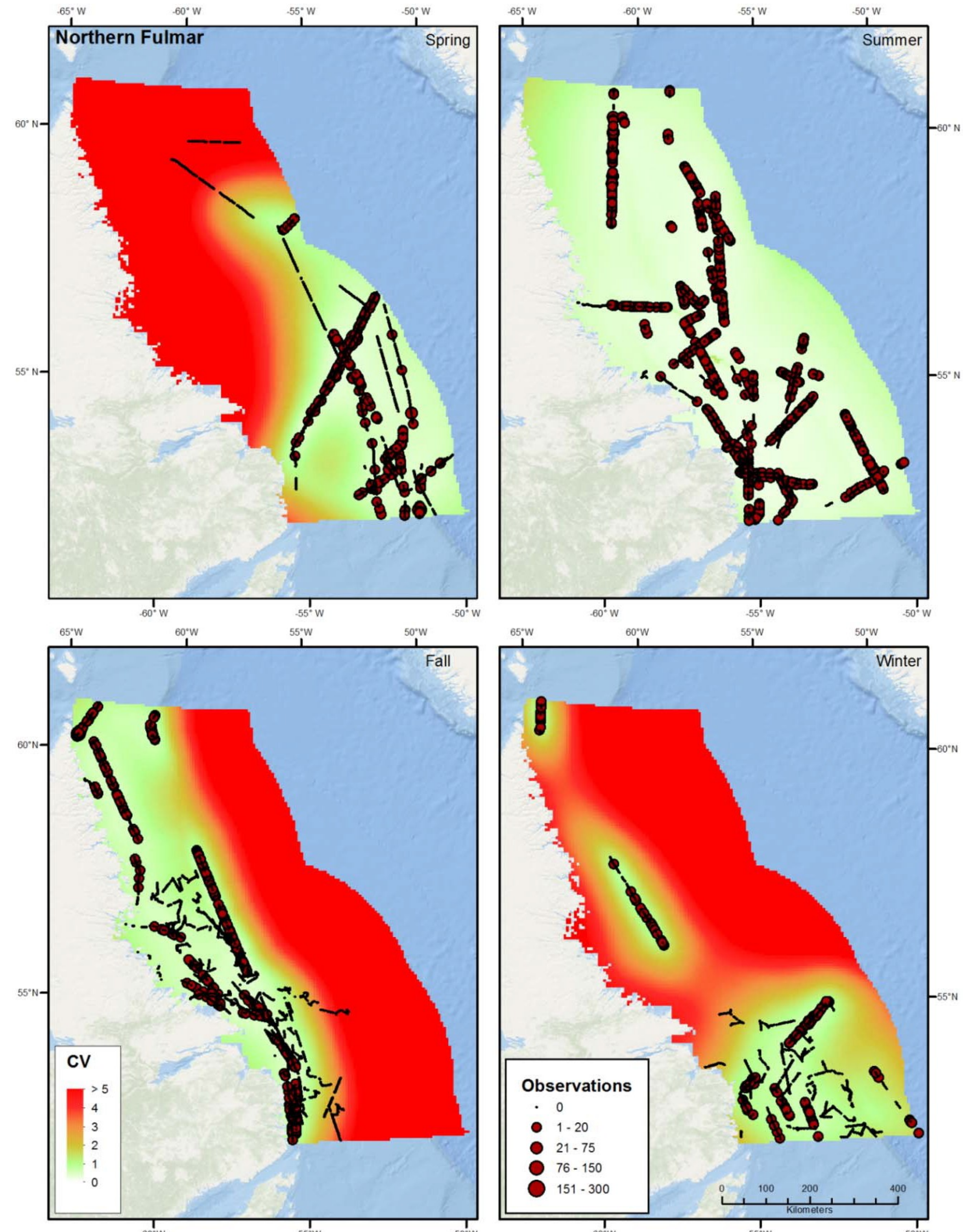

Figure 20. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of Northern fulmar based on Generalized Additive Models (GAMs)

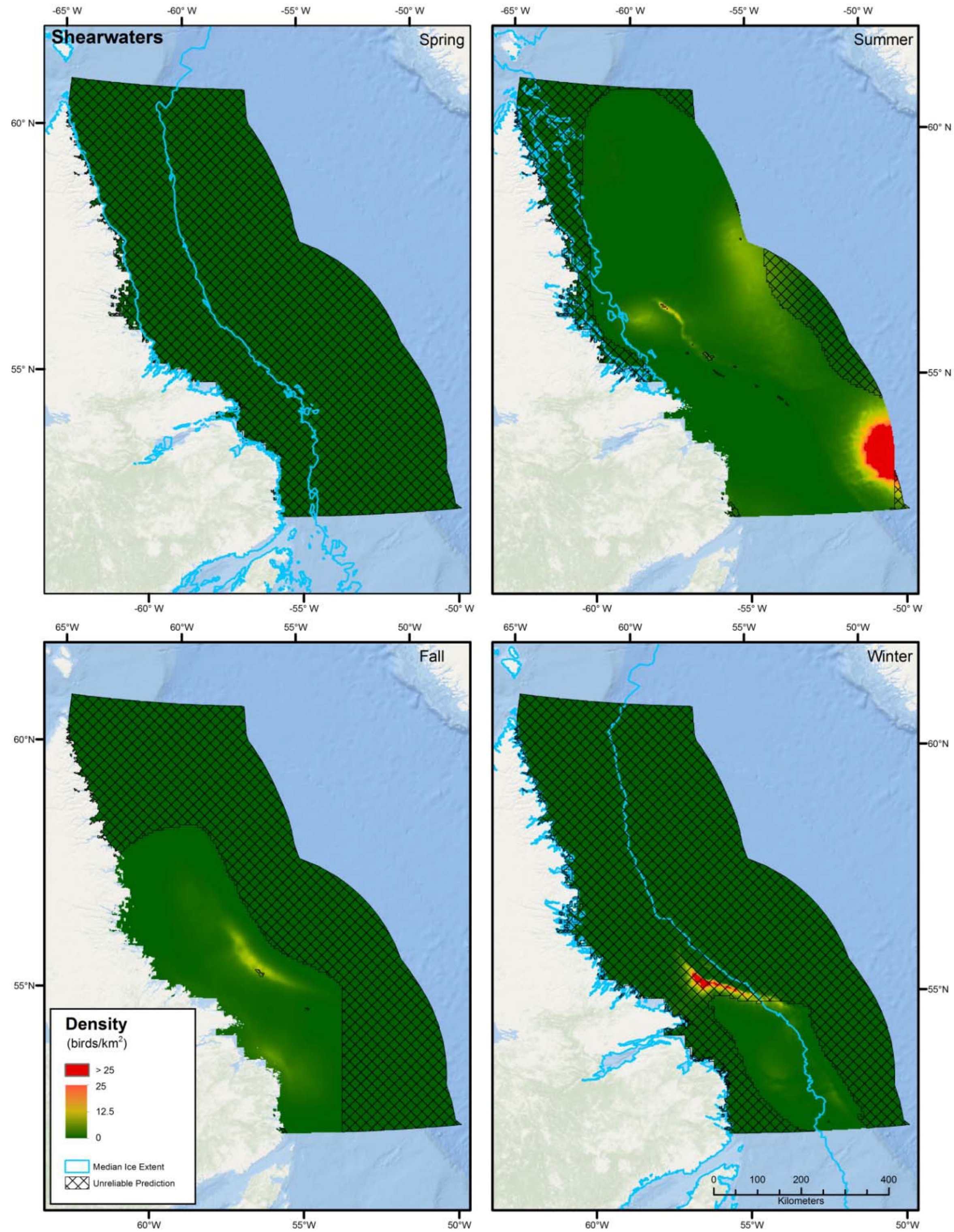

Figure 21. Seasonal predicted densities (2 km x 2 km grid) of shearwaters based on Generalized Additive Models (GAMs).

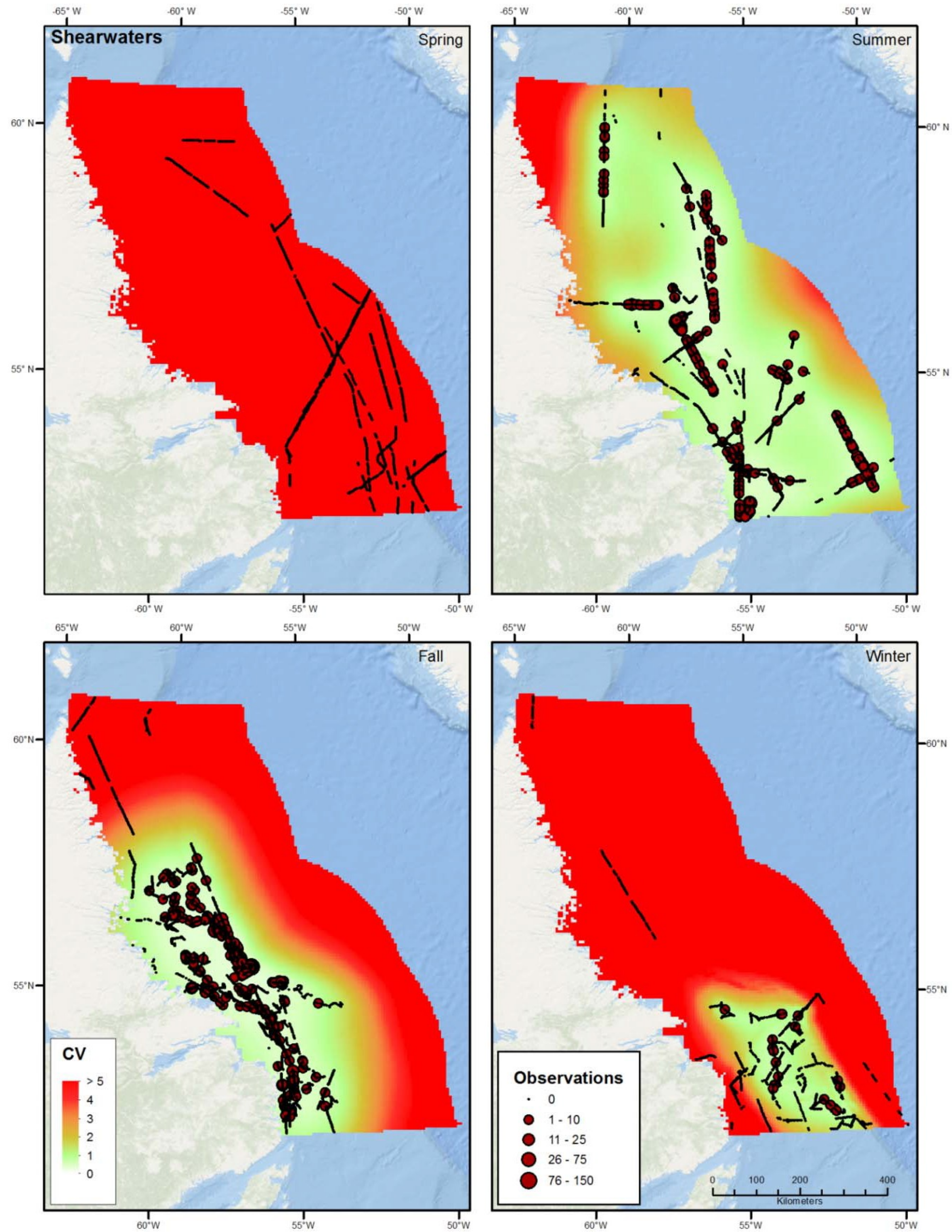

Figure 22. Seasonal bird observations and coefficient of variation (CV, 6 km by 6 km grid) for predicted densities of shearwaters based on Generalized Additive Models (GAMs)

8.2 Appendix 2: Summary of recommendations stemming from this report

***Recommendation 1**: Density surface models should be further validated using cross-validation and tracking studies.*

***Recommendation 2:** Further development of modeling approaches should consider a wide range of model types and ensembles methods.*

***Recommendation 3:** Expand modeling exercise to incorporate seabird data from adjacent oceanographic regions to provide a more holistic view of important seabird areas.*

***Recommendation 4:** Continue to fill data gaps for the Labrador Sea, especially to address seasonal patterns. In particular, spring and winter surveys (when there are fewer surveys in general) and off-shelf coverage in areas of land issuance require survey effort.*

Recommendation *5:* Continue to *develop techniques for aerial surveys including the use of digital methods, and formalize the methodology to compute detection functions and densities.*

Recommendation 6*: Industry, C-NLOPB and ECCC work together to ensure that any seabird survey data collected by industry follows established protocols and is submitted to C-NLOPB and ECCC in a timely manner. Points of contact within C-NLOPB and ECCC should be identified and follow-up on outstanding data should be conducted.*