Distribution of seabirds in the Lower Estuary and Gulf of St Lawrence (Canada) during summer

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Abstract

We investigated the abundance and distribution patterns of a range of seabird species in the Lower Estuary and Gulf of St Lawrence in the western North Atlantic Ocean using ship-based surveys during the summers of 2007, 2008 and 2009. This area is known to be of particular importance for several seabird and cetacean species. We analysed distribution and abundance of common seabird species in mid and late summer, and estimated total numbers for the Southern Gulf, which was most intensively surveyed. Northern Gannets *Morus bassanus* were overall most abundant and widespread. Our at-sea estimate of 150,000 birds for the Southern Gulf constitutes 64% of the North American breeding population, rendering the site one of the most important areas for this species worldwide during this period. Our at-sea estimates suggest that according to the 1% threshold of the Ramsar Convention considerable proportions of the Canadian breeding population of Razorbills *Alca torda* (5–11%), Common Guillemots *Uria aalge* (2–3%), Black-legged Kittiwakes *Rissa tridactyla* (2–4%) and Black Guillemots *Cepphus grylle* (1–2%) use the Southern Gulf. Relative to their biogeographic populations, at-sea totals were also considerable in American Herring Gulls *Larus smithsonianus* (3–4%), Great Black-backed Gulls *L. marinus* (1–4%) and Great Northern Divers *Gavia immer* (1–4%). Areas of high seabird densities and multispecies aggregations (hotspots) occurred around the Gaspé Peninsula (Northern Gannets, alcids, Black-legged Kittiwakes, *Larus* gulls), in the Northwestern Gulf, along the Lower North Shore (near St Mary's Islands), along the west coast of Newfoundland (Bay of Islands to St Georges Bay), in Cabot Strait, around Cape Breton Island and the Magdalen Islands, as well as west and east of Prince Edward Island.

Introduction

Since the 1960s, considerable effort has been directed at surveying seabirds in the marine environment. Previous studies resulted in detailed publications on seabird distribution and estimated total numbers of seabirds at sea (e.g. Brown *et al*. 1975; Brown 1986; Skov *et al*. 1995; Sonntag *et al*. 2006; Garthe *et al*. 2007a). The methods for ship-based surveys started with qualitative approaches, collecting data on the relative abundance of seabirds as for PIROP (*Programme Integré de Recherches sur les Oiseaux Pélagiques*) in Canada (Brown 1986). Standardisation and improvement of survey methods (Tasker *et al*. 1984) has led to widely used and compatible protocols (e.g. Garthe *et al*. 2002; Camphuysen *et al*. 2004; Gjerdrum *et al*. 2012). Many current survey programmes apply distance sampling (Buckland *et al*. 2001) for clearly defined sampling units (e.g. adjusted line-transect) to account for imperfect detection of animals. These approaches enable the estimation of total numbers at sea for large marine areas (e.g. Sonntag *et al*. 2006; Garthe *et al*. 2007a; Fifield *et al*. 2009). We applied these methods to gain information on the current distribution patterns of the most common seabirds in the Lower Estuary and Gulf of St Lawrence.

The study area is a highly productive marine area (White & Johns 1997; Dufour & Ouellet 2007) holding important breeding colonies of Northern Gannets *Morus bassanus*, alcids, and Black-legged Kittiwakes *Rissa tridactyla* (Cotter & Rail 2007; Rail & Cotter 2007; Cotter *et al*. 2012; Chardine *et al*. 2013). The area has been subject to profound changes, such as the collapse of demersal fish stocks, which have altered the structure of the marine ecosystem, with fundamental effects on many fish species (e.g. Savenkoff *et al*. 2007a,b; Bundy *et al*. 2009) that are important prey for a multitude of seabirds. Moreover, seabirds were intensively surveyed at sea in this area during the 1970s and 1980s (Brown 1986), but only little effort was subsequently available between the 1980s and 2006 and current and easily available information is lacking. We identified areas of high seabird densities and multispecies aggregations (i.e. hotspots) in the entire Gulf and Lower Estuary and estimated total numbers at sea for common seabird species in the Southern Gulf to characterise its importance in a regional and international context.

Methods

Study area: The Lower Estuary and Gulf of St Lawrence in the western North Atlantic Ocean is a semi-enclosed shelf sea influenced by boreal and arctic climate. Its bathymetry and hydrography is highly complex and combines oceanic and estuarine traits (Koutitonsky & Bugden 1991). It is a hotspot for seabirds, marine mammals, and a variety of other marine life (White & Johns 1997; Dufour & Ouellet 2007).

Seabird data: We carried out surveys of seabirds and other marine megafauna (i.e. cetaceans, seals, sea turtles, sharks etc.) during ship-based research cruises and along ferry routes. The surveys took place between June and August/September from 2007–09 in cooperation with the Canadian Wildlife Service (CWS) in Québec and scientists from the Department of Fisheries and Oceans (DFO), the Maurice Lamontagne Institute (MLI, Mont-Joli, QC), and the Gulf Fisheries Center (Moncton, NB). Most of the data (> 80%) were collected onboard the CCGS 'Teleost' during three oceanographic and two fisheries research cruises. The oceanographic surveys were part of the Atlantic Zone Monitoring Program (AZMP) in June 2007–09 and covered the whole study area with most effort occurring in the southern part. The fisheries research cruises ('Groundfish Survey') took place in August/September of 2008 and 2009 in the Southern Gulf (Figure 1). The Southern Gulf was thus most intensively studied (Figure 2) which enabled us to estimate at-sea totals for several seabird species (see below). Surveys were conducted by a single observer (NG) using

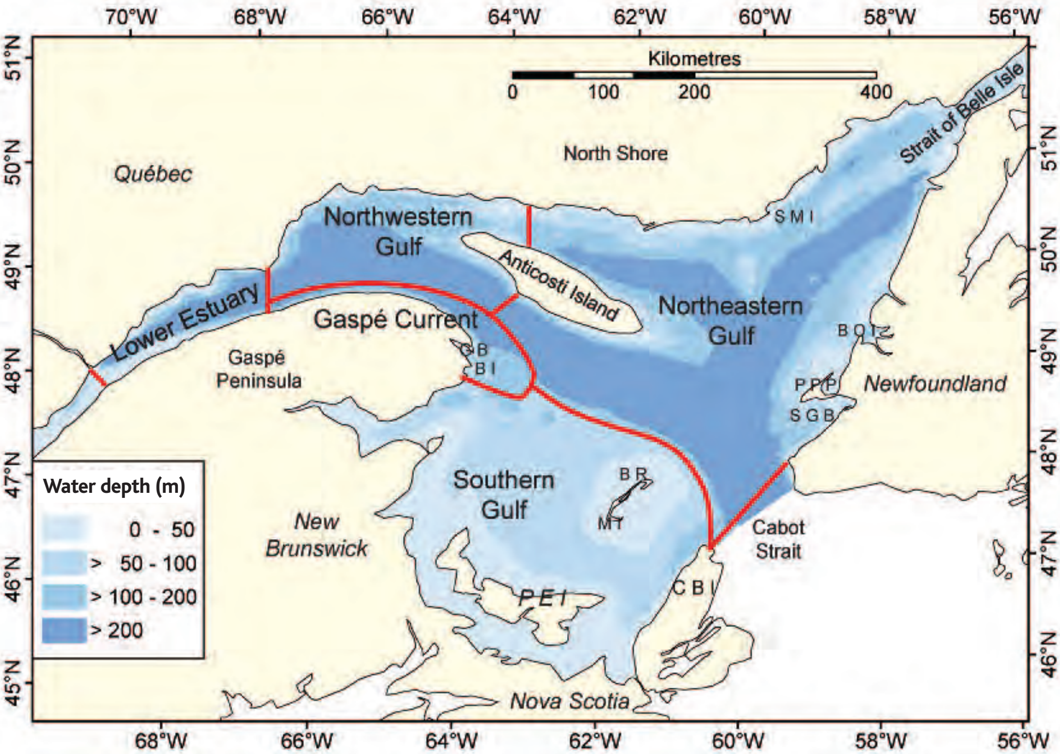


Figure 1. Subdivisions of the Lower Estuary and Gulf of St Lawrence modified after de Lafontaine *et al*. (1991) and Government of Canada (1991). Depicted are the five main marine subdivisions (Lower Estuary, Gaspé Current, Northwestern Gulf, Northeastern Gulf and Southern Gulf), the different provinces (in italics) and other locations mentioned in the text. Abbreviations: BI = Bonaventure Island, BOI = Bay of Islands, BR = Bird Rocks, CBI = Cape Breton Island, GB = Gaspé Bay, MI = Magdalen Islands, PEI = Prince Edward Island, PPP = Port au Port Peninsula, SGB = St George's Bay, SMI = St Mary's Islands.

an adjusted line-transect protocol (Tasker *et al*. 1984; Garthe *et al*. 2002; Camphuysen *et al*. 2004). Our method implements distance sampling (Buckland *et al*. 2001) and allows the calculation of abundance as seabird density (= individuals per km²). Distances of swimming birds were recorded at the time of first sighting in four spatial intervals (A = 0–50 m, B = 50–100 m, C = 100–200 m, and D = 200–300 m) covering a total distance of 300 m perpendicular to the transect line. Swimming birds were counted continuously. Flying birds within 300 m were counted during snapshots only to avoid overestimation of frequently or fast flying species (Tasker *et al*. 1984). Snapshots were conducted every minute. Each snapshot covered the area of the transect width (300 m) multiplied by the distance the ship travelled within a minute. As an exception, perpendicular distances were also estimated for flying storm-petrels recorded during snapshots and additional individuals which made contact with water within 300 m. In these cases, distances were not recorded at first sighting but during snapshots or at the time of water contact.

The surveys were carried out from the deck providing unobstructed views ahead of 90° to 180° at 13 m (> 80% of survey height data, range: 6–27 m) above sea level with an average speed of 12 knots (range: 4–21 knots). The observer only surveyed one side of the ship at a time, depending on glare intensity. Surveys during fisheries research cruises were only conducted in periods between fishing operations when the vessel had regained its travelling speed and the number of ship-following birds was low and manageable (see Camphuysen 2011). We assumed that overestimation of densities of known ship-following species such as gulls, Northern Fulmars *Fulmarus glacialis* (hereafter 'Fulmars') and Northern Gannets (hereafter 'Gannets') due to responsive movement towards the survey vessel to be rather unimportant in our study. These species have been shown to utilise fisheries' discards and offal and thus may be attracted to fishing vessels (e.g. Hudson & Furness 1988; Camphuysen *et al*. 1995) but in our study area the discard-intensive fishery for demersal fish has declined dramatically (see e.g. Savenkoff *et al*. 2007a,b) and discarding has been completely forbidden. Moreover, if any bird was obviously attracted to our survey vessel, it was excluded from further analyses.

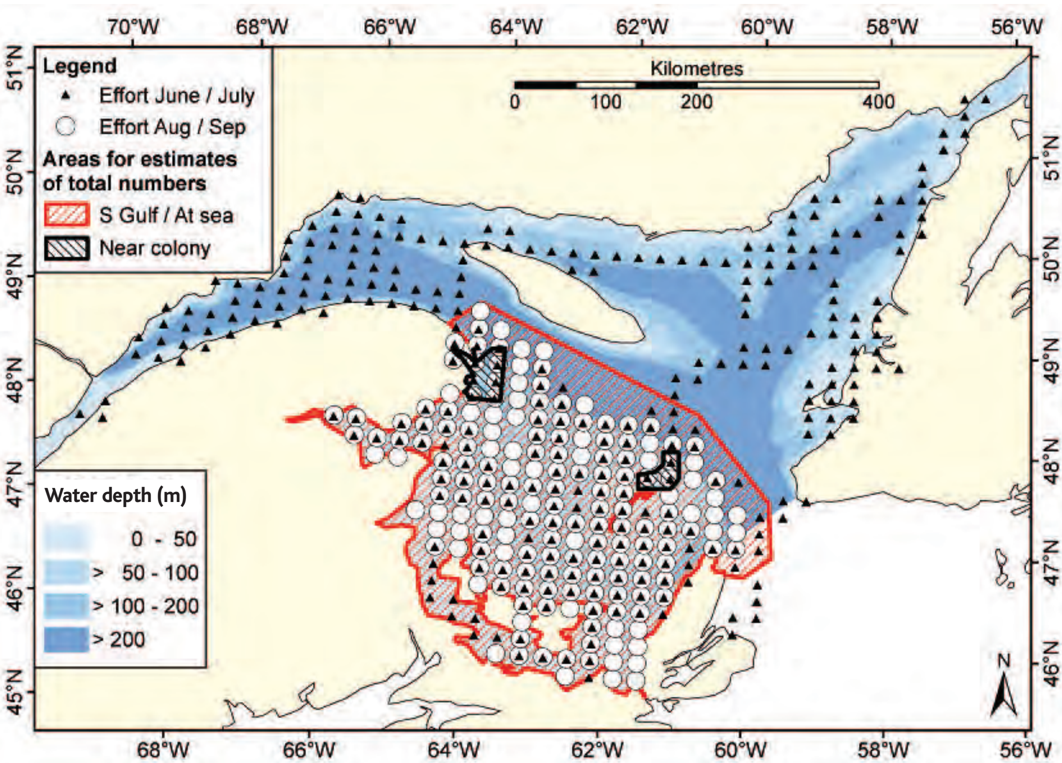


Figure 2. Reference areas of estimated seabird totals in the Southern Gulf and adjacent waters. Total numbers for most species were calculated by multiplying mean density by the size of the Southern Gulf area (104,604 km², including sub-area 'near colony'). Totals of Common Guillemots *Uria aalge* were calculated separately for the high density 'near colony' area and the remaining 'at sea' area; for details see text. The underlying seasonal survey effort in the Lower Estuary and Gulf of St Lawrence in 2007, 2008 and 2009 is depicted for 10'x20' grid cells. Black triangles and white circles show grid cells in which seabird survey data were collected during June and July, or August and September, respectively.

The overall survey effort totalled an area of 4,660 km² and a distance of 15,532 km during 116 days at sea. We calculated densities for all common seabird species applying the distance sampling technique (Buckland *et al*. 2001) following the procedure described by Markones & Garthe (2012). Distance sampling accounts for the fact that the detection probability of birds decreases with increasing distance from the observer. To estimate detection probabilities, perpendicular distances of single observations of birds (individuals or clusters) were recorded using the above-mentioned four distance intervals. At sea, these distances were measured with a ruler held in the hand, which was calibrated for the eye level of the observer above the sea surface and the observer's arm length applying the formula of Heinemann (1981). We calculated correction factors of detection probability for all species and species groups (Table 1) that comprised at least 50 observations within one of the four distance intervals (A, B, C or D) during the entire study. We used the half-normal function with cosine smoothing of the DISTANCE software (version 5.0; www.ruwpa.st-and.ac.uk/distance/distanceabout.html) to model detection functions and to calculate the 'effective strip width' (ESW). The ESW is defined as the transect width at which the number of animals detected outside exactly equals the number of animals missed inside. The respective correction factor is then calculated as the ratio between the transect width of 300 m and the species-specific ESW (being less than 300 m). We only corrected swimming individuals as we assumed a detection rate of 100% for flying individuals within the 300 m transect.

An exception was made for flying storm-petrels that almost always hovered near the water surface, making them particularly hard to detect due to their small size and dark colour. Our survey data consistently showed decreasing detection probabilities of flying storm-petrels with increasing perpendicular distance of observation and thus required the calculation of a correction factor for this group too. For swimming Razorbills *Alca torda* and Common Guillemots *Uria aalge* a common correction factor was calculated due to their similarity in size, colour, and behaviour including all birds identified only as 'Razormots'. This was a mixed category comprising Razorbills, Common Guillemots and Brünnich's Guillemots *Uria lomvia*.

Great Northern Divers *Gavia immer* mostly showed an escape reaction in response to the approaching survey vessel. They often swam or dived away from the transect line even at distances of > 1 km ahead. This reaction violated the critical assumption for distance sampling that *all* birds occurring at the transect line (i.e. in transect interval A) are recorded ($g(0) = 1$). This most probably led to a higher proportion of birds emerging in the outer transect intervals C and D, thus violating the assumption that birds are evenly distributed across the transect. We consequently were not able to calculate a valid detection function, and instead estimated a correction factor to account for the birds that were missed within transect. This was based on personal observations during surveys and by taking into account distance correction factors for other diver species from German Sea areas (Garthe *et al*. 2009; Markones *et al*. 2012).

To calculate a given species' density, we multiplied the observed number of birds by its correction factor. We also took the effect of bird clusters' size on detection rates into account in the computation of detection probabilities (Buckland *et al*. 2001).

As sea state influences detection probability, we used only survey data collected during excellent to moderate conditions (sea states 0 to 4; 96% of the total effort) to calculate densities of species. Only for highly visible and frequently flying species, such as all gull species, Gannets, and Fulmars was the full data set was used.

We used a spatial grid based on a cell size of 10'x20' to map the distribution of all common species in mid (June/July) and late summer (August/September). The first period additionally contained 1 August 2007 as this was the final day of a coherent survey that had begun at the end of July; the next survey effort available was from 12 August onwards. All birds were identified to the lowest possible taxon. For (1) Leach's Storm-petrel *Oceanodroma leucorhoa* and Wilson's Storm-petrel *Oceanites oceanicus*, (2) Common and Brünnich's Guillemot and Razorbill the number of individuals not identified to species level (e.g. 'Razormots') in each grid

Table 1. Correction factors for detection probability of common seabird species and species groups in the Lower Estuary and Gulf of St Lawrence in summer 2007, 2008 and 2009 used for the calculation of densities (ind./km²) and estimates of seabird totals. Derivation explains whether the correction factor was calculated by distance sampling for a single species or a species group or estimated otherwise (for details see text).

Taxon/Category	Correction Factor	Derivation
Great Northern Diver *Gavia immer*	1.5	Estimate
Northern Fulmar *Fulmarus glacialis*	1.6	Calculation
Wilson's Storm-petrel *Oceanites oceanicus*	1.6	Calculation for all swimming and flying storm-petrels
Leach's Storm-petrel *Oceanodroma leucorhoa*	1.6	Calculation for all swimming and flying storm-petrels
unidentified storm-petrel	1.6	Calculation for all swimming and flying storm-petrels
Northern Gannet *Morus bassanus*	1.2	Calculation
American Herring Gull *Larus smithsonianus*	1.2	Calculation
Great Black-backed Gull *Larus marinus*	1.0	Calculation
Black-legged Kittiwake *Rissa tridactyla*	1.0	Calculation
Common Guillemot *Uria aalge*	1.6	Calculation for all alcids
Razorbill *Alca torda*	1.6	Calculation for all alcids
Brünnich's Guillemot *Uria lomvia*	1.6	Calculation for all alcids
Unidentified alcid	1.8	Calculation for all unidentified alcids
Common/Brünnich's Guillemot *Uria aalge/U. lomvia*	1.8	Calculation for all unidentified alcids
Common/Brünnich's Guillemot/Razorbill *Uria aalge/U. lomvia/Alca torda*	1.8	Calculation for all unidentified alcids
Black Guillemot *Cepphus grylle*	1.8	Calculation

cell was divided proportionally between the two or three species in question based on the ratio identified to species level in the neighbouring cells (Markones & Garthe 2011). With this approach the potential spatial differences of species were taken into account. We included all known and potentially active seabird colonies since 1978 onwards (see Guse 2013) based on databases from Environment Canada (*Seabird and Waterbird database of Québec*, status 13 July 2010 and *Atlantic Waterbird Colony Database*, status 10 July 2010) into the maps of the at-sea distribution of seabirds. Here we present maps on seabird densities and estimated totals for a selection of the common seabird species. Species groups such as seaducks and terns, which have important colonies in the study area (CWS unpubl. data) were not considered as their main habitat could not be sampled with surveys mostly conducted in waters beyond 10 m depth. A list of all observed taxa of seabirds and seaducks and their total numbers is given in an Appendix.

Estimating seabird totals for the Southern Gulf: It is important to have sufficient spatial and temporal survey effort in an area before estimating total numbers because seabird distribution patterns can change within short time spans (e.g. Markones *et al*. 2008). Thus, we only generated estimates of seabird totals for the Southern Gulf, which was most intensively surveyed during the three years of our study, which enabled us to compute at-sea totals for the majority of seabird species during mid and late summer. We used the same sea state restrictions for estimating these totals as for calculating densities, resulting in slight differences in available survey effort and therefore the database between the different species (Table 2).

Beyond estimating the average at-sea total of a species we took the associated error (see below) into account using the bootstrap approach of Markones & Garthe (2009). We used a grid with a cell size of 10'x20' (as above) and calculated the distance-corrected mean density for each seabird species and grid cell. Each

Table 2. Sea state restrictions and resultant survey effort for estimating seabird totals in the Southern Gulf of St Lawrence and adjacent waters in summer 2007, 2008 and 2009. *The data set used for Northern Gannets *Morus bassanus* in August/September comprised one additional survey leg where light conditions allowed a quantitative survey only of this species.

Species	Sea state	Period	Area (km²)	Distance (km)
Great Northern Diver, Wilson's Storm-petrel, Black Guillemot, Common Guillemot, Razorbill	0–4	June/July	1,494	4,981
Northern Fulmar, Northern Gannet, American Herring Gull, Great Black-backed Gull, Black-legged Kittiwake	0–6	June/July	1,538	5,127
Great Northern Diver, Wilson's Storm-petrel, Black Guillemot, Common Guillemot, Razorbill	0–4	August/September	1,769	5,898
Northern Fulmar, American Herring Gull, Great Black-backed Gull, Black-legged Kittiwake	0–6	August/September	1,849	6,163
Northern Gannet*	0–6	August/September	1,857	6,188

species' mean density over the entire study area, standard deviation, and 95% confidence interval was calculated using a bootstrap with 10,000 iterations. If a species occurred frequently and the bootstrapped mean density showed a normal distribution, we multiplied the resultant overall mean density with the size of the reference area 'Southern Gulf' (104,604 km²; Figure 2) to estimate its total number at sea. For Black Guillemots *Cepphus grylle* and Common Guillemots during midsummer (June/July) we used a different approach. These species occurred frequently but their abundance at sea was highly skewed with large areas of low densities or zero counts and a few small areas of very high densities. Thus, their resultant bootstrapped mean density was not normally distributed leading to an erroneously high estimated total. Thus, we defined sub-areas of high density for both species for which we chose different approaches to estimate their total number (see below). We calculated total numbers based on bootstrapped mean densities for the remaining waters of the Southern Gulf. We then added results of the high-density sub-area to that of the remaining waters to obtain the estimated total number for the entire Southern Gulf (Table 3). For Black Guillemots, the available survey effort probably only partially overlapped with their main concentration areas, as this species was mostly observed up to a few km from land, particularly around the Gaspé Peninsula. Thus, we defined a high-density sub-area inside the Gaspé Bay comprising a single short survey leg where density was exceptionally high. We added the corrected number on this survey leg to the estimate of the remaining area as well as to its lower and upper 95% confidence intervals to obtain their estimated total number at sea. The density of Common Guillemots near the main colonies was orders of magnitudes higher than areas further away. We defined a sub-area of high density comprising waters around the two main colonies (3,160 km², sub-area: 'near colony' vs. remaining 'at sea' area, 101,444 km²; Figure 2, Table 3). We calculated the median density and multiplied it by the size of this sub-area to generate the sub-area estimate (Table 3). We rounded the estimated total number of the different seabird species and its confidence intervals according to Garthe *et al*. (2007a).

Results

Seabird distribution, densities and estimated totals: Gannets were the most abundant species and occurred in both coastal and offshore waters (Figure 6). The Southern Gulf and the distal part of Gaspé Current held highest densities, with a total of 140,000 to 150,000 individuals in these waters throughout the summer period (Table 3).

Common Guillemots were also very abundant and widespread (Figure 11). The highest densities were observed in the Northeastern and Northwestern Gulf, in the Gaspé Current area, and around the Magdalen Islands. With a total of 57,000 individuals, Common Guillemots were among the most numerous species in the Southern Gulf in midsummer (Table 3). Apart from the western part of the Southern Gulf, fewer birds were observed in late summer.

Table 3. Estimated totals of common seabird species in the Southern Gulf of St Lawrence and adjacent waters in mid (June/July) and late summer (August/September) of 2007, 2008 and 2009. Given is the estimated average total number and its lower and upper limits of the 95% confidence intervals (= CI) calculated by bootstrapping. For Black Guillemot* *Cepphus grylle* and Common Guillemot** *Uria aalge* another method was used (see Methods); X = no value calculated due to low occurrence; NA = non-applicable i.e. confidence intervals could not be calculated; ? = reference population was not available. Numbers were rounded according to Garthe *et al.* (2007): 50–500: to the nearest 10; 500–1,000: to the nearest 50; 1,000–5,000: to the nearest 100; 5,000–20,000: to the nearest 500; 20,000–100,000: to the nearest 1,000; > 100,000: to the nearest 5,000. Literature sources for reference populations: 1 = Wetlands International 2012; 2 = J.-F. Rail pers. comm.; 3 = Chardine *et al.* 2013.

Species	Period	Estimated total (Ind.)	95% CI (lower)	95% CI (upper)	% of Reference population	Reference population	Size reference population (Ind.; Mean)	Source
Great Northern Diver	June/July	7,500	3,500	12,000	1%	North American pop.	620,000	1
Great Northern Diver	Aug/Sep	26,000	4,700	47,000	4%	North American pop.	620,000	1
Northern Fulmar	June/July	36,000	20,000	51,000	10%	Canadian breeding pop.	348,000	2
Northern Fulmar	Aug/Sep	6,500	4,200	9,500	2%	Canadian breeding pop.	348,000	2
Wilson's Storm-petrel	June/July	65,000	37,000	93,000		?		
Wilson's Storm-petrel	Aug/Sep	28,000	8,000	48,000		?		
Northern Gannet	June/July	150,000	90,000	205,000	64%	North American breeding pop.	234,000	3
Northern Gannet	Aug/Sep	140,000	110,000	170,000	60%	North American breeding pop.	234,000	3
American Herring Gull	June/July	11,500	7,000	16,000	3%	Total pop. *smithsonianus*	410,000	1
American Herring Gull	Aug/Sep	17,500	10,500	24,000	4%	Total pop. *smithsonianus*	410,000	1
Great Black-backed Gull	June/July	4,600	1,600	7,500	1%	NW Atlantic pop.	420,000	1
Great Black-backed Gull	Aug/Sep	18,000	8,000	27,000	4%	NW Atlantic pop.	420,000	1
Black-legged Kittiwake	June/July	19,000	12,000	26,000	4%	Canadian breeding pop.	470,000	2
Black-legged Kittiwake	Aug/Sep	7,500	3,700	11,000	2%	Canadian breeding pop.	470,000	2
Black Guillemot*	June/July	6,500*	2,500*	10,500*	1%	Canadian breeding pop.	458,000	2
Black Guillemot	Aug/Sep	X	X	X				
Common Guillemot** (near colony)	June/July	29,000	NA	NA				
Common Guillemot** (at sea)	June/July	28,000	18,500	36,000				
Common Guillemot** (total)	June/July	57,000	NA	NA	3%	Canadian breeding pop.	1,700,000	2
Common Guillemot	Aug/Sep	27,000	14,000	39,000	2%	Canadian breeding pop.	1,700,000	2
Razorbill	June/July	6,000	2,700	9,500	5%	Canadian breeding pop.	110,000	2
Razorbill	Aug/Sep	12,000	4,700	19,500	11%	Canadian breeding pop.	110,000	2

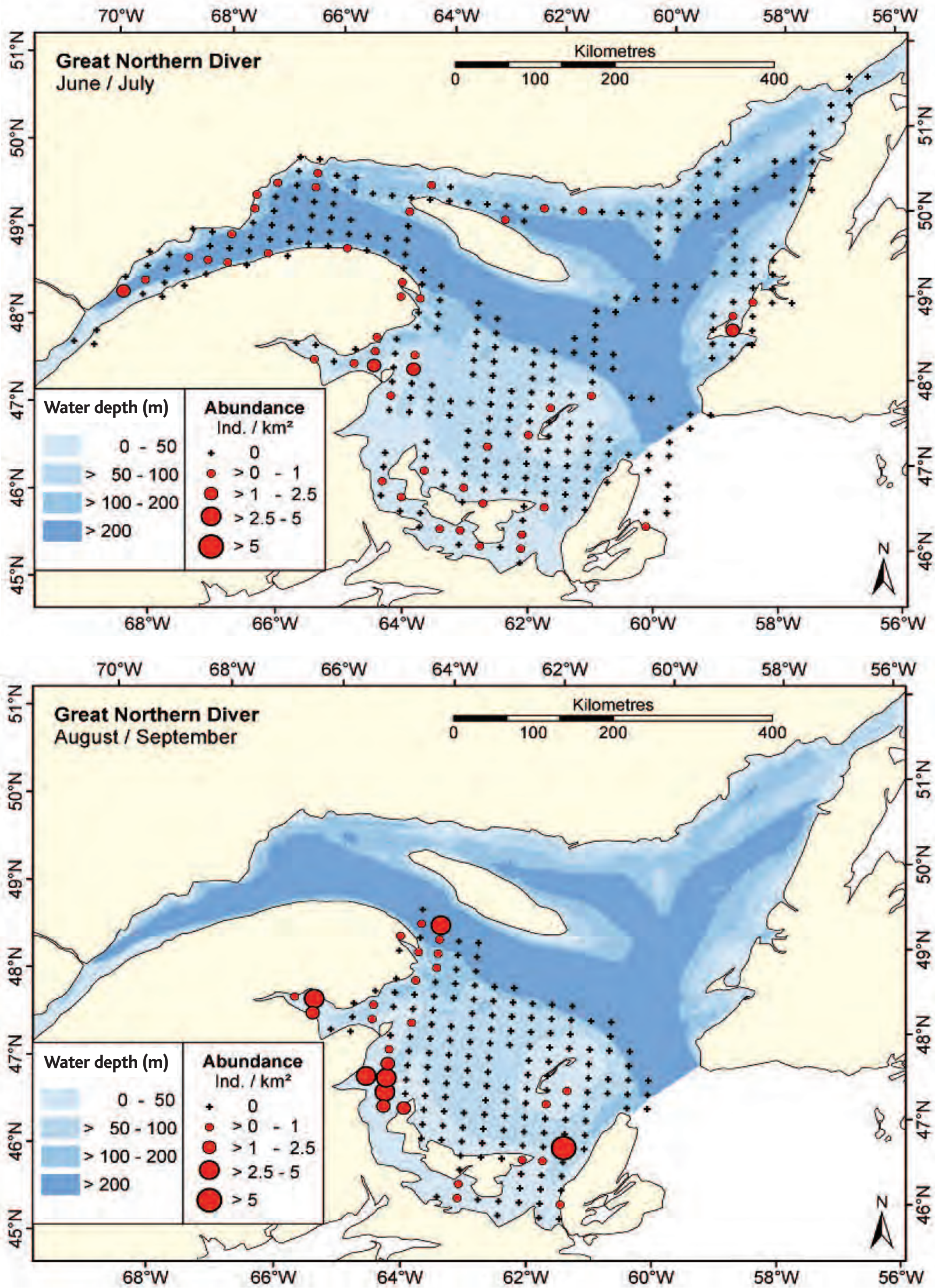


Figure 3. Distribution and abundance of Great Northern Divers *Gavia immer* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

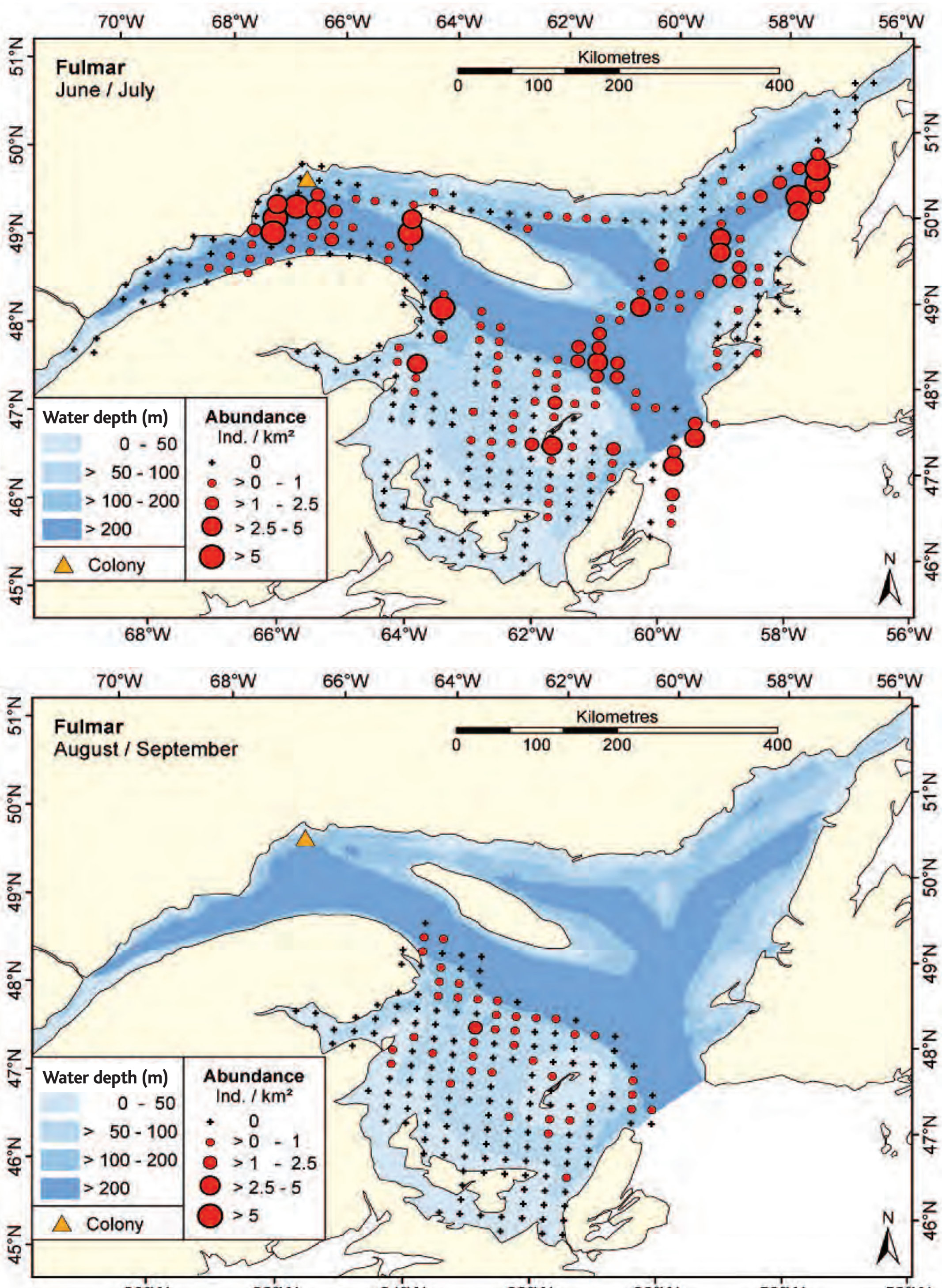


Figure 4. Distribution and abundance of Northern Fulmars *Fulmarus glacialis* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20'grid cells.

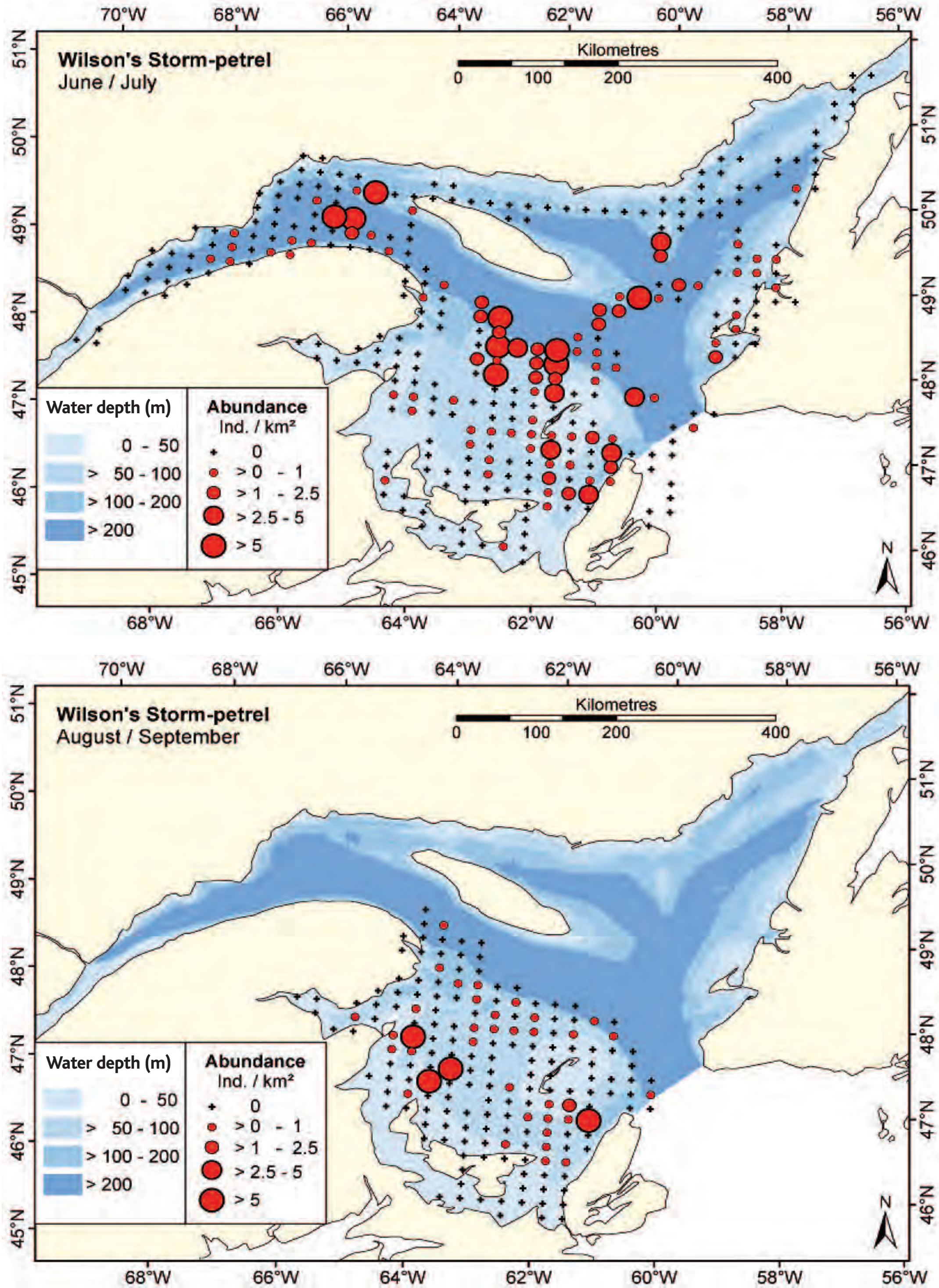


Figure 5. Distribution and abundance of Wilson's Storm-petrels *Oceanites oceanicus* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

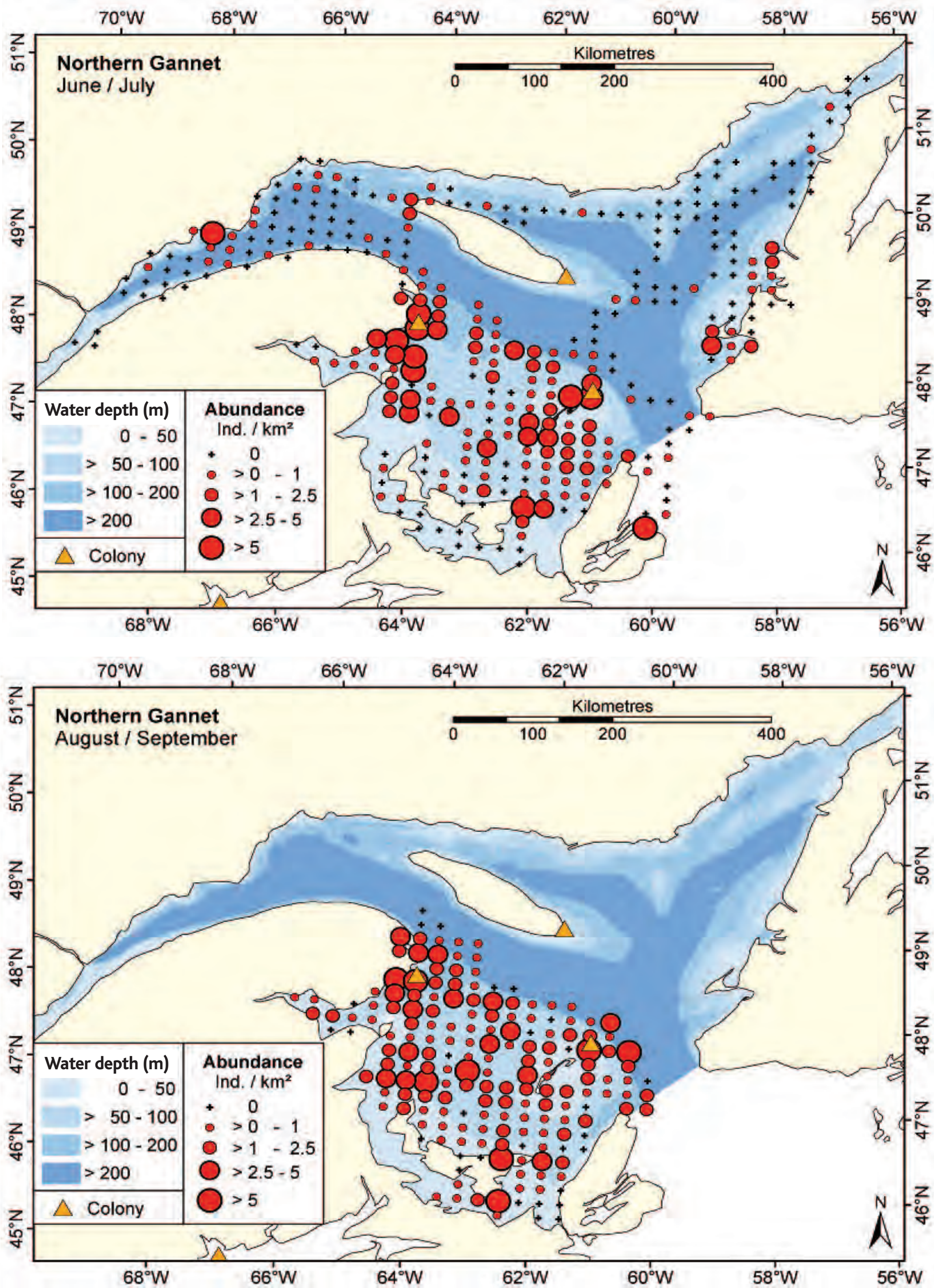


Figure 6. Distribution and abundance of Northern Gannets *Morus bassanus* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

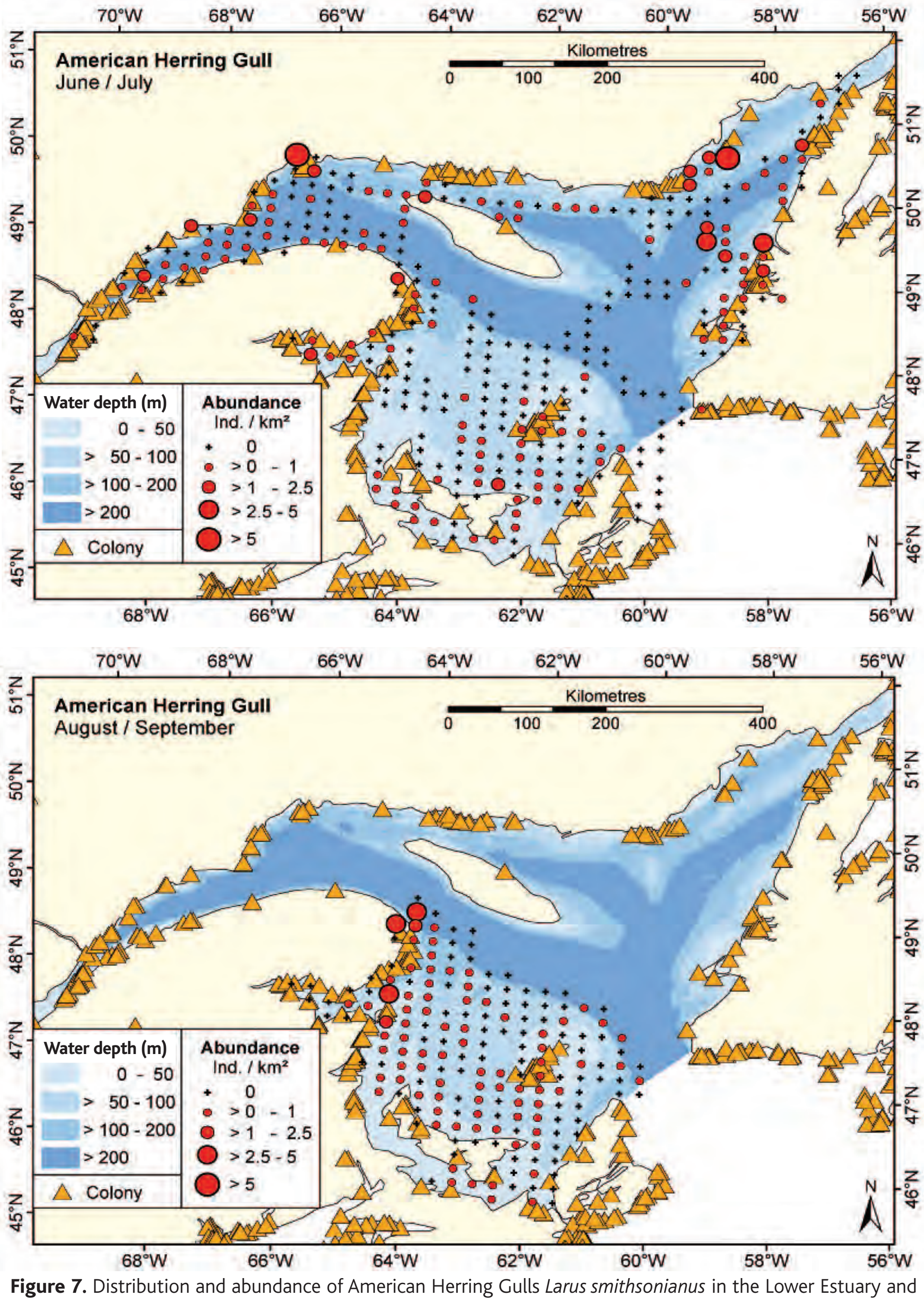


Figure 7. Distribution and abundance of American Herring Gulls *Larus smithsonianus* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

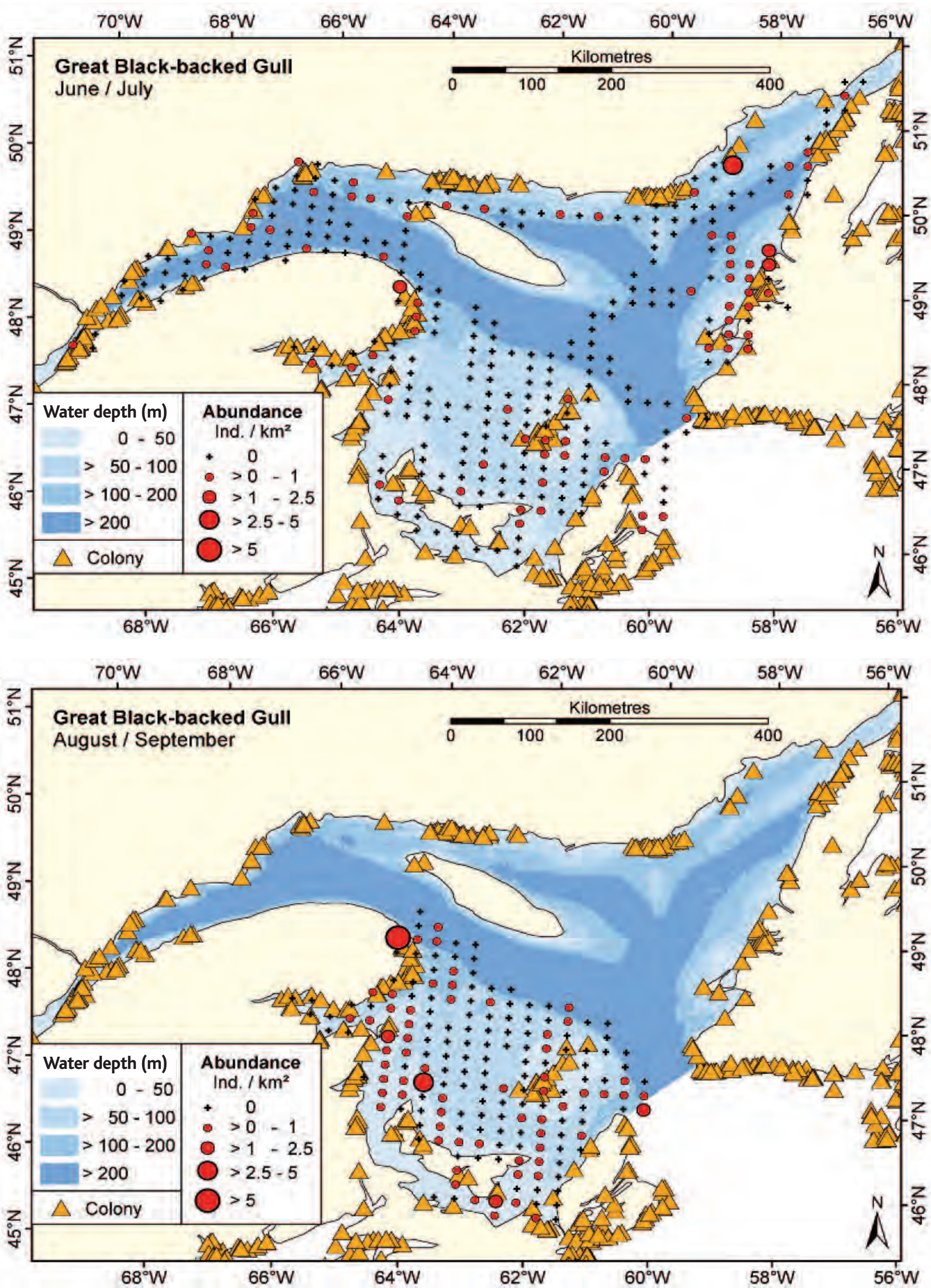


Figure 8. Distribution and abundance of Great Black-backed Gulls *Larus marinus* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

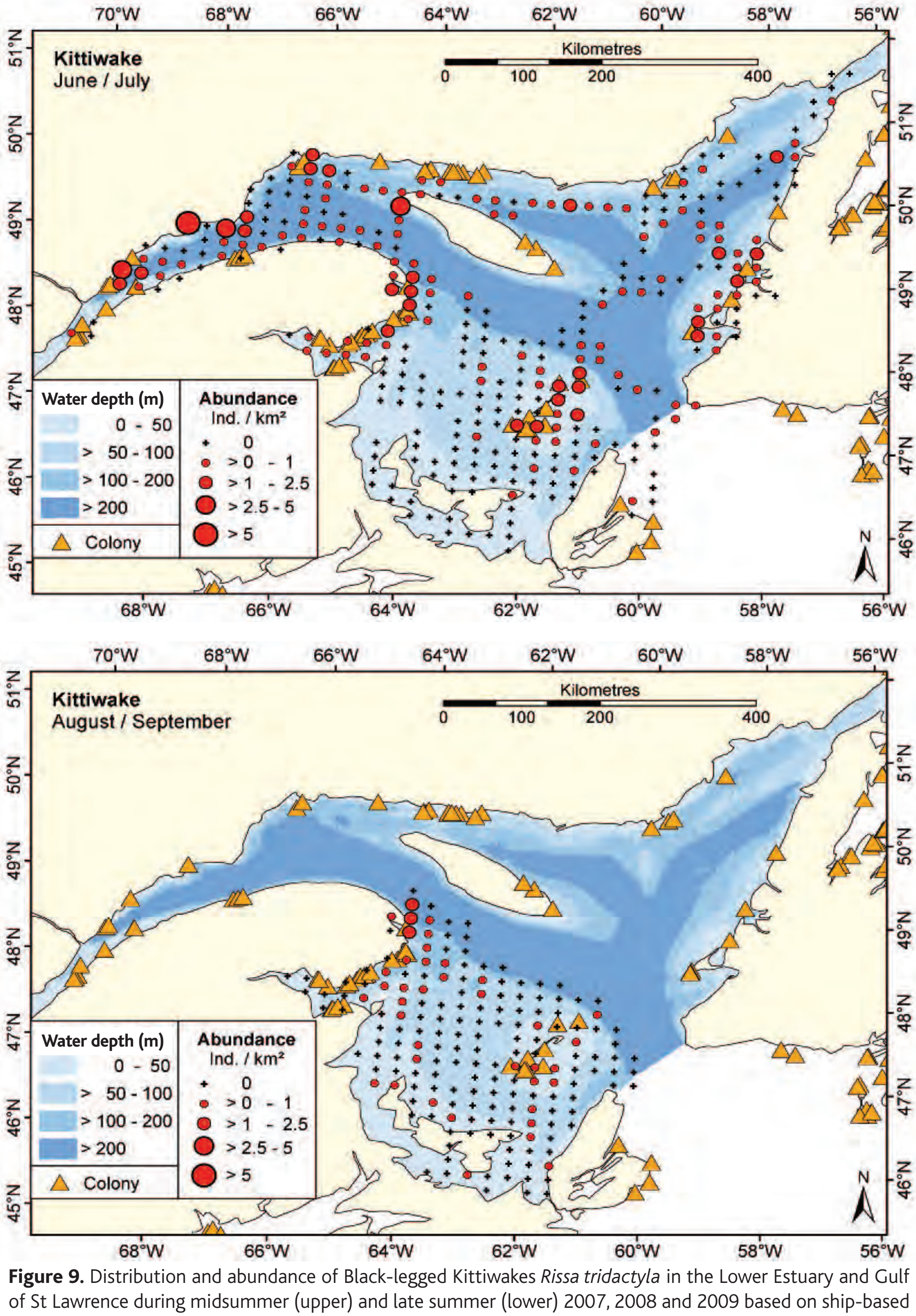


Figure 9. Distribution and abundance of Black-legged Kittiwakes *Rissa tridactyla* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10’x20’ grid cells.

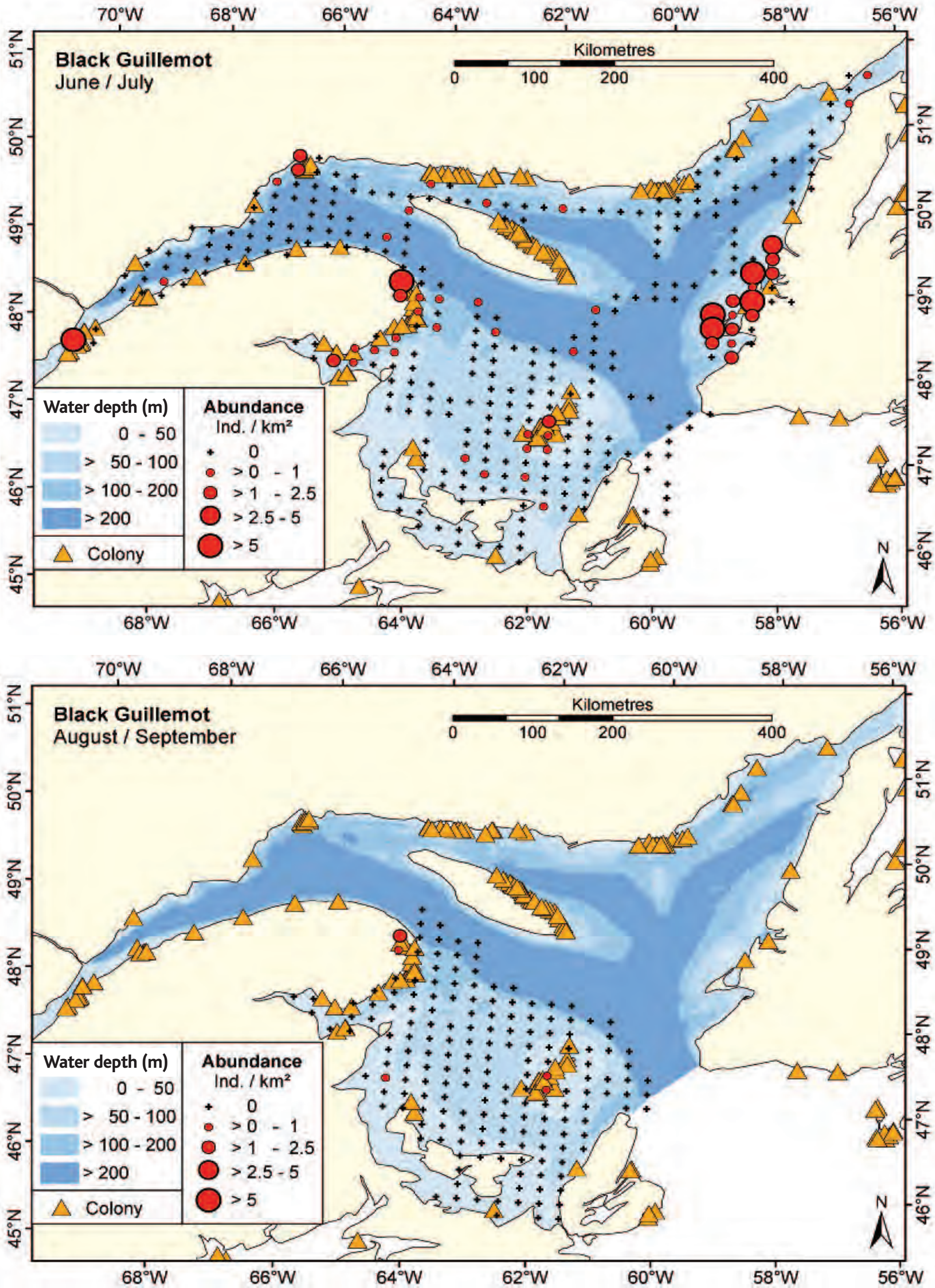
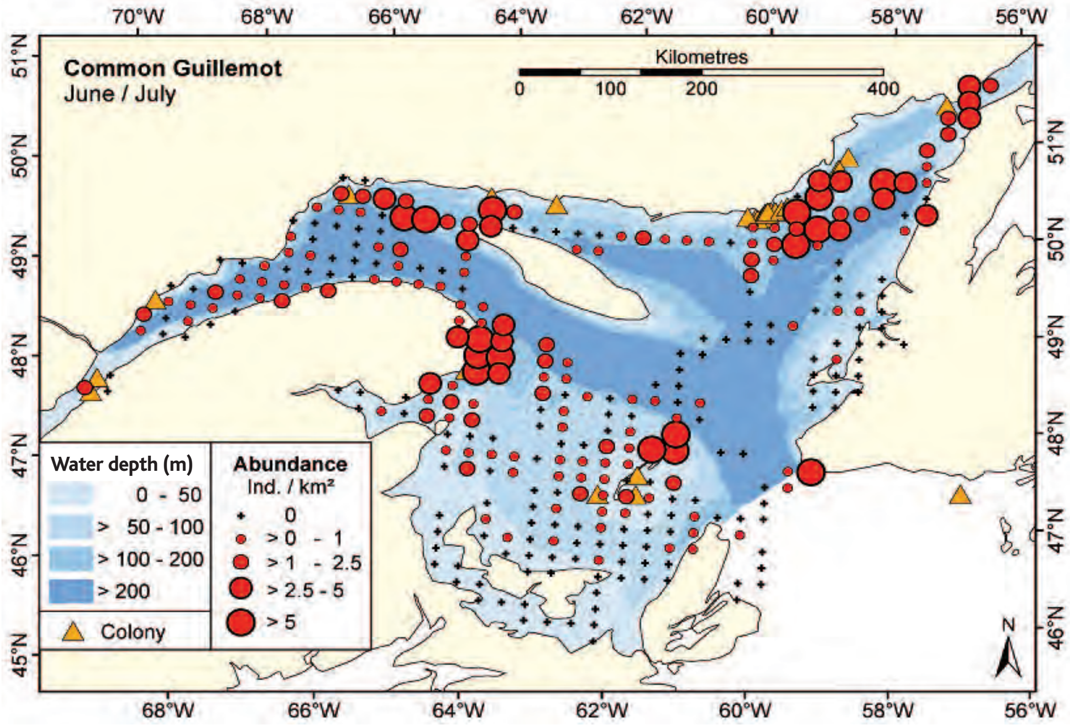


Figure 10. Distribution and abundance of Black Guillemots *Cepphus grylle* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.



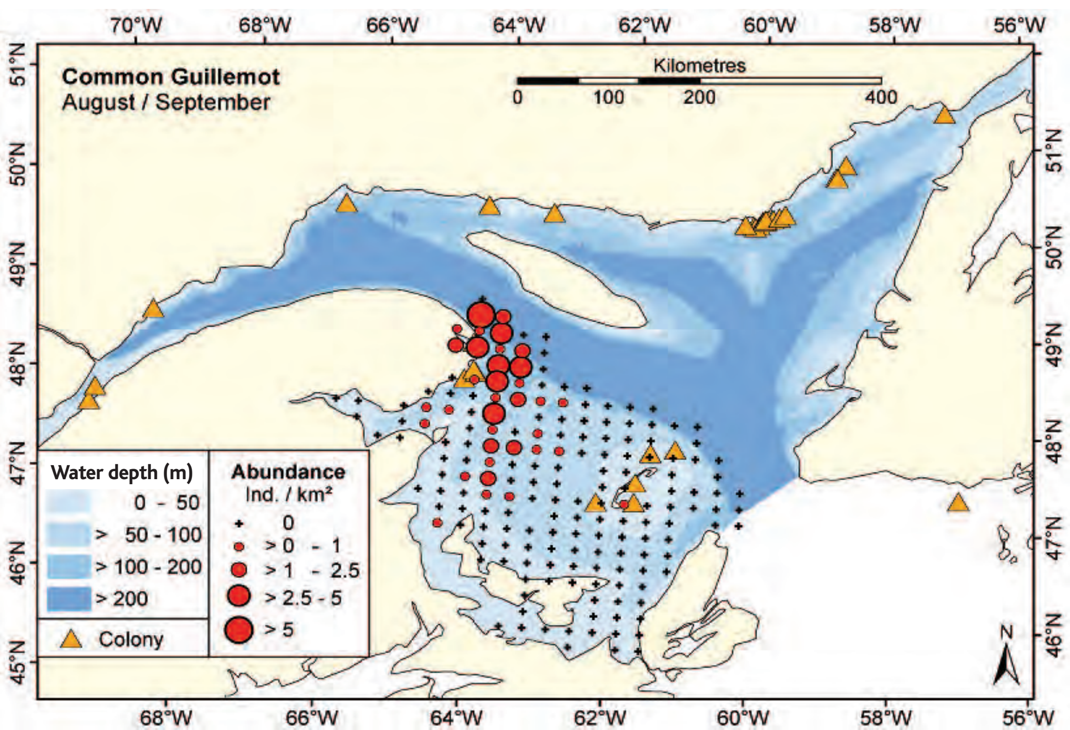


Figure 11. Distribution and abundance of Common Guillemots *Uria aalge* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

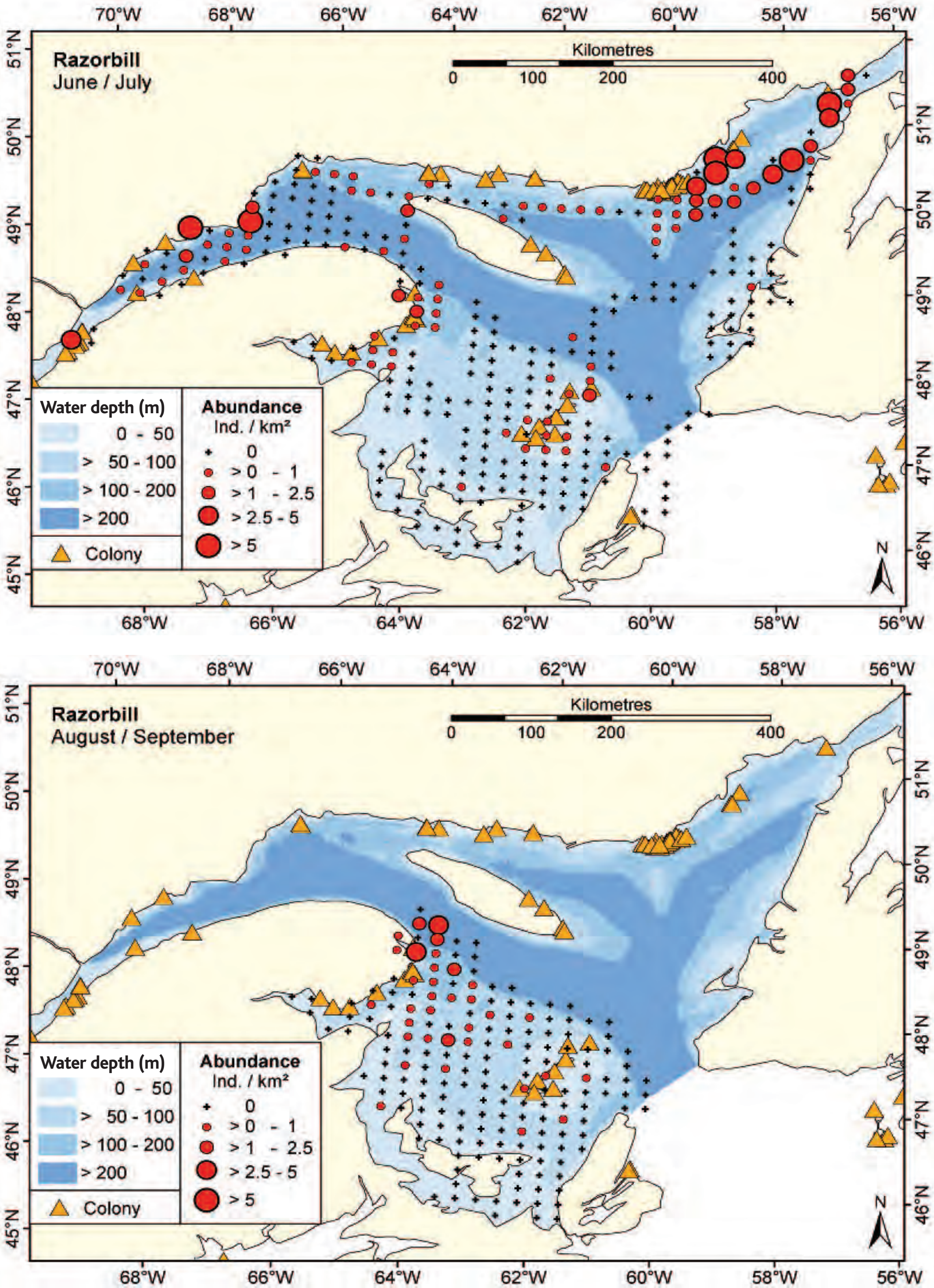


Figure 12. Distribution and abundance of Razorbills *Alca torda* in the Lower Estuary and Gulf of St Lawrence during midsummer (upper) and late summer (lower) 2007, 2008 and 2009 based on ship-based surveys depicted in 10'x20' grid cells.

The distribution pattern of Razorbills (Figure 12) resembled that of Common Guillemots, but in much lower densities and total numbers (Table 3) and with some distinct regional differences. Razorbills were particularly abundant in the Lower Estuary and along the Lower North Shore in the Northeastern Gulf. In contrast to other alcids, they were more numerous in the Southern Gulf in late summer compared to midsummer.

Black Guillemots showed the strongest link to coastal waters of all alcid species (Figure 10), with highest densities along the west coast of Newfoundland and the Gaspé Peninsula during midsummer.

Wilson's Storm-petrels and Fulmars were amongst the most numerous seabird species in the Southern Gulf in midsummer with an estimated total of 65,000 and 36,000 individuals, respectively (Table 3). Fulmars showed highest densities in the Northwestern and Northeastern Gulf and along the rim of the Southern Gulf during midsummer, but were less abundant in this area later in the season (Figure 4). This paralleled the seasonal occurrence of Wilson's Storm-petrel in these waters (Figure 5). The offshore distribution of Leach's Storm-petrels (Guse 2013) resembled that of Wilson's, although the latter was much more abundant overall.

American Herring Gulls *Larus smithsonianus* and Great Black-backed Gulls *L. marinus* were also abundant and widespread in the study area. Both showed a strong link to coastal waters during midsummer (Figures 7 & 8) and occurred more widely and in larger numbers (Table 3) in the Southern Gulf in late summer. The distribution of Black-legged Kittiwakes (hereafter 'Kittiwakes') during midsummer was more pelagic than the large gulls (Figure 9); their density and total numbers decreased markedly in the Southern Gulf from mid- to late summer.

Great Northern Divers (Figure 3) were restricted to certain areas showing low to moderate densities in coastal waters.

Discussion

Survey technique, densities and estimated totals: Generating reliable results on abundance and numbers by surveying highly mobile species in a dynamic environment from a mobile platform is a rather challenging task. However, the methods for counting seabirds have generally evolved and matured from relative abundance (see Brown 1986) to densities based on distance sampling (Buckland *et al*. 2001). The latter takes the incomplete detectability of seabirds at sea into account (Fifield *et al*. 2009). Our protocol is widely used in European waters and is the standard method applied in the North Sea (Camphuysen 2011). Moreover, it is compatible with the protocol of the eastern Canada pelagic seabird monitoring program (ECSAS; Fifield *et al*. 2009) which was restarted in 2005 and applies the methods described by Gjerdrum *et al*. (2012). This allows for comparisons of our study results with those in adjacent waters as well as with waters in the Northeast Atlantic Ocean. Another advantage of our dataset is its homogeneity as the entire dataset was collected by a single observer. Thus, any inter-observer variability effect on detection probability or identification had no impact on our results.

Despite the advantages and advances in standardising survey techniques (Tasker *et al*. 1984), some problems remain. With our method, distance sampling is based on perpendicular distance whereas birds often are detected ahead (but see Bolduc & Desbiens (2011) for a method to delineate distance intervals in front of the observation platform). We therefore necessarily have to assume that we detect 100% of birds that are ahead of the vessel. In distance sampling this would relate to g(0)=1 which is an important assumption for the reliability of abundance calculations (Bächler & Liechti 2007) that we cannot verify with our method. This could have been resolved by using double platform surveys (e.g. an independent observation platform using a different detection technique), which was not possible in our case.

Ideally, individual seabirds would not react to the platform as it approaches, but many individuals do and some species are particularly prone to either attraction or escape. Regarding the latter response, divers are known to be particularly sensitive (Garthe & Hüppop 2004; Bellebaum *et al*. 2006) and most Great Northern Divers detected during our surveys tried to escape as the vessel approached, often more than 1 km ahead, which probably biased their spatial distribution inside the 300 m transect (Hyrenbach *et al*. 2007). This probably led to a correction factor calculated with distance sampling that underestimated the proportion of birds actually missed. We tried to circumvent this problem by conservatively estimating how many Great Northern Divers were missed. All alcids and several of the other species also frequently showed escape reactions or other signs of disturbance but these were not as pronounced as in divers.

In contrast to disturbance, responsive movement towards the survey vessel of seabird species feeding on discards and offal such as Gannets, gulls and Fulmars bears the risk of artificially inflating seabird numbers within our transect leading to a potential overestimation (Kober *et al*. 2010). We acknowledge that we cannot fully exclude this source of error but would argue that the problem was rather negligible in our study area due to the general decline of the fishery for demersal fish (Savenkoff *et al*. 2007 a,b) and a ban of discards in these waters. In fact we observed low overall fishing intensity in waters more than 10 km from shore where most of our survey effort occurred. Moreover, the overall number of seabirds attracted to fishing vessels was very low compared with similar studies e.g. from the Northeast Atlantic (own unpubl. data vs. e.g. Hudson & Furness 1988; Garthe 1993; Camphuysen *et al*. 1995). Less than 0.5% of all Gannets we observed were associated with fishing vessels (Guse 2013) and even lower numbers with our own survey vessel (own unpubl. data).

We also cannot exclude responsive moment towards the observation platform due to attraction to the bow wash of species such as storm-petrels that tend to forage over small patches of turbulence. Biased results on the occurrence of storm-petrels were probably also caused by the fact that flying individuals that also made contact with the water inside the 300 m transect were rated as flying individuals at snapshot, i.e. were used for estimating densities at sea. This approach could lead to an overestimation of species like storm-petrels or terns that make frequent contact with the water as they fly (A. Webb pers. comm.). For future surveys it is recommended to record distances of flying storm-petrels at first sighting, and only to include birds from snapshot counts in analyses.

The distance correction factors we calculated were all low compared with studies from adjacent waters (Fifield *et al*. 2009) or from the North Sea (Garthe *et al*. 2007a). One possible explanation might be that the bulk of our survey data was collected on a large research vessel with an eye level of 13 m above the sea surface. This high outlook probably enabled many seabirds to be detected in the outer transect intervals. Moreover, the weather conditions and associated sea states were mostly excellent to moderate, further improving detection probability.

Because our data were collected from ships of opportunity, some gaps existed in our dataset, particularly in the central and northeastern part of the Gulf. For several species, especially Great Northern Divers, Black Guillemots, Razorbills, and *Larus* gulls, the precision of current estimated totals for the Southern Gulf might be affected by poor coverage in coastal waters shallower than 10 m depth. Dedicated surveys in these areas would be useful to widen the database of potentially important habitats for these species.

Hotspots: Species with large breeding colonies in the study area, particularly Gannets, Common Guillemots, Razorbills, Black Guillemots and Kittiwakes (Cotter & Rail 2007; Rail & Cotter 2007; Cotter *et al*. 2012; Chardine *et al*. 2013) contributed substantially to the local at-sea seabird community during summer. Several areas seemed of particular importance and held high seabird densities of single or multiple species. Some of these areas changed over the course of the summer, whereas others were used throughout the study period. Many of these hotspots had been identified previously despite methodological differences (Brown 1986). Hotspots occurred in all subdivisions of the Lower Estuary and Gulf of St Lawrence (Figure 1) but some stood out persistently and were often related to oceanographic and bathymetric features. The eastern tip of the Gaspé Current was one such area, where deep nutrient-rich waters from the St Lawrence River meet warmer and shallower waters of the Southern Gulf, resulting in extremely high productivity (de Lafontaine *et al*. 1991). As a consequence, a wide range of seabird species including Gannets, alcids, and Kittiwakes, showed high at-sea densities in these waters that also host important colonies of these species. American Herring and Great Black-backed Gulls were also highly abundant there.

Bonaventure Island holds some of the most important seabird colonies in the study area, including one of the world's largest Gannet colonies, with close to 60,000 breeding pairs in 2009 (Chardine *et al*. 2013), which was reflected by the high densities of Gannets found in these waters. Regarding alcids, only the adjacent waters of the Gaspé Current held high concentrations during the whole summer period. The significance of this area was also underlined by the highest abundance of cetaceans in our study; in particular, Atlantic White-sided Dolphins

Lagenorhynchus acutus, Fin Whales *Balaenoptera physalus,* and Blue Whales *B. musculus* were observed there frequently. Accordingly, an AOI (Area of Interest) for a Marine Protected Area has been announced for a part of this area (see www.dfo-mpo.gc.ca/oceans/marineareas-zonesmarines/mpa-zpm/index-eng.htm#).

Other areas supporting high seabird densities and multispecies aggregations occurred during midsummer along the northern rim of the Lower Estuary, in the Sept Iles region, west and north of the Anticosti Gyre in the Northwestern Gulf and along the Lower North Shore near the St Mary's Islands towards the Strait of Belle Isle where alcids in particular were abundant. Another hotspot occurred along the west coast of Newfoundland from the Bay of Islands area south around the Port au Port Peninsula into St George's Bay. Cabot Strait represented another important area for various species, which had already been observed in autumn by Fifield *et al*. (2009). These authors attributed the strong currents and large concentrations of zooplankton (Head & Pepin 2007), which might support a high availability of different types of prey (Gjerdrum *et al*. 2008), as likely drivers behind these patterns. Other hotspots were observed around Cape Breton Island and the Magdalen Islands, as well as west and east of Prince Edward Island where frontal structures could frequently be observed.

Comparison with past distribution patterns: Although the distribution patterns shown by Brown (1986) mostly comprised data collected in the 1970s and 1980s, some species and groups showed similar distribution and concentration patterns compared with our results. These were Fulmar, Gannet and Great Black-backed Gull. Wilson's Storm-petrels were far less abundant in the past compared with our surveys. The distribution of Common Guillemots also differed between our results and earlier studies, particularly in the Southern Gulf. Here, we found highest abundance around the two main colonies of Bonaventure Island, in the distal part of the Gaspé Current, and Bird Rocks, northeast of the Magdalen Islands, whereas Brown (1986) recorded the main concentrations at greater distances from these colonies. Some of these differences can presumably be attributed to the different seasonal divisions applied and to different spatial coverage. Our midsummer distribution covered the breeding season for most species (see Québec Breeding Bird Atlas, www.atlas-oiseaux.qc.ca/donneesqc/calendrier.jsp?lang=en), but during late summer many species will have left their colonies, accompanying their young at sea or having started autumn migration. In Brown's atlas (1986), the period April to June comprised patterns of pre-breeding and breeding. Consequently, concentrations further away from colonies might well have occurred in the earlier period. For future analyses of seabird distribution in this area, the definition of species-specific seasons (Garthe *et al*. 2007a) might be valuable as the phenology and related usage and function of particular marine areas differs between species. Further insights might also be gained by comparing our results with current data from the adjacent waters of the Maritime Provinces where the Eastern Canadian Seabirds at Sea (ECSAS) programme restarted in 2005 (Fifield *et al*. 2009).

Seabird totals in relation to population sizes: The significance of particular marine areas can be viewed from many different perspectives and scales. Here, we discuss our results on estimated seabird totals for a significant part of the entire study area - the Southern Gulf. This part of the Gulf hosts the most diverse zooplankton community and is an important nursery area for many species of fish, such as Atlantic Mackerel *Scomber scombrus* and Atlantic Herring *Clupea harengus* (de Lafontaine *et al*. 1991). Consequently, this area hosts large seabird colonies in addition to a variety of cetaceans. Our study suggests that at-sea abundance of several species in the Southern Gulf is of international importance when applying the 1% threshold of the Ramsar Convention on Wetlands, i.e. a site regularly supports 1% of the individuals in a population (www.ramsar.org).

For Gannets, it may be the most important area worldwide during summer. Their estimated at-sea total during summer constituted c. 80% of the Gulf breeding population, which is a rather high figure given a considerable proportion of breeders will be attending the colony at any one time. Even in relation to the entire North American breeding population of c. 234,000 breeding birds in 2009 (Chardine *et al*. 2013), we estimated the Southern Gulf held 60–64% of these numbers (Table 3). This demonstrates that comparing at-sea totals with breeding numbers is not entirely valid as there was a range of non-breeders present in our estimate (e.g. immature birds) that were observed in varying proportions (N. Guse unpubl. data). However, the breeding population currently constitutes the best available reference point since an estimate for the biogeographic population is lacking. We believe our data to be excellent for Gannets, due to their frequent and widespread occurrence, and that our estimate of overall Gannet numbers is realistic. It underlines the high importance of the Southern Gulf during summer and strongly suggests that resident breeders predominantly used these waters rather than the Northern Gulf even though the latter would be within the known foraging range (Garthe *et al*. 2007b; Hamer *et al*. 2007).

For Razorbills, a biogeographic population figure was not available either, but the Canadian breeding population estimate constitutes 110,000 birds (J.-F. Rail pers. comm.). The Southern Gulf estimates for Razorbills at sea comprised a minimum of 5% of this figure in midsummer to a maximum of 11% in late summer (Table 3), although as in Gannets, the proportion of non- or pre-breeders might be substantial (Cairns *et al*. 1991). Nevertheless, the Southern Gulf waters probably held a substantial proportion of the entire Canadian Razorbill population during summer. Significant at-sea numbers comprising > 1% of the entire Canadian breeding population were also found for Common and Black Guillemots as well as for Kittiwakes (Table 3).

For American Herring and Black-backed Gulls, as well as Great Northern Divers, available biogeographic population values allowed straightforward comparisons that yielded significant population figures of 1% to 4% (Table 3) according to the 1% threshold. The estimated numbers of Great Northern Divers for the Southern Gulf may be less certain compared with other species (e.g. Gannet) with a more robust database. However, in late summer our estimate of Great Northern Divers would exceed the total estimates of wintering individuals on the continental shelf of the southeastern United States (Haney 1990), suggesting the Gulf region to be important for this species. In particular, the waters off the coast of New Brunswick (opposite Prince Edward Island) had previously been recognised as an important summering area for immature Great Northern Divers, based on counts from land (McIntyre 1988). Moreover, in this area, the waters to the northwest of Prince Edward Island in particular seemed to have an important function during late summer. Groups of several Great Northern Divers with visible differences in plumages were frequently encountered, and we assumed that these consisted of families or of birds of different ages.

In conclusion, our findings demonstrate that during summer the Southern Gulf hosts high numbers of several seabird species that correspond to significant proportions relative to their biogeographic populations or breeding populations of Canada or North America, respectively. This emphasises the importance of the Southern Gulf for seabirds in a regional and international context, which has not yet been described quantitatively so far.

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Appendix

Table 1. Total numbers of individual seabirds and seaducks recorded during ship-based surveys in the Estuary and Gulf of St Lawrence in mid (June/July) and late (August/September) summer of 2007, 2008 and 2009, in descending order of the total sum.

Species	June/July	Aug./Sept.	Total
Northern Gannet *Morus bassanus*	5,500	10,504	16,004
Common Guillemot *Uria aalge*	4,544	227	4,771
American Herring Gull *Larus smithsonianus*	1,614	740	2,354
Northern Fulmar *Fulmarus glacialis*	2,078	255	2,333
Black-legged Kittiwake *Rissa tridactyla*	1,866	340	2,206
Unidentified Razorbill/guillemot *Alca torda/Uria sp*.	1,396	242	1,638
Wilson's Storm-petrel *Oceanites oceanicus*	948	365	1,313
Great Black-backed Gull *Larus marinus*	503	718	1,221
Unidentified storm-petrel *Hydrobatidae sp*.	763	143	906
Double-crested Cormorant *Phalacrocorax auritus*	252	587	839

Razorbill *Alca torda*	674	105	779
Great Northern Diver *Gavia immer*	311	353	664
Black Guillemot *Cepphus grylle*	611	37	648
Unidentified large gull *Larus sp.*	10	408	418
Ring-billed Gull *Larus delawarensis*	326	33	359
Unidentfied gull *Laridae sp.*	205	126	331
Surf Scoter *Melanitta perspicillata*	39	286	325
Unidentified phalarope *Phalaropus sp.*	90	200	290
Bonaparte's Gull *Chroicocephalus philadelphia*	79	197	276
Common Eider *Somateria mollissima*	236	10	246
Common Tern *Sterna hirundo*	159	67	226
Great/Double-crested Cormorant *Phalacrocorax carbo/auritus*	119	88	207
Common/Arctic Tern *Sterna hirundo/paradisaea*	97	60	157
Great Shearwater *Puffinus gravis*	148	7	155
Black/Surf Scoter *Melanitta americana/perspicillata*	128	23	151
Sooty Shearwater *Puffinus griseus*	145	2	147
Leach's Storm-petrel *Oceanodroma leucorhoa*	80	55	135
Red-throated Diver *Gavia stellata*	70	30	100
Arctic Tern *Sterna paradisaea*	82	14	96
Puffin *Fratercula arctica*	70	26	96
Unidentified auk *Alcidae sp.*	56	40	96
Velvet Scoter *Melanitta fusca*	64	30	94
Grey Phalarope *Phalaropus fulicarius*	5	77	82
Unidentified diver *Gavia sp.*	48	28	76
Brünnich's Guillemot *Uria lomvia*	65		65
Red-necked Phalarope *Phalaropus lobatus*	11	41	52
Unidentified guillemot *Uria sp.*	29		29
Unidentified scoter *Melanitta sp.*	19	7	26
Manx Shearwater *Puffinus puffinus*	18	3	21
Great Cormorant *Phalacrocorax carbo*	7	6	13
Unidentified skua *Stercorarius sp.*		11	11
Lesser Black-backed Gull *Larus fuscus*		11	11
Arctic Skua *Stercorarius parasiticus*	2	7	9
Unidentified shearwater *Puffinus/Calonectris spec.*	7	1	8
Great/Cory's Shearwater *Puffinus gravis/Calonectris borealis*	4	2	6
Black Scoter *Melanitta americana*	4		4
Long-tailed Duck *Clangula hyemalis*	2	1	3
Pomarine Skua *Stercorarius pomarinus*		3	3
Pacific Diver *Gavia pacifica*	2		2
Black-necked Grebe *Podiceps nigricollis*		2	2
Glaucous Gull *Larus hyperboreus*	2		2
Red-necked Grebe *Podiceps grisegena*		1	1
Great Skua *Stercorarius skua*		1	1
Laughing Gull *Larus atricilla*	1		1
Sabine's Gull *Xema sabini*		1	1
Caspian Tern *Hydroprogne caspia*		1	1
Sandwich Tern *Sterna sandvicensis*	1		1
Black Tern *Chlidonias niger*		1	1