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Research Document 2012/157

Quebec Region

Document de recherche 2012/157

Région du Québec

Distribution, densities, and annual occurrence of individual blue whales (*Balaenoptera musculus*) in the Gulf of St. Lawrence, Canada from 1980-2008

Répartition, densités et présence annuelle de baleines bleues (*Balaenoptera musculus*) dans le golfe du Saint-Laurent, Canada de 1980 à 2008

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

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Correct citation for this publication:

Ramp, C. and Sears, R. 2013. Distribution, densities, and annual occurrence of individual blue whales (*Balaenoptera musculus*) in the Gulf of St. Lawrence, Canada from 1980-2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/157. vii + 37 p.

ABSTRACT

This document describes the distribution of individually identified blue whales (*Balaenoptera musculus*) in the Gulf of St. Lawrence (GSL), Canada. Data were collected by the Mingan Island Cetacean Study (MICS) from 1980 to 2008. The aim of this project was to provide additional information for designating blue whale critical habitat as required under the Canadian Species at Risk Act. Data from photo-identification surveys yielding over 13,000 blue whale sightings were used to identify the distribution and densities of blue whales in the north-western section of the GSL. Surveys focused on the area west of 63ºW and included opportunistic sightings from collaborators. Daily first sightings of individually identified blue whales were used to calculate encounter rates and sightings per unit of effort in each region. The largest concentrations of blue whales were found in the lower St. Lawrence Estuary, around the eastern tip of the Gaspé Peninsula, along the north shore of the Jacques-Cartier Passage, and in the waters adjacent to Sept-Îles. Several changes in blue whale distribution were observed over the course of the study period. A major shift occurred in 1992/1993, when blue whales abandoned the Jacque-Cartier Passage. The GSL is a major summer feeding ground for blue whales and they occur predominantly along the productive coasts. In general, blue whales can be observed almost anywhere in the north-western GSL. In some areas, for example along the north shore of the Gaspé Peninsula, blue whales seem to pass through on their way to and from the lower St. Lawrence Estuary. The areas with highest blue whale densities and longest residency times included the north shore of the lower St. Lawrence Estuary and the eastern tip of the Gaspé Peninsula between Rivière-au-Renard and Percé. The northern banks of the Jacques-Cartier passage were important in the years prior to 1994. Although blue whales come mainly to the GSL to feed in summer, they can occur year-round. The number of sightings tended to increase throughout the summer season, peaking in late August and early September; however, regional differences were apparent. The first peak in sightings occurred in June/July when blue whales were observed off of the Gaspé Peninsula, while sightings in the lower Estuary drove the main peak in August/September. A total of 402 blue whales have been identified in the GSL since 1980 and a maximum of 32% of these were sighted in any given year. Blue whales were observed an average of only two days per season (occurrence), with an average occupancy of 22 days. The low numbers of re-sightings within years suggest that blue whales in the GSL are highly mobile.

RÉSUMÉ

Le présent document rend compte de la répartition des rorquals bleus (*Balaenoptera musculus*) identifiés individuellement dans le golfe du Saint-Laurent (GSL), au Canada. Des données ont été recueillies par la Station de recherche des îles Mingan (SRIM), de 1980 à 2008. Ce projet avait pour but de fournir des renseignements supplémentaires pour la désignation de l'habitat essentiel du rorqual bleu, en vertu de la *Loi sur les espèces en péril du Canada*. Les données des relevés par identification photographique ont permis de recueillir plus de 13 000 observations de rorqual bleu, lesquelles ont été utilisées pour déterminer la répartition et la densité de l'espèce dans la portion nord-ouest du GSL. Les relevés visaient essentiellement la région à l'ouest du 63^{e} degré de longitude ouest et comprenaient des observations fortuites faites par les collaborateurs. Les premières observations quotidiennes de rorquals bleus identifiés individuellement ont servi à calculer pour chaque région les taux de rencontre et les indices des observations par unité d'effort. Les plus importantes concentrations de rorquals bleus ont été aperçues dans l'estuaire maritime du Saint-Laurent, autour de l'extrémité est de la Gaspésie, le long de la rive nord du détroit de Jacques-Cartier et dans les eaux adjacentes à Sept-Îles. Plusieurs changements dans la répartition des rorquals bleus ont été observés au cours de la période de l'étude. Un changement majeur est survenu en 1992-1993, alors que l'espèce a abandonné le détroit de Jacques-Cartier. Le GSL constitue une aire d'alimentation importante pour les rorquals bleus l'été. Ceux-ci se trouvent principalement le long des côtes fertiles. En général, les rorquals bleus peuvent être observés presque partout dans le nord-ouest du GSL. Certains secteurs, par exemple le long de la rive nord de la Gaspésie, semblent être empruntés par les rorquals bleus qui se rendent vers l'estuaire maritime du Saint-Laurent ou qui en reviennent. Les secteurs présentant les densités les plus importantes de rorquals bleus et les plus longues durées de séjour comprennent la rive nord de l'estuaire maritime du Saint-Laurent et l'extrémité est de la Gaspésie, entre Rivière-au-Renard et Percé. Les bancs au nord du détroit de Jacques-Cartier jouaient un rôle important avant 1994. Bien que ce soit principalement l'été que les rorquals bleus se rendent dans le GSL (dans le but de se nourrir), ils peuvent s'y trouver toute l'année. Le nombre d'observations tend à augmenter tout au long de la saison estivale et connaît un pic à la fin août et au début de septembre. On remarque toutefois des différences entre les régions. Le premier pic dans les observations a lieu en juin/juillet, alors que les rorquals bleus sont observés au large de la Gaspésie. Pour ce qui est de l'estuaire maritime du Saint-Laurent, les observations connaissent un sommet en août/septembre. Un total de 402 rorquals bleus ont été identifiés dans le GSL depuis 1980 et un maximum de 32 % d'entre eux ont été aperçus dans une année donnée. Les rorquals bleus n'étaient observés en moyenne que deux journées par saison (occurrence), pour une durée moyenne d'occupation de 22 jours. Le faible nombre re-observations au fil des ans suggèrent que les rorquals bleus dans le GSL sont très mobiles.

INTRODUCTION

Blue whales (*Balaenoptera musculus*) occur in the entire North Atlantic Ocean. Early whalers distinguished between two main populations, one in the eastern North Atlantic and one in the western North Atlantic (Ingebrigtsen, 1929). Not a single match was ever made between the north-western (470 IDs) and the north-eastern (284 IDs) blue whale catalogues as of the end of 2011 (MICS unpublished data). The IWC, however, never adopted this idea and currently regards the North Atlantic as one panmictic stock (Donovan, 1991; National Marine Fisheries Service, 1998).

The blue whale population in the north-western Atlantic was designated as endangered by Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2002 and listed as endangered under the Species at Risk Act (SARA) in 2005. Blue whales are believed to spend the winter in warm waters at low latitudes, and the summer in to colder and more productive waters at higher latitudes (Sears & Calambokidis, 2002). Although this north-south migration generally holds true, the extent of this migration appears to differ between stocks. There are no known blue whale wintering areas in the Northwest Atlantic and it is not known where they reproduce, or if specific breeding grounds exist at all. Blue whales have been observed along the Scotian Shelf, in the Gully, in the Gulf of Maine, and off the coasts of Newfoundland and west Greenland, mainly in summer and fall (Sears & Calambokidis, 2002). In general, our knowledge of blue whale migration and distribution is limited due to both the elusive nature of this species and the logistical and financial constraints of marine mammal research over such wide areas.

The Mingan Island Cetacean Study (MICS) has been conducting blue whale surveys in the GSL since 1980. The primary focus of MICS is the individual identification of animals, resulting in individual sighting histories, which are used to estimate population parameters. In order to obtain a high recapture rate, MICS has mostly sampled areas known for their high frequentation by blue whales, as opposed to random and/or systematic surveys, thus preventing classical estimation of abundance in each area. Moreover, it is not known what proportion of the north-western Atlantic population frequents GSL in summer (Hammond *et al.*, 1990), and thus it is difficult to make inferences about he entire population. However, this long-term data set contains valuable information on whale occurrence and spatial distribution.

This study describes the distribution of blue whales in the GSL from 1980 to 2008. Individually identified blue whale sightings were used to identify the most commonly used habitats and any changes in distribution that occurred over the course of the 29-year study period.

MATERIALS AND METHODS

RESEARCH AREAS

Seven research areas were defined within the GSL (Figure 1). These included the Jacques-Cartier Passage between the Mingan Islands and Anticosti Island and adjacent waters (MING), the Gaspé Peninsula (GASP), the Estuary (ESTU), the north shore between Sept-Îles and Pointe-des-Monts (SIPM), the south of Anticosti Island (SANT) and the north-eastern GSL (NEGU) until the Strait of Belle Isle. Region boundaries tended to reflect logistical constraints rather than ecological boundaries. Very few surveys occurred east of 63ºW, since these areas are difficult to reach due to lacking infrastructure. For simplicity, we will refer to the GSL. The spatial distribution of the effort was highly variable in each region depending on where blue whales were most commonly found. In the lower ESTU we focused on the north shore, while in Gaspé most surveys occurred along the eastern tip of the peninsula. The MING region had the most evenly distributed effort, covering the Mingan Shoals (Mitchell and Reeves 1983) along the north shore and to Anticosti Island between 63 and 66ºW.

DATA COLLECTION

Sighting data were collected annually in the GSL between the end of May and early November, however variability existed in the timing of surveys amongst regions. The MING area had continuous effort over all years and during the entire summer season. The ESTU was, with a few exceptions, typically surveyed in late summer from mid-August to mid-September. The effort off of the Gaspé Peninsula was more variable, however, regular surveys were started in the early 2000s and predominantly occurred from mid-June to mid-July, with some surveys occurring in late summer in more recent years. The most opportunistically sampled area was SIPM, where blue whale concentrations were targeted when reported by local observers; this most commonly occurred in late summer or early fall. The number of observation days per year by region are listed in Appendix 1.

Surveys were conducted using small semi-rigid inflatable boats enabling the close approaches necessary to photograph and biopsy blue whales. Due to the nature of the work, the effort was restricted by the sea state (<4 on the Beaufort scale) visibility (>5km) and daylight. The data collection protocol, and therefore the quality and precision of the sighting information, changed over the 29-year study period. Positions of blue whale sightings in the 1980s were estimated using cross-bearings with a compass, whereas a Global Positioning System (GPS) was used from the 1990s on. Since 2007, a GPS has been used to record exact track lines and therefore the exact spatial effort.

Initially, MICS studies focused on the individual recognition of blue whales, thus the emphasis was placed on the identification of all encountered individual blue whales rather than dedicated surveys to determine their spatial distribution. Blue whales were approached during their surfacing sequences until high quality pictures were obtained (Sears *et al.*, 1990). In most cases, more than one sighting of an individual blue whale was obtained per day (up to 50), yielding repeated, non-independent measurements.

In addition to our own data, we have received opportunistic sightings of blue whales over time. Almost all opportunistic sightings were made in populated areas in which recreational boating occurs, such as the Estuary, around Sept-Iles, and the Gaspé Peninsula. We typically received photographs with various supplemental data such as date, time, approximate location, and in some cases, exact positions, but always without any information of effort. Opportunistic sightings lacking a high-quality identification photograph were not included in this analysis. Since our surveys were concentrated in coastal areas, all data from outside the Gulf of St. Lawrence came from third parties (Figure 2).

DATA ANALYSIS

The MICS database contains over 13,000 blue whale sightings pooled over the 29-year study period, including opportunistic data. Observations that did not include a position or were of unidentified animals were discarded for this analysis. To minimize bias due to repeated encounters, the spatial analysis used only the first sighting of an identified blue whale from every on-effort day (Figure 3). This minimum count represents a conservative measure of the number of blue whales encountered. All density estimators (the number of blue whale sightings per unit effort) were therefore conservative, but should be easier to compare among regions. Henceforth, “sightings” in this document refer to the first sightings of identified blue whales unless otherwise stated.

In the first part of the results we described the spatial distribution of blue whales in the GSL in terms of total numbers, raw densities, and effort-corrected densities using Manifold, a Geographic Information System (GIS) software program. To determine the raw densities, we used the blue whale first sightings from all sources and divided this number by the area of the grid cells. We used 10 x 10km grid cells for the large-scale maps (entire study area, Figure 4) and 3 x 3km grid cells for detailed maps of individual research regions (Figures 7, 10, 12, 14). Raw densities represent the number of first sightings per square kilometer (the number of sightings per grid cell could not be used because some grid cells were truncated by the coastline).

For the effort corrected density maps, only MICS data from the years 2000-2008 were used, since we processed data for almost all regions for this time span. Secondly due to more modern GPS receiver, the sighting data and especially the effort data became more precise. The number of blue whale sightings was pooled over the 9-year study period and then divided by the total number of kilometers travelled in each 3 x 3km grid cell (sightings per unit of effort SPUE). For 2007 and 2008 we used the exact GPS tracks, while for 2000-2006 we used the manually recorded positions of the boats and animals. Tracks were reconstructed from GPS positions taken for each marine mammal sighting, changes in weather conditions, changes in survey directions, and at relatively regular time intervals (approximately 30min). However, these reconstructed track lines underrepresented the actual effort. When it was unclear if the track line between two subsequent positions represented the true effort, it was omitted. This further reduced the apparent effort, but was done to avoid creating false effort in some grid cells. For all maps showing blue whale sightings per km surveyed, we did not show this ratio for any cell with a value of less than 10 km of effort to reduce the bias of rarely surveyed regions with opportunistic sightings, although the effort is still shown (Figure 6, 9, 11, 13, 15). The ratio was put on a logarithmic scale to be able to distinguish the subtle differences in the lower range of the SPUE.

ANNUAL IDENTIFICATION OF BLUE WHALES

In the second part of the results, we focused on the information based on photo-identified individuals: changes in the number of identified blue whales over time, temporal distribution (seasonal and over the study period) as well as occurrence and occupancy of blue whales in the GSL. This dataset includes all photographic information, including opportunistic sightings, unless otherwise stated.

We counted animals photographed in a given year only once for annual comparison regardless of how often and in how many research areas they were sighted (Figures 16, 17 and 25). In order to show the use of the different research areas by individuals, we counted the unique blue whales once per region per year (Figures 18 and 19). To account for the highly variable effort in these areas over time, we calculated a ratio of blue whale first sightings (as for the encounter rates/maps) per observation day (Figure 20), based on the data shown in Appendix 1. This ratio was converted to a logarithmic scale to account for low but dedicated effort in some areas, particularly in SIPM. In these areas, we targeted reported blue whale concentrations, which were sampled over short time frames (days), resulting in a high ratio and therefore biasing the comparison between regions. For opportunistic data, we only had information on days when blue whales were sighted and photographed, therefore the ratio was always greater than one.

For the seasonal distributions, we divided the research period in half months (Figures 21, 22, 23, 24, 25 and 26) from April to October. April 1st to April 15th was coded 41 (April 1st half) and April 16th to April 30th was coded as 42 (April 2nd half) etc. We did not possess enough data to apply a weekly division, while using months resulted in a coarse representation. All first sightings of blue whales were used and pooled over the half-month periods for each study area. To account for the varying effort, we divided the number of first sightings in each half-month period by the number of observation days in the same period and area. In a different approach, we counted each unique blue whale once per half-month period in any given year and averaged them over the study period (Figure 26).

Occurrence and occupancy were defined following Clapham *et al.* (1993). Occurrence described the number of days an individual was observed in a given year. Occupancy was the period in days between the first and the last date an individual was seen in any given year and was only calculated for animals observed on two or more days. Occupancy, however, did not necessarily mean that the animals spent that entire time span in the area, especially if the dates were particularly far apart. Calves were omitted from these calculations since their occurrence was dependent on their mothers'. We pooled the sightings of all research areas, since the effort was too variable to compare these two parameters between regions.

RESULTS

SIGHTINGS OUTSIDE THE GULF OF ST. LAWRENCE

The blue whales inhabiting Canadian waters are part of the north-western Atlantic population and some individuals have been sighted outside the GSL. The following summary of sightings is based purely on opportunistic observations by various sources, including research organizations, cruises, and government bodies. As stated in the methods, we mostly received sightings of blue whales when some pictures were taken. In addition, contribution to the data-base was voluntary so the following overview is by no means a complete overview of historic sightings of blue whales outside the Gulf of. Lawrence. All sightings with positions are shown in Figure 2.

Gulf of Maine

Over the entire study period 17, individuals were sighted in the Gulf of Maine, and usually each individual was only seen on one occasion. MICS received exact positions for only six sightings, five which were in the vicinity of Jeffrey's Ledge and Stellwagen Bank, and one from the Bay of Fundy. Ten of these 17 individuals were also seen in the GSL. These data were provided by the Provincetown Center for Coastal Studies and the Whale Center of New England.

Nova Scotia

The sightings from Nova Scotia were mostly made on the shelf ledge. Blue whales were most commonly seen around 'The Gully,' a deep-water canyon, where research on bottlenose whales is conducted regularly (Dalhousie University, Hal Whitehead). A total of 21 individuals were identified from 29 sightings, although only 21 had complete records with positions. Eleven of these animals were sighted in the GSL and 10 were exclusively sighted off Nova Scotia.

Newfoundland and Labrador

MICS received nine blue whale sightings east of Newfoundland and Labrador of which five individuals were identified. Only three had a complete sighting record with a position. None of the five identified animals were seen in the GSL.

Greenland

Four individual blue whales were observed west of Greenland. The three known positions are shown in Figure 2. One of the animals was seen in the GSL both before and after the Greenland sighting.

BLUE WHALE SIGHTINGS IN THE GULF OF ST. LAWRENCE

Over 12,000 blue whale sightings were recorded with a position in the GSL west of 63°W. These yielded 2,479 first sightings, 2,023 of them by MICS. Several sightings outside the main research areas were made during aerial surveys, without photographic information of the individual. Those sightings were not included in the GSL map (Figure 3). For instance, there were a few sightings of blue whales in the Northeastern Gulf (NEGSL, Figure 1).

The majority of the first sightings pooled for the entire study period were observed in the Jacques Cartier Passage between Anticosti Island and the north shore of the GSL (MING), around Sept-Îles, off the Gaspé Peninsula and along the north shore of the lower ESTU (Figure 3 and 4). This distribution was strongly linked to regional effort as shown in Figure 5, presenting the pooled effort for 2000-2008. The SPUE for the years 2000-2008 (Figure 6) showed a pattern similar to that of the raw densities for the entire study period, except for the MING area. The SPUE was very low in MING due to few sightings and high effort. We observed the greatest densities (SPUE) of blue whales in the lower Estuary and along the tip of the Gaspé Peninsula. Several surveys were conducted along the Gaspé Peninsula and animals were observed in many places along the peninsula.

Mingan (MING)

In MING, blue whales were sighted mostly along the north shore of the GSL or close to the northern shore of Anticosti Island (Figure 7). The highest raw densities were found along the northern banks. However, the vast majority of these sightings date from the 1980s. Relatively few blue whales were observed in this area after 1993, despite constant high effort. Figure 8 shows the number of sightings for 1980-1993 (n=435) and 1994–2008 (n=75). The low SPUE in the years 2000-2008 (n=54) is clearly shown in Figure 9.

Sept-Îles to Pointe-des-Monts (SIPM)

A total of 204 blue whale sightings were made in SIPM from 1980 to 2008; the majority of which was made by MICS collaborators. This area was the least surveyed (Appendix 1), resulting in high fluctuation of annual blue whale sightings. Blue whales were mainly seen south-west of Sept-Îles all the way to Pointe-des-Monts (Figure 10). For the years 2000-2008, MICS obtained very few sightings (n=30), however, the majority were made in close proximity to the islands of Sept-Îles (Figure 11).

The Lower Estuary (ESTU)

The majority of blue whale sightings during the entire study period were made in ESTU, especially along the northern shore (Figure 12) where up to five blue whales per square kilometer were sighted. For all years, MICS recorded 1392 first sightings (56% of all observations; Appendix 1). Most sightings were made in August and/or September, however blue whales were observed during the entire summer (Figure 22).

In the period 2000-2008, 706 first sightings were made, with the majority also observed between Les Escoumins and Portneuf-sur-Mer. However, in later years MICS surveys were expanded further east, after reports of blue whales along the south shore in the Matane/Les Méchins area were received (Figure 13). It was not clear if the presence of blue whales in this area was relatively new, or if they had been previously unnoticed. In general, over the last three years of the study period the number of first sightings, individual blue whales, and the sightings per survey kilometer decreased (Table 1).

Gaspé Peninsula (GASP)

Pooled over all years, there were 373 sightings in GASP, of which 291 (78%) of occurred in the 2000s since there was little effort in the 1980s and 1990s (Appendix 1). The highest raw densities of blue whales occurred between Percé and Rivière-au-Renard, with whales even entering deep into the Gaspé Bay (Figure 14). The opportunistic sightings were also typically from the Percé/ Gaspé area. For the effort corrected map spanning the years 2000 to 2008 (Figure 15), we used 245 MICS sightings. Sightings and records of individuals increased over the last four years of the study period, but this was linked to an increased effort in that area (Table 2 and Appendix 1).

BLUE WHALES IN THE GSL – INFORMATION BASED ON INDIVIDUALS

MICS is the curator of the North Atlantic blue whale catalogue. At the end of the 2008, 437 individual animals had been identified in the western North Atlantic, including observations along the eastern seaboard and western Greenland. For the following estimates, only individuals identified within the GSL (n=402) were used. In contrast to the blue whale distribution data, all photographic information was included, even if it lacked spatial information (i.e. a GPS position).

Number of Identified Individuals

A total of 402 individual blue whales were identified in the GSL from 1980-2008. High annual variation in the number of identified blue whales was observed (Figure 16), with sometimes as many as 100 or as few as 22 different individuals sighted per year. Some blue whales were sighted in up to a maximum of 20 years, although 132 (33%) were only seen in a single season (Figure 17). On average, a blue whale was sighted 4.1 years. We did not find any striking difference between the site fidelity of males (n=96) and females (n=89). Males were seen on average in 6 different years, while females were sighted in 6.4 different years. The observed number of years between subsequent sightings varied greatly and ranged from 1 to 22 years (Figure 18). The vast majority (>95%) of the re-sightings occurred with the first 7 years.

Annual Sightings per Region

There was a large amount of variation in the regional occurrence of blue whales over the study period (Figures 19, 20, and 21). Although the effort varied considerably, one significant shift was prominent. Blue whales were observed regularly in the MING area until 1992, but afterwards they were only rarely sighted despite consistent effort (Figure 19). The proportion of identified animals in MING dropped to a small percentage. From 1990-2005, more than 50% of blue whales per year were identified solely in the ESTU (Figure 20). From 2006-2008, the majority of individuals identified were observed in GASP. However, when corrected for effort, the picture was less obvious as both the proportion of sightings per observation days and the effort dropped in the ESTU (Figure 21). The proportion of animals sighted in GASP increased from 2000 to 2008 (Figure 20), although the sighting per observation day ratio increased only slightly (Figure 21) due to higher effort (Table 2 and Appendix).

Overall, the ESTU appeared to be the most important area for blue whales during the entire study period: 293 individuals (73%) were at least seen once there, 140 (35%) in MING, 146 (36%) in GASP, and 143 (35%) in SIPM. Overall, 40% of the total blue whale sightings were made in the ESTU, while each of the other three regions accounted for approximately 20% of the sightings. Almost half of the animals (46%) were seen exclusively in one region. For example, 23% were seen only in the ESTU but were likely not observed in other regions as they passed through.

Temporal distribution over the season

Blue whales were observed year-round in the GSL we but do not possess enough data in the winter to quantify year-round blue whale occurrence. Pooling all the first sightings from the entire study period, we observed two seasonal peaks in blue whale abundance (Figure 22). The first one occurred in the first half of July and the second larger one in the second half of August and in the first half of September. The two peaks correspond to the temporal variability in effort (Figure 24). Timing of the sightings from GASP caused the first peak, while the second one was driven mainly by sightings in the ESTU, and to a lesser extent sightings from MING (Figure 23).

Using the ratio of first sightings per observation day resulted in similar but slightly different picture of blue whale temporal distribution. While the total ratio shows the same two peaks, the regional distribution varied slightly (Figure 25). In the ESTU, there was a second peak in October with almost 3 blue whale sighting/day that was linked to the observation of blue whales on relatively few observation days (Figure 23 and 24). In GASP, the ratio was varied between 1 and 1.5 sightings per observation day for the majority of the season, with a peak in sightings the beginning of September. The highest ratio of sightings per day in Gaspe in the first half of September corresponded to the increased effort in that time in the years 2003-2008 (Table 2). The least biased distribution was likely from MING, where there was constant effort over all years independent of blue whale distribution. Again, the ratio was low (usually below 0.5 sighting/day) since all effort was taken into account but most blue whale sightings were made prior to 1994 (Figure 19).

Across all regions, blue whales were predominantly observed in August and September, with a small peak of observations in July. The number of opportunistic sightings continuously increased over the season but dropped slightly after August (Figure 22). A similar trend was apparent with MICS data (Figure 26). The first peak in the first half of July is driven by dedicated surveys along the Gaspé Peninsula, followed by a dip in sightings due to little effort in

GASP and the ESTU (Figure 24). In MING, the sightings/day ratio increased until the peak in observations was reached in the first half of September.

The number of unique blue whales over the season showed a distribution similar to that of the ratio first sightings/observation days. A first peak with seven unique blue whales per two-week period was reached in the first half of July and a second one occurred at the end of August and the beginning of September with 14-15 individual blue whales after which the number of sightings decreased. In late October seven individual blue whales continued to be observed per half-month in the GSL.

Occurrence & Occupancy

The average annual occurrence was 1.97±0.07 days. Many animals were sighted only once in a season (Figure 28). The mean occupancy pooled over all years was 10.5±0.8 days. Ignoring animals with an occurrence of 1, the mean occupancy increased to 22 days±1.7. The annual variation in annual occupancy is shown in Figure 29.

DISCUSSION

We have described the distribution of St Lawrence blue whales based on 29 years of sighting data from several research areas in the estuary and north-western GSL. Although these observations were not collected using systematic sampling designs, they still provide valuable information of the presence of blue whale at different times of year. The resulting maps show that blue whales can be observed in most coastal areas of the estuary and north-western GSL, with areas of particularly high density along the tip of the Gaspé Peninsula and the north shore of the lower estuary.

Several caveats must be taken into account when interpreting these data. In particular, coverage between the main research areas and in offshore waters is spotty at best, and absence of sightings should not be interpreted as absence of blue whales. Moreover, our knowledge of blue whale distribution is extremely limited east of 63ºW and along the entire eastern seaboard. During the TNASS survey, few blue whales were reported in the south-eastern GSL, but some sightings were made along the Scotian Shelf and at the entrance of the Laurentian Channel (Lawson & Gosselin, 2009). Clearly, additional survey effort or satellite telemetry studies are needed to elucidate blue whale distribution in those areas.

Another caveat is the heterogeneous effort in space, due to the focus on photo-identification studies, which require seeking areas of high whale density. The number of whale sightings cannot easily be corrected by the number of hours spent in a given grid cell, because when conducting photo-identification, finding more whales usually leads to more time being spent in the area (rather than the reverse relationship where more effort usually results in more whale sightings). For this reason, we have applied effort correction based on the distance travelled in each grid cell, which is less likely to be biased by photo-identification efforts. This correction for uneven spatial coverage of different areas allows rough comparison of the spatial density of blue whales among regions. Comparison is limited, however, by the fact that most surveys in the different research areas have not been completed at the same time of year.

The individual sighting histories, issued from long-term photo-identification studies, provide additional insights into the relative importance of different areas. Once corrected for the number of observation days, the number of individually identified blue whales in the estuary and Gaspe region were equivalent (at about 1.5 whales per day). Over the entire study period, however, the estuary appeared to have been the most important area for blue whales (73% of all individuals were seen there at least once, and 23% were seen only in that area).

Overall, the high re-sighting rates between years and the occupancy patterns of some areas by a large number of blue whales highlight the importance of the GSL for North Atlantic blue whales. Although the exact size of the western North Atlantic blue whale population is not known, the high proportion of matches to the MICS catalogue among the sightings made outside the GSL attest of its importance to a significant proportion of the population. The GSL has long been known to be an important feeding ground, and recent tagging studies have confirmed that blue whales can achieve high feeding rates in the estuary (Doniol-Valcroze et al. 2012). To better understand habitat use within the GSL, the maps of sighting density could be used to determine areas of high use and to study their characteristics within the main research areas. However, long-term, frequent surveys with coverage over the entire GSL can identify and characterize important habitats for blue whales in these waters. In addition, the use of autonomous acoustic recording units has been shown to monitor the distribution and movements of whales in less accessible areas.

Sightings of GSL individuals made outside the GSL in summer suggest that blue whales can select other feeding grounds in some years, and may even move among these feeding grounds within the same summer. Similarly, low resighting rates *within* seasons (occurrence) suggest that blue whales are highly mobile within GSL waters. In contrast to other baleen whale species, blue whales do not appear to remain at one feeding site for the entire summer. Moreover, throughout the course of the study period, the importance of different areas has changed. The combination of spatial density maps and sighting histories illustrates well the case of the Jacques Cartier Passage (MING, where frequentation by blue whales has changed drastically, both in distribution and in abundance). The MING area was an important habitat in the 1980s and early 1990s, but is currently not used by this species. There also might have been additional, so far unknown areas during the early years of the study.

We also note that the vast majority of individual blue whales are unaccounted for at any given time during the summer, suggesting the existence of important habitats in unstudied areas. Taken together, and despite methodological biases, these observations paint a complex picture of habitat use by blue whales in the GSL, characterized by fidelity to feeding sites by individual blue whales at the same time as high within-season mobility among those areas, and evidence of long-term changes in site frequentation. Since blue whales occupy a wide range of habitats, it is important that conservation strategies consider not only their known foraging areas but also moving corridors linking them. Combined with our ignorance of offshore distribution and in the eastern GSL, this suggests that a careful approach will be necessary to delimitate critical habitat.

ACKNOWLEDGEMENTS

MICS would like to thank all the team members and volunteers who have participated in fieldwork since 1980. In addition, we thank the many organizations and individuals who have contributed to the blue whale data collection and who have provided opportunistic sightings. We would especially like to thank Janie Giard and GREMM, ROMM, DFO Québec, DFO Newfoundland and Labrador, Meriscope, Croisières Baie de Gaspé, the Provincetown Center for Coastal Studies, the Whale Center of New England, the Whitehead lab, Tonya Wimmer, René Roy, Jacques Gélineau, Yvon Belanger and many other individuals. Special thanks for the extensive assistance of Rene Swift with Manifold and ACCESS. Also to Thomas Doniol-

Valcroze and Véronique Lesage for helpful comments and fruitful discussions, as well as Phil Hammond for advice about analyzing the existing data in the least biased way.

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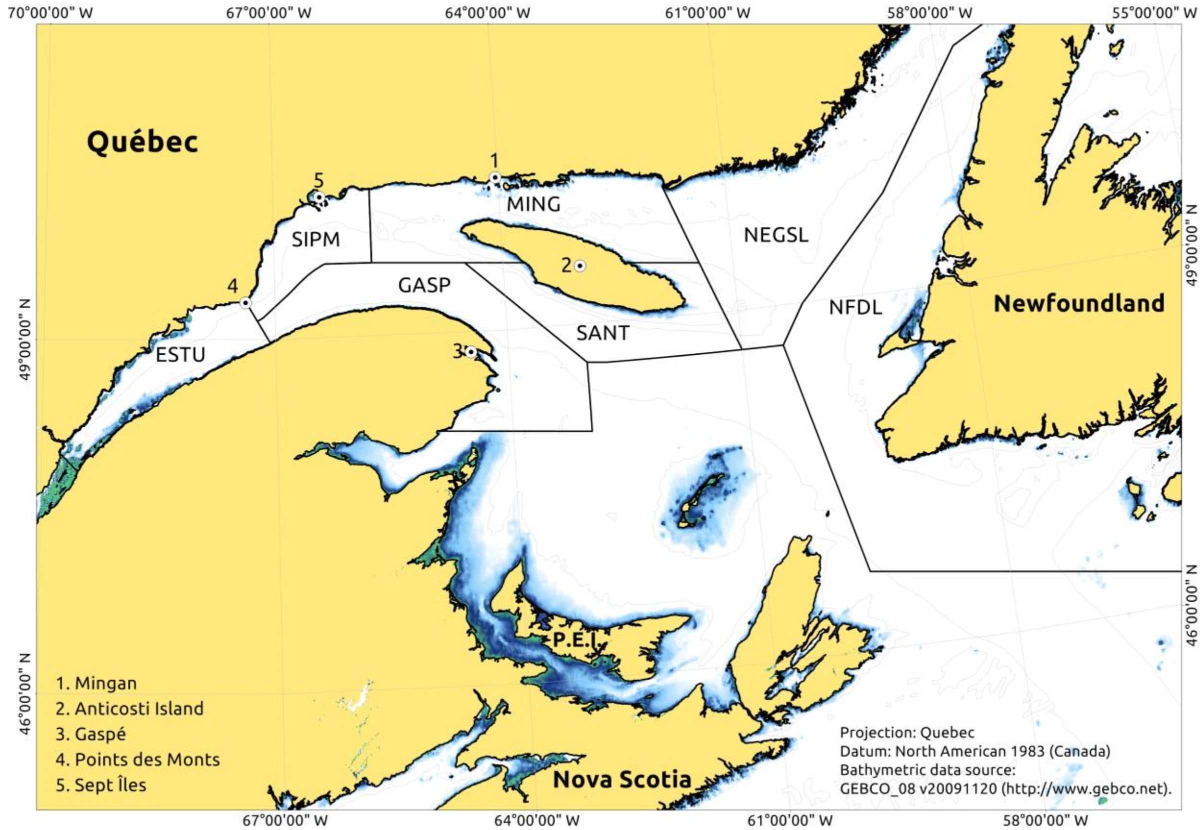

Figure 1. Primary research areas of the Mingan Island Cetacean Study (MICS).

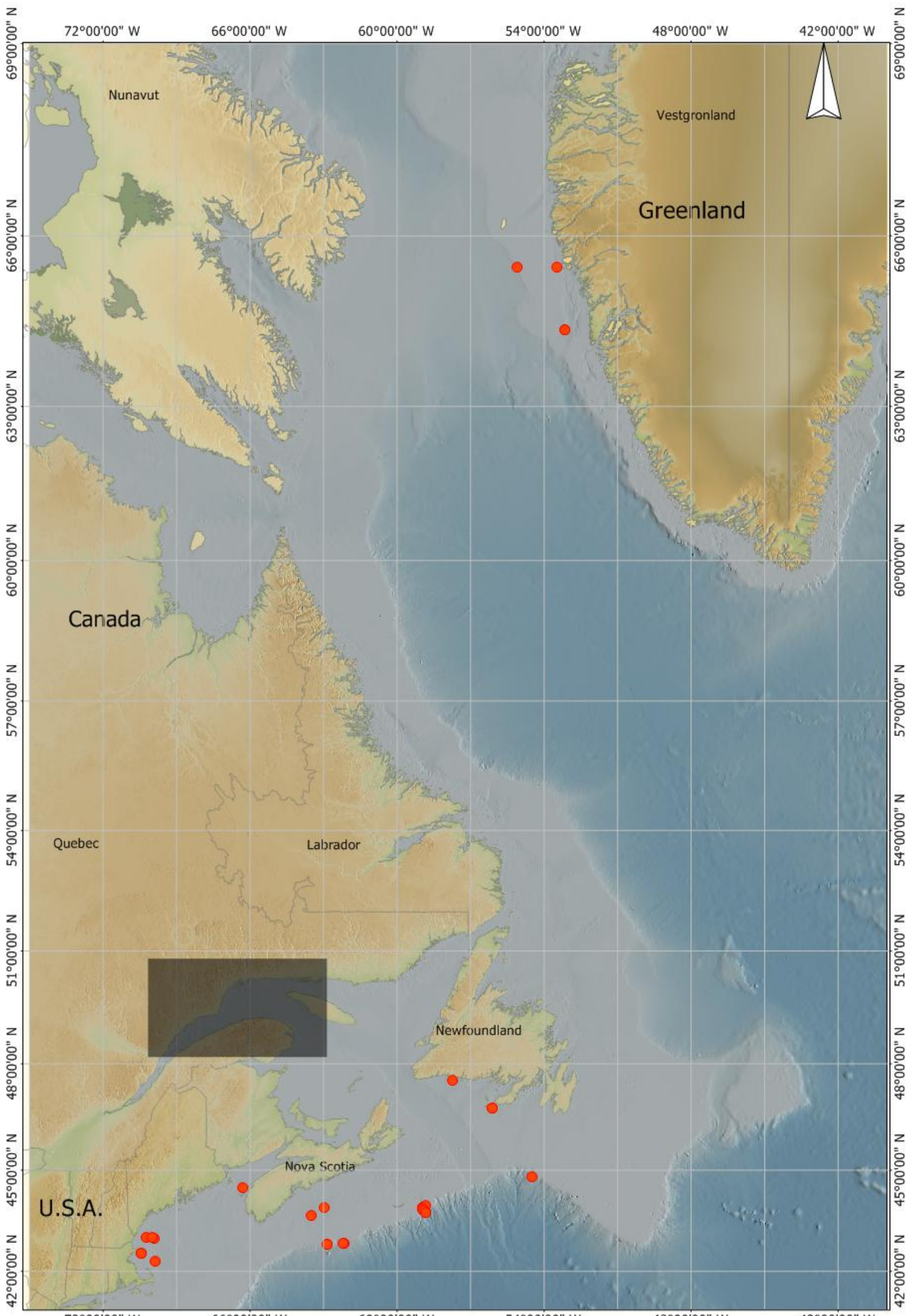

Figure 2. Opportunistic blue whale sightings outside the GSL received by MICS. It is neither a representative nor complete overview of historic blue whale sightings outside the Gulf of St. Lawrence. Most sightings occurred in a very small area in the vicinity known as 'The Gully,' a deep-sea canyon between Nova Scotia and New Brunswick. The gray box indicates approximately the extent of the research area.

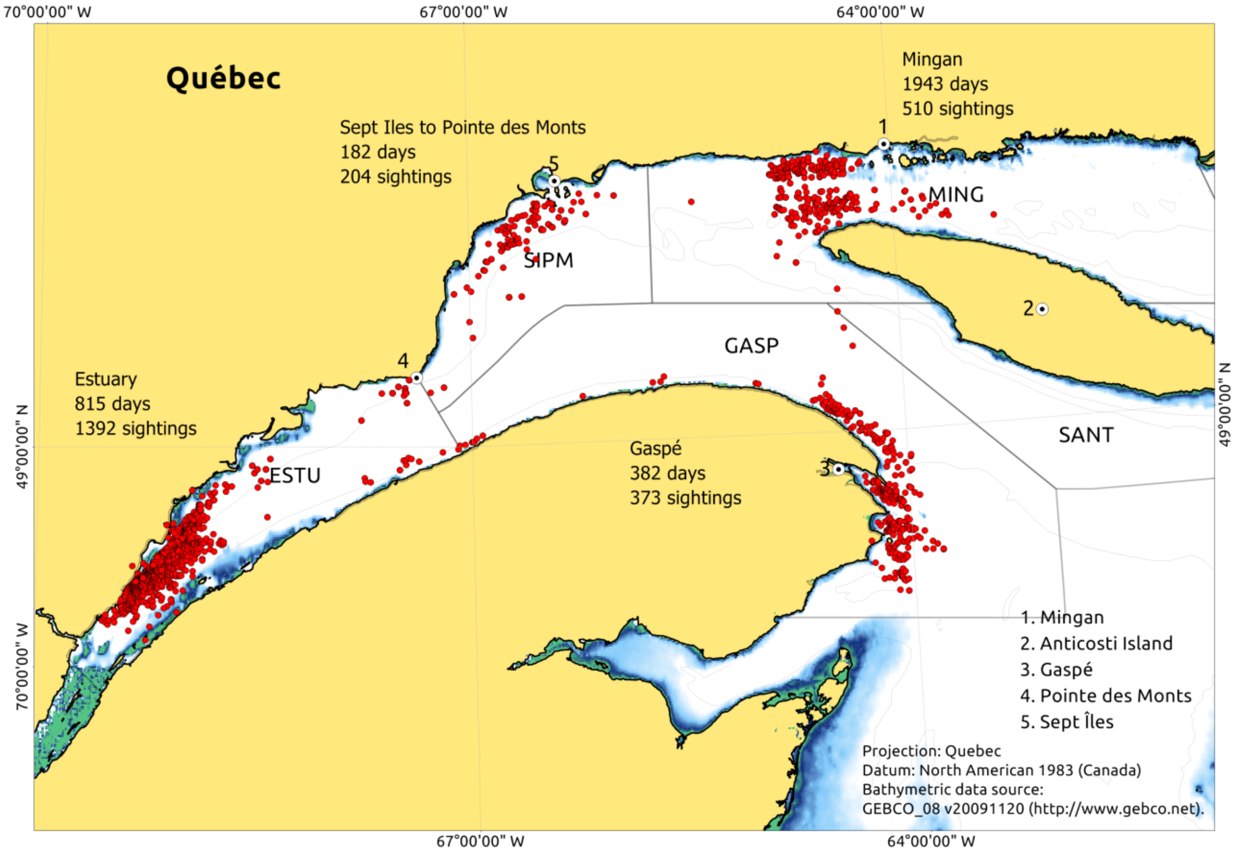

Figure 3. All first sightings of identified blue whales in the principal research areas from 1980 to 2008.

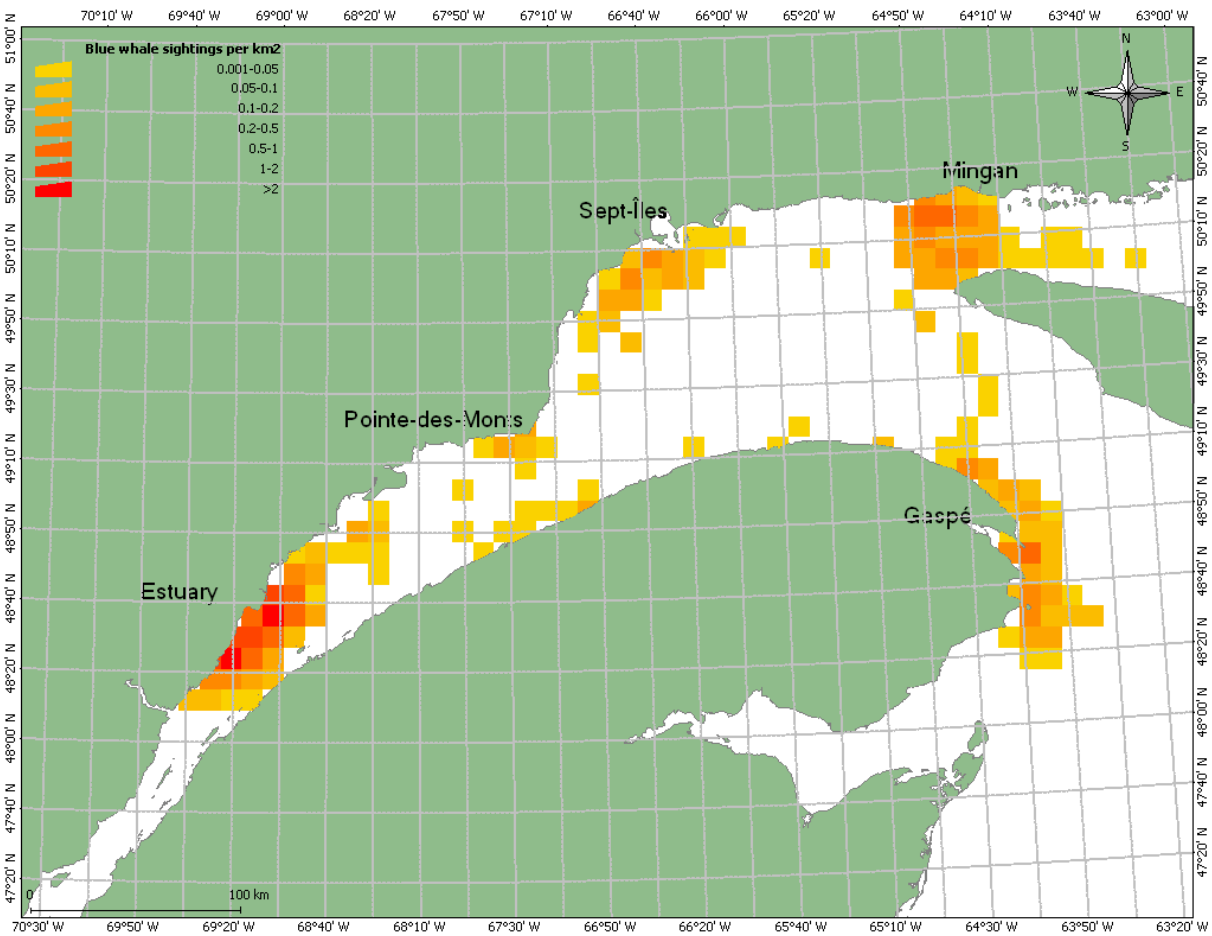

Figure 4. Raw blue whale densities for the entire study area from 1980 – 2008. Coloured squares indicate the number of blue whale sightings per square kilometer, and each grid cell represents an area of 100 km^2.

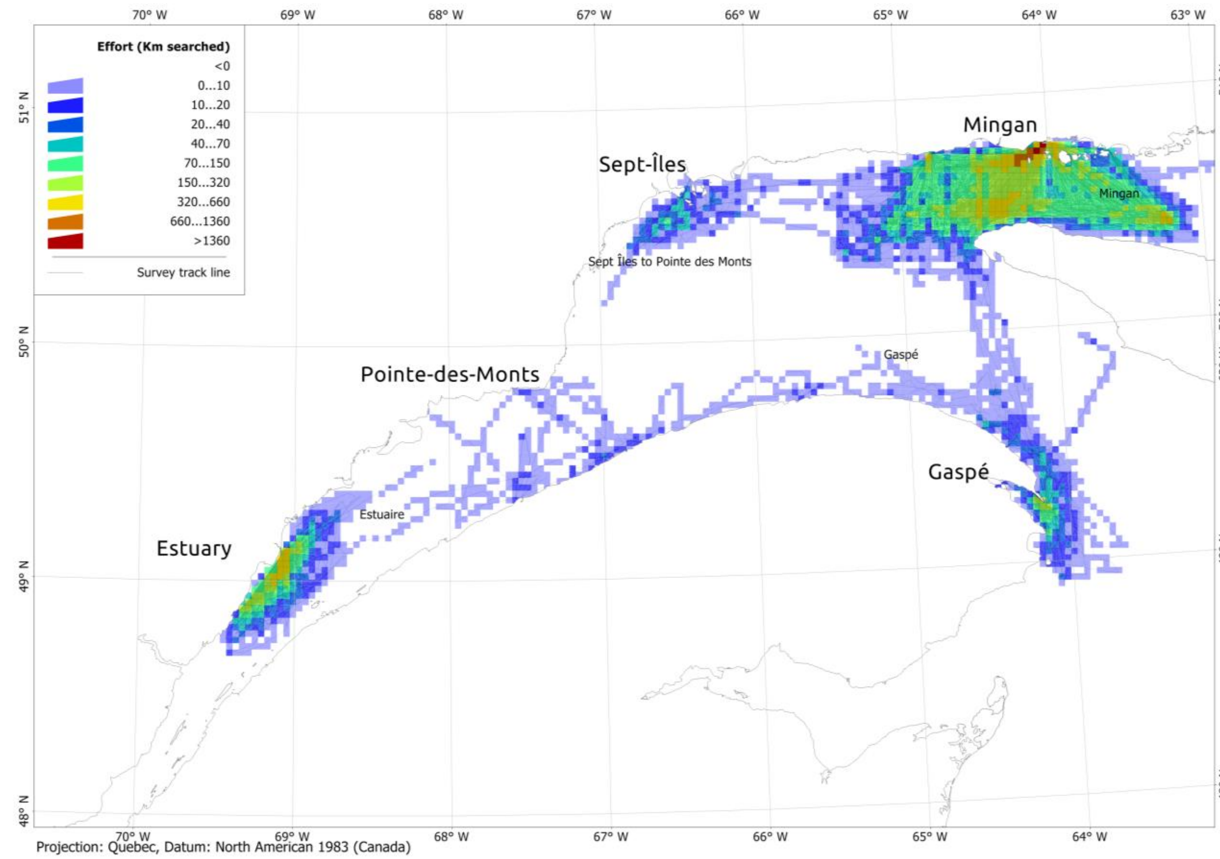

Figure 5. The effort (km) per 3 x 3km grid cell for the entire study area during the period 2000-2008.

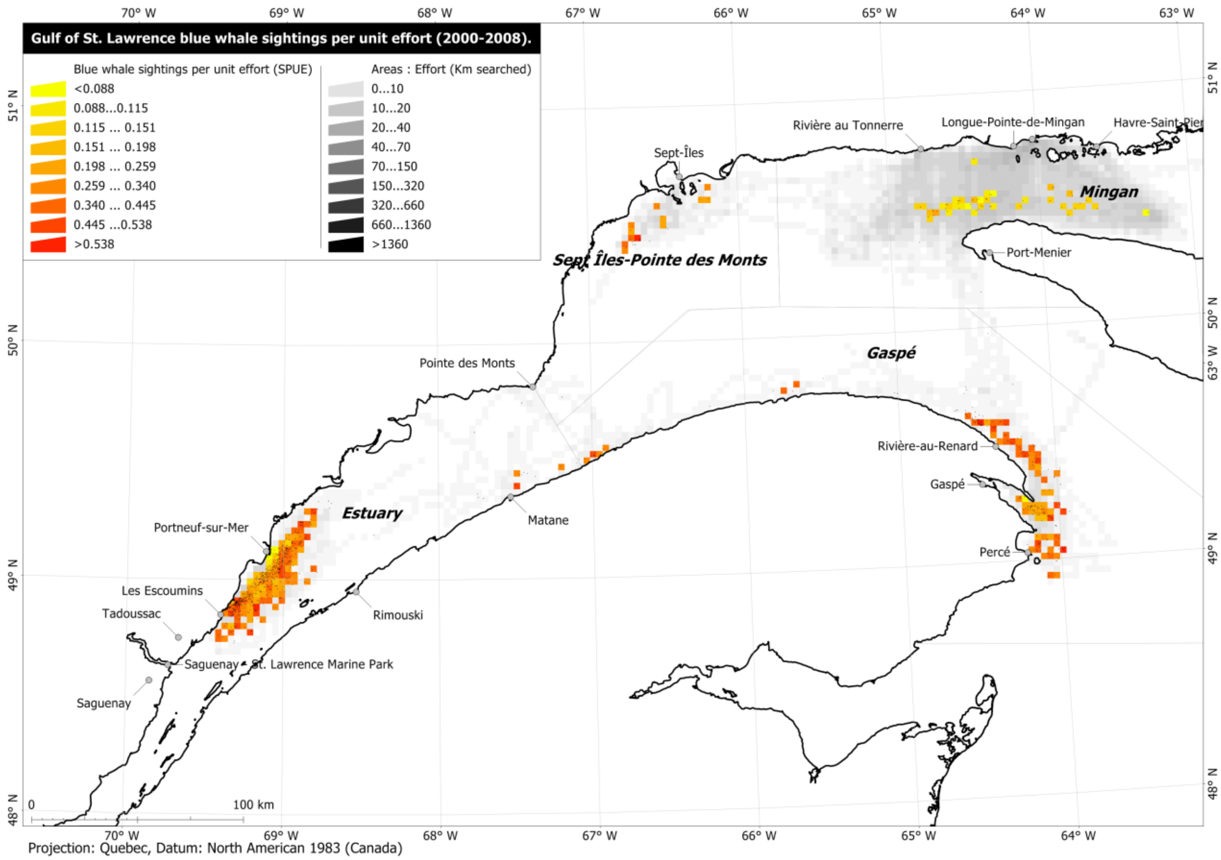

Figure 6. MICS blue whale sightings per km of effort in 3 x 3km grid cells for the entire study area during the period 2000-2008. Effort in km surveyed is also shown for comparison. SPUE for cells with less than 10km of effort are omitted, but effort is shown.

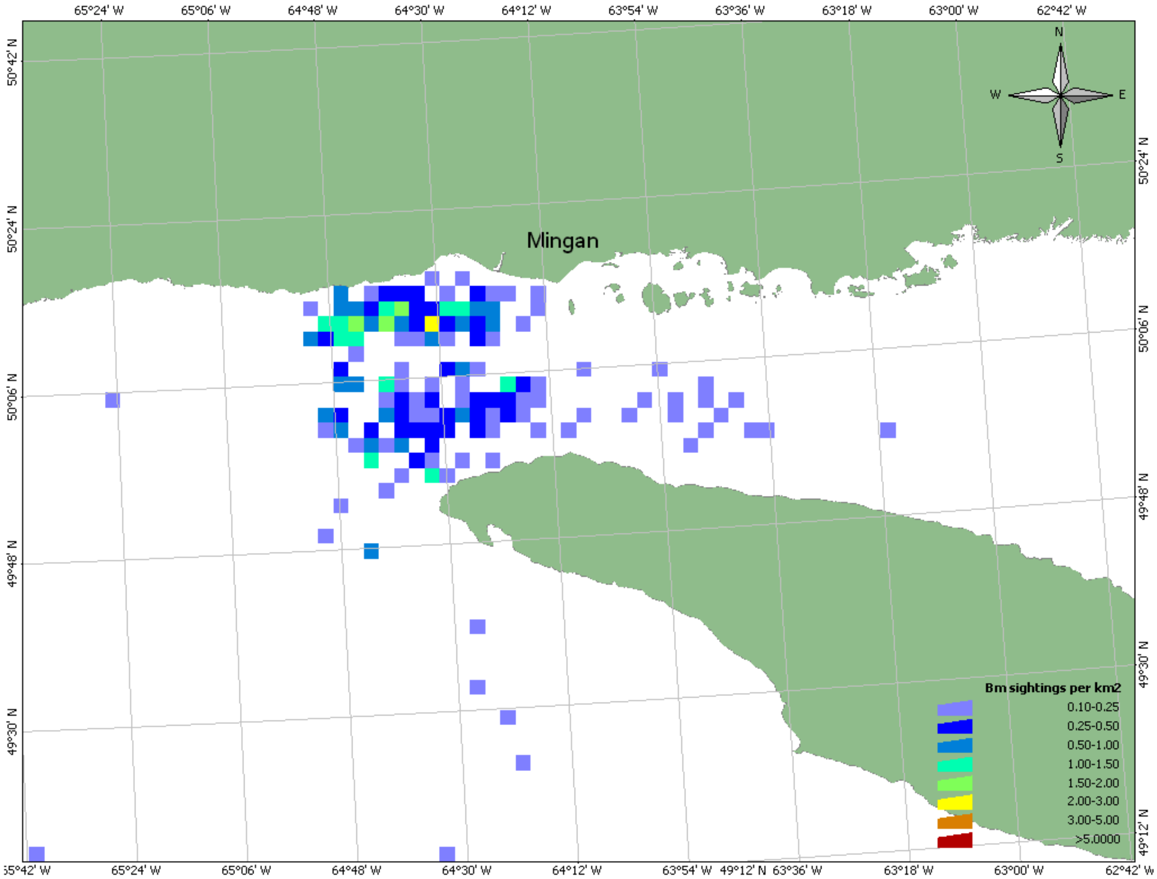

Figure 7. Raw blue whale densities for Mingan from 1980 – 2008. Coloured squares indicate the number of blue whale sightings per square kilometer, and each grid cell represents and area of 9 km^2.

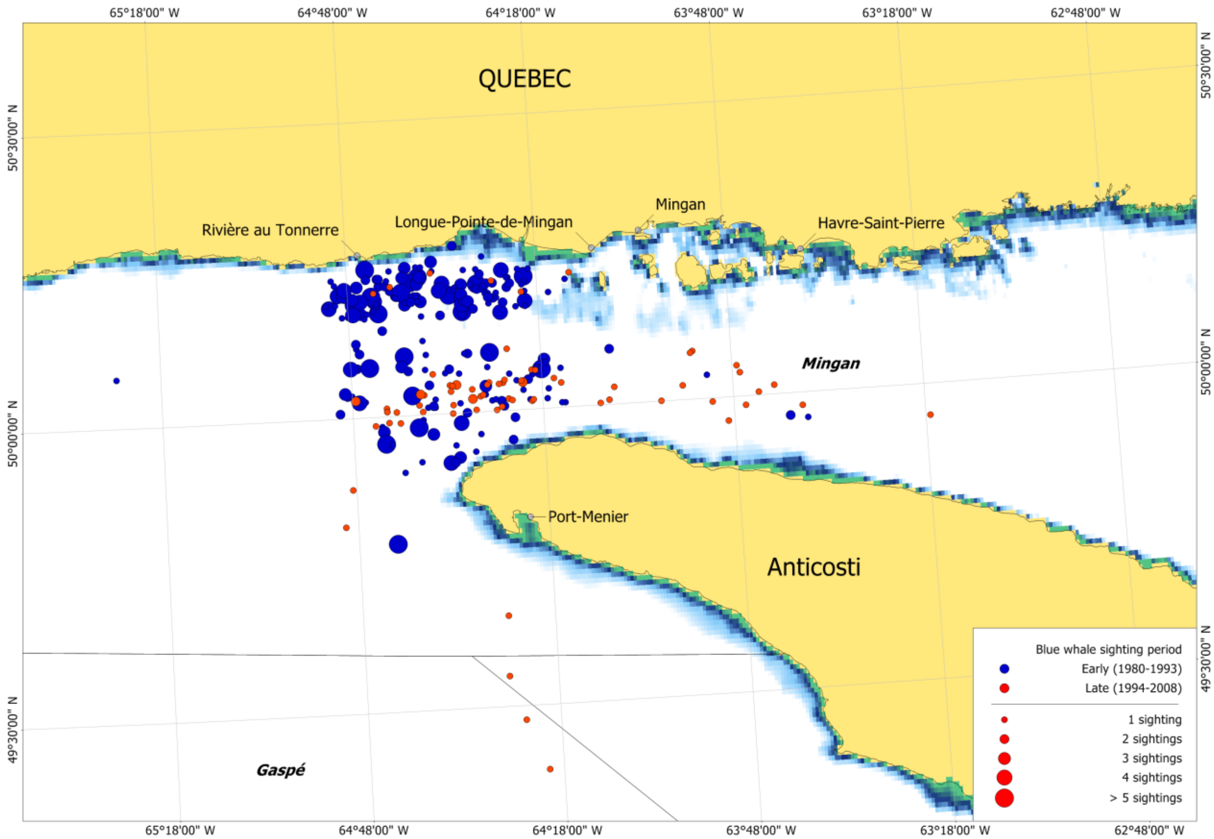

Figure 8. First sightings of identified blue whales observed by MICS in Mingan from 1980 to 2008. They are divided in the periods of 1980-1993 and 1994-2008. In the 1980s, positions were estimated with a compass and few positions were taken during a day. Several whales therefore appear at the same position although they were only seen in the same general area.

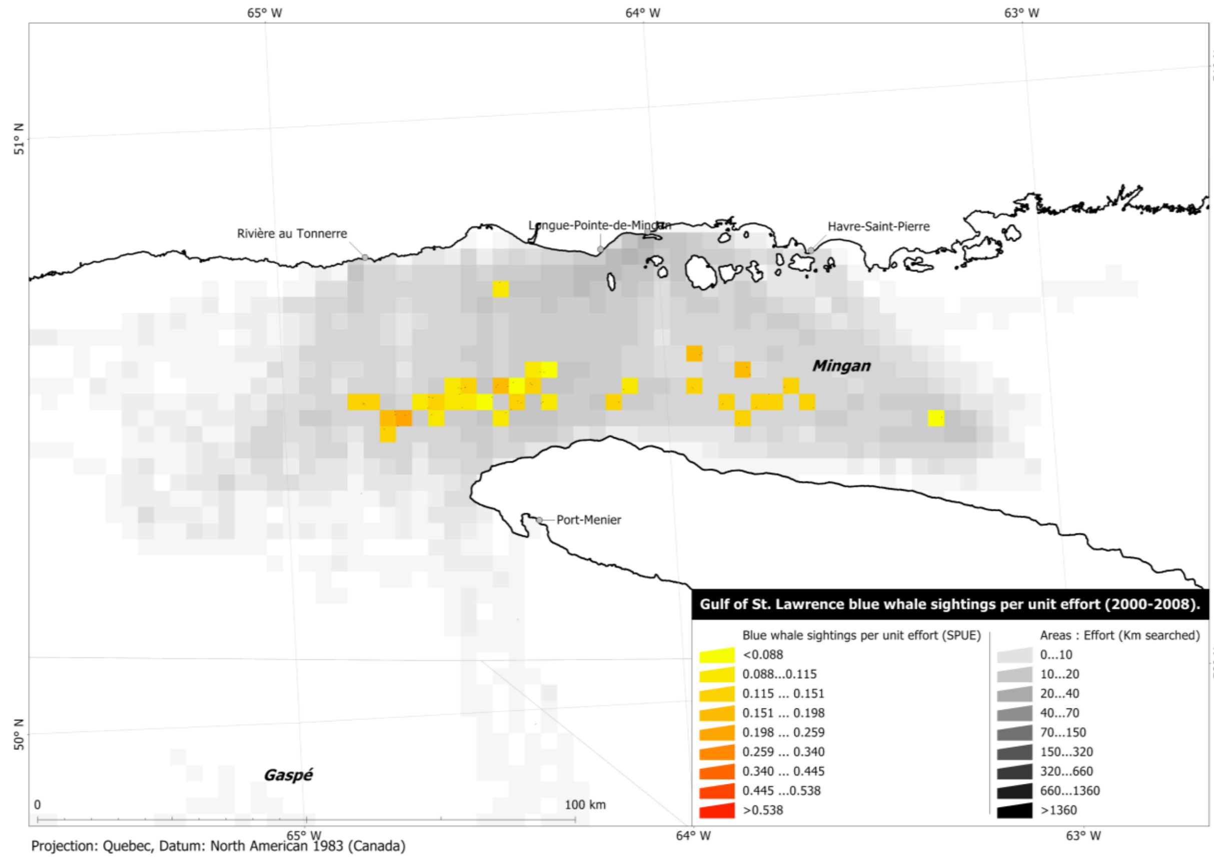

Figure 9. MICS blue whale sightings per km of effort in 3 x 3km grid cells for Mingan during the period 2000-2008. Effort in km surveyed is also shown for comparison. SPUE for cells <10km are omitted, but effort is shown.

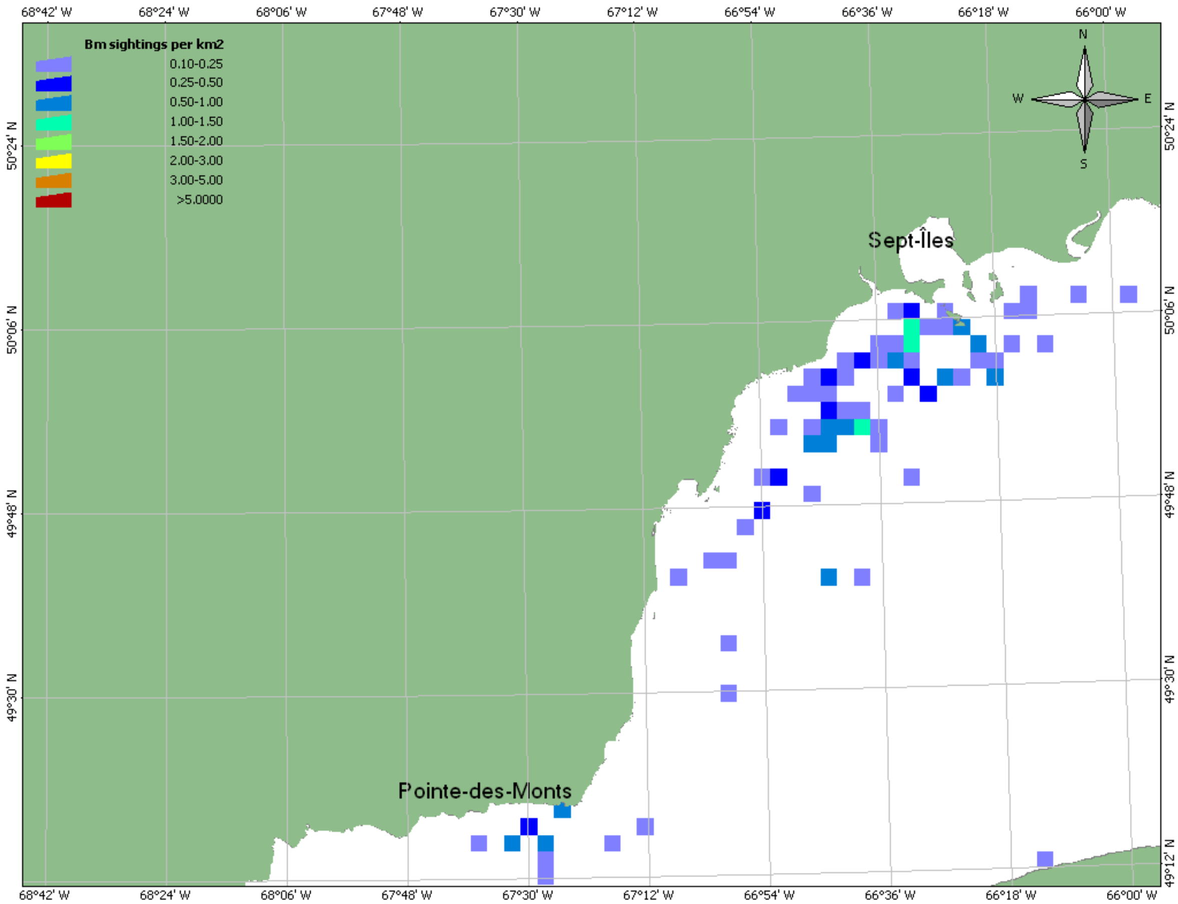

Figure 10. Raw blue whale densities for SIPM from 1980 – 2008. Coloured squares indicate the number of blue whale sightings per square kilometer, and each grid cell represents and area of 9 km^2.

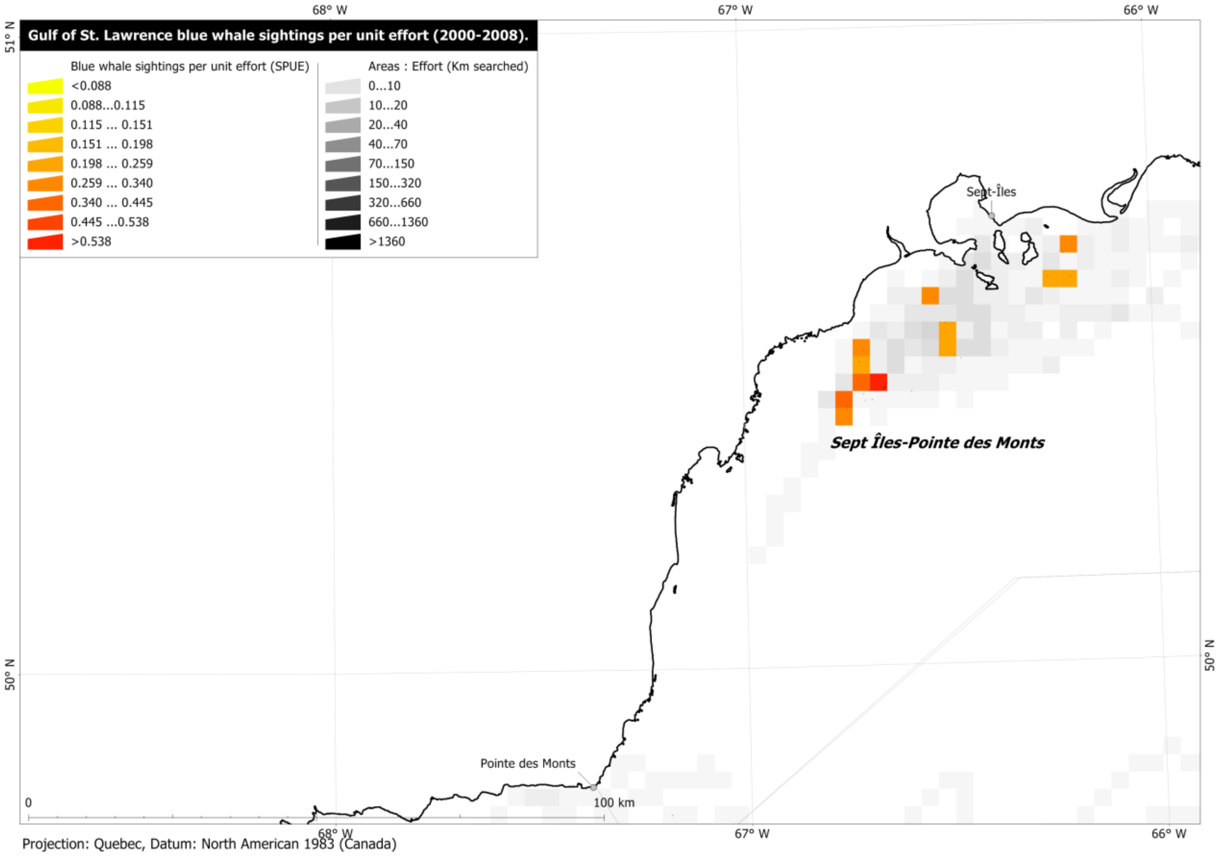

Figure 11. MICS blue whale sightings per km of effort in 3 x 3km grid cells for SIPM during the period 2000-2008. Effort in km surveyed is also shown for comparison. SPUE for cells <10km are omitted, but effort is shown.

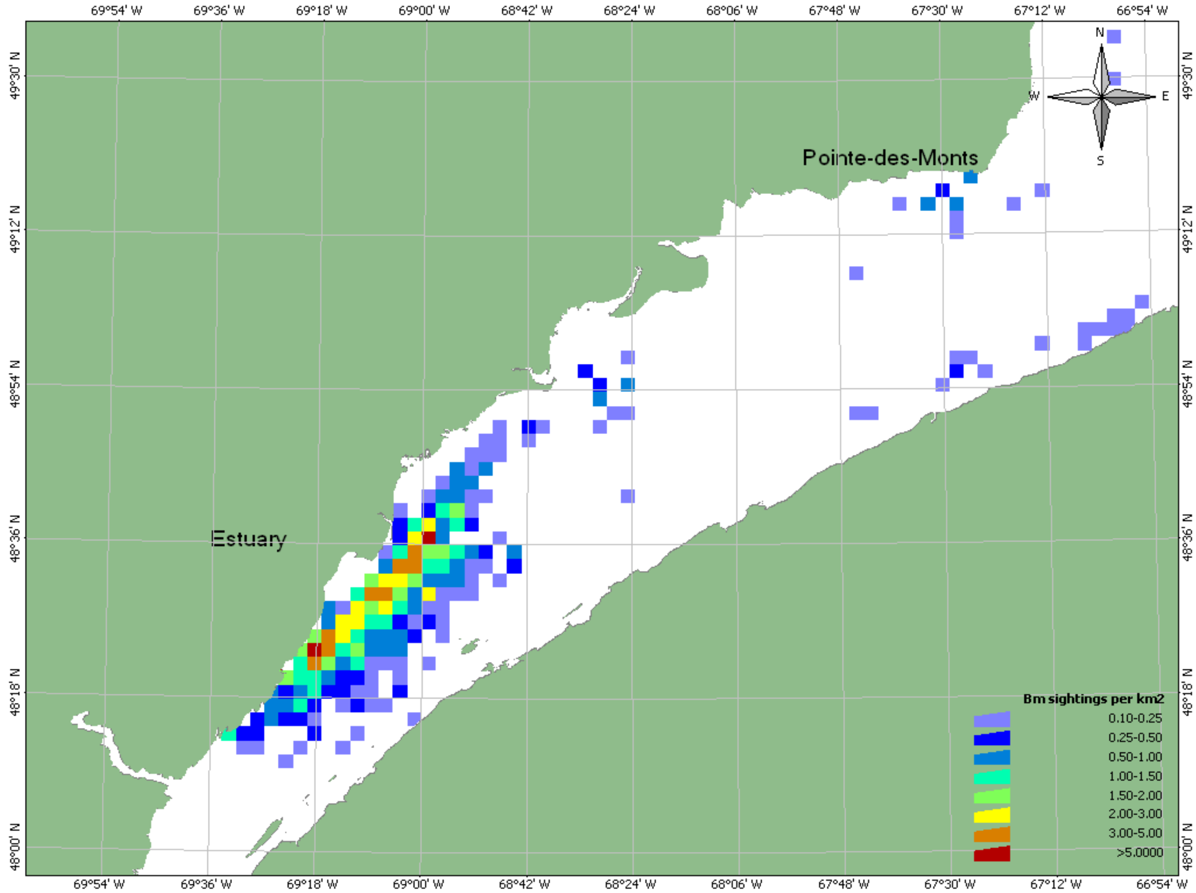

Figure 12. Raw blue whale densities for ESTU from 1980 – 2008. Coloured squares indicate the number of blue whale sightings per square kilometer, and each grid cell represents and area of 9 km^2.

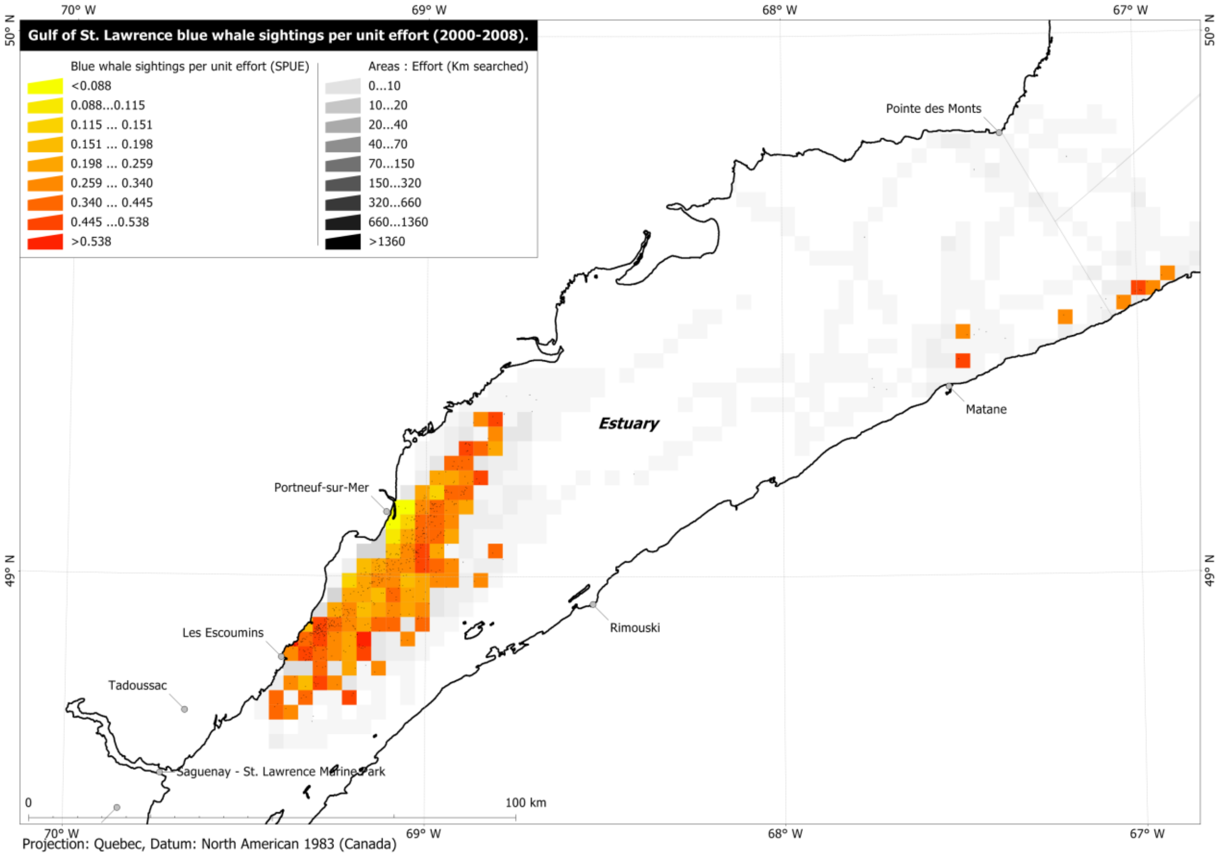

Figure 13. MICS blue whale sightings per km of effort in 3 x 3km grid cells for ESTU during the period 2000-2008. Effort in km surveyed is also shown for comparison. SPUE for cells <10km are omitted, but effort is shown.

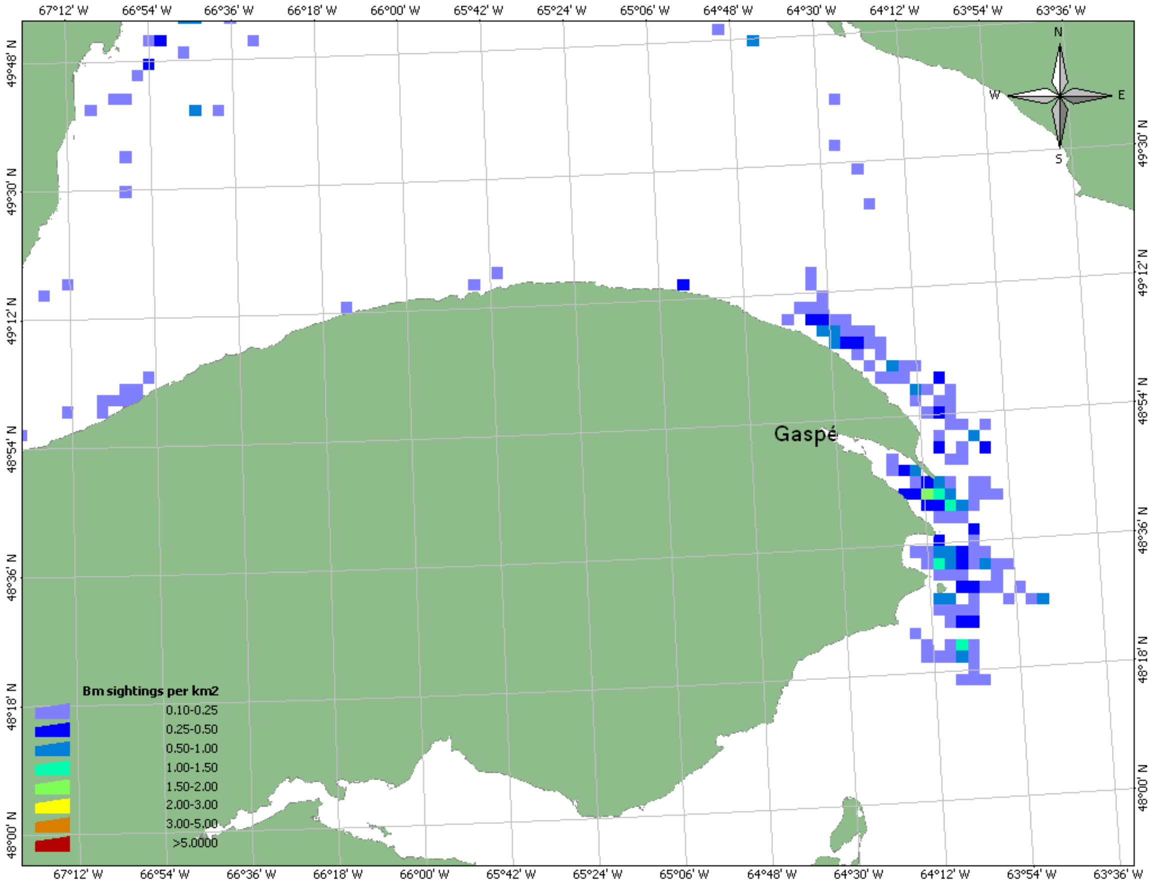

Figure 14. Raw blue whale densities for GASP from 1980 – 2008. Coloured squares indicate the number of blue whale sightings per square kilometer, and each grid cell represents and area of 9 km^2.

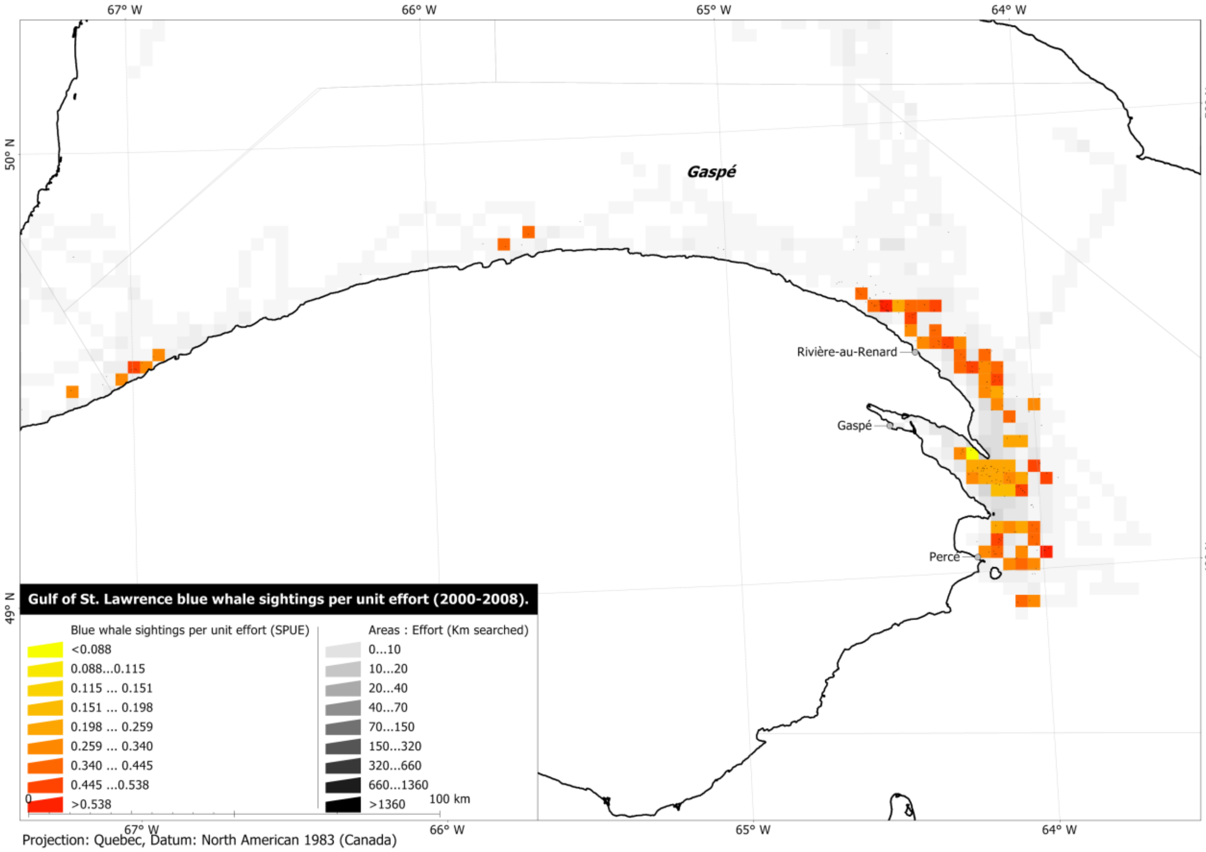

Figure 15. MICS blue whale sightings per km of effort in 3 x 3km grid cells for GASP during the period 2000-2008. Effort in km surveyed is also shown for comparison. SPUE for cells <10km are omitted, but effort is shown.

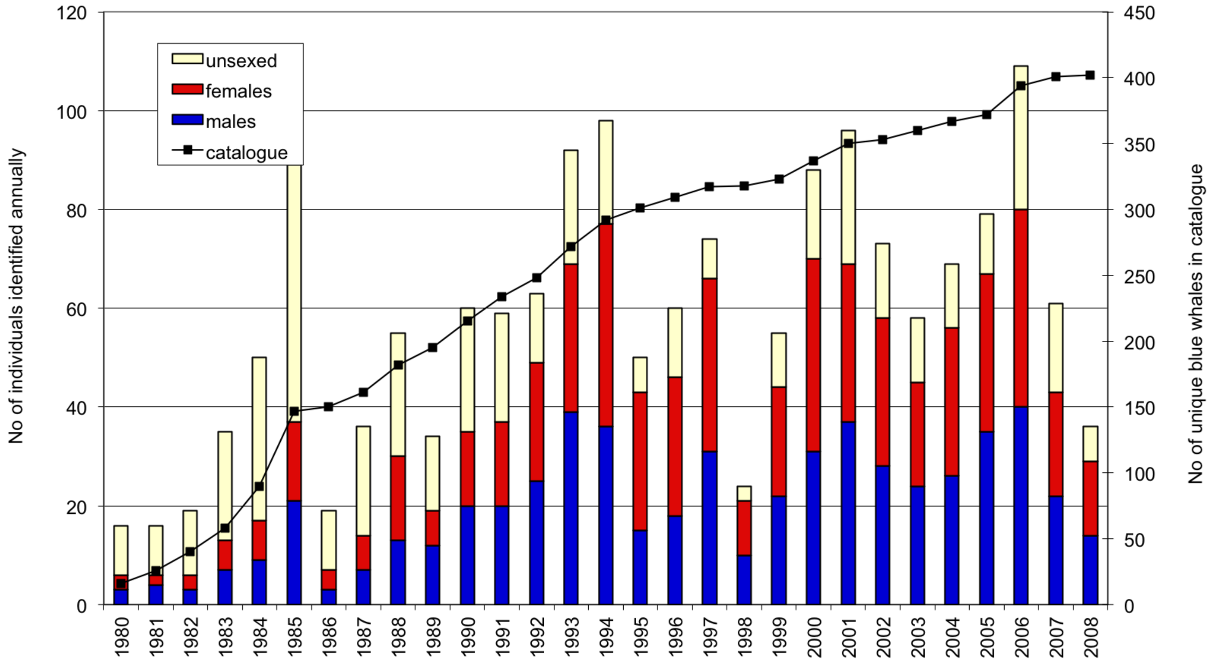

Figure 16. Number of annually identified and unique blue whales from 1980 and 2008. This graph includes only animals sighted within the GSL.

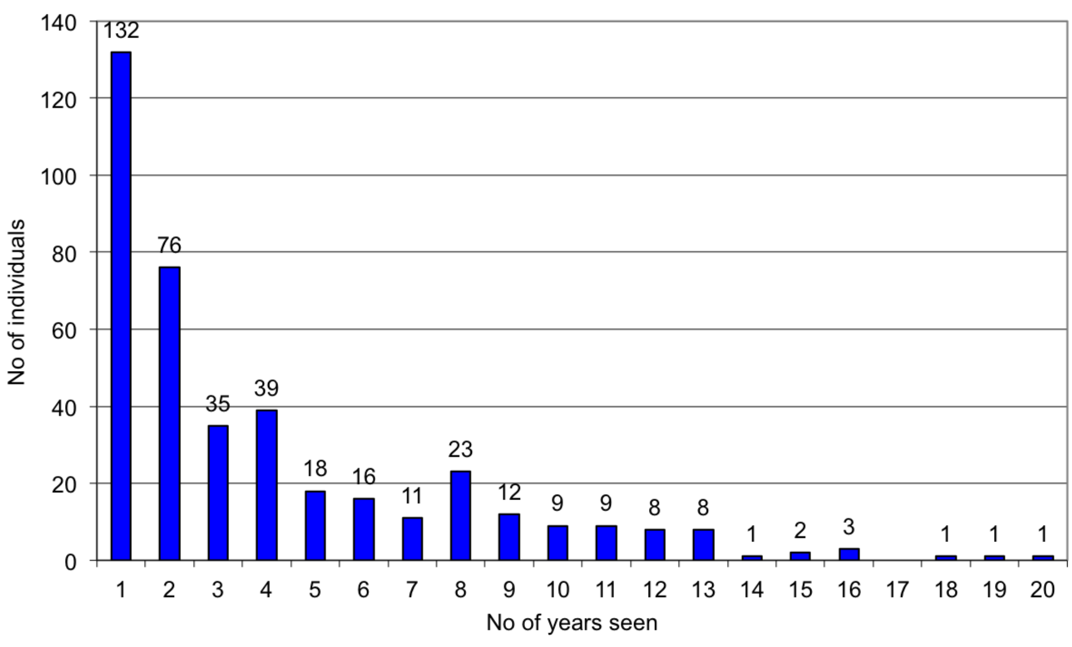

Figure 17. Frequency of capture (years) for identified blue whales.

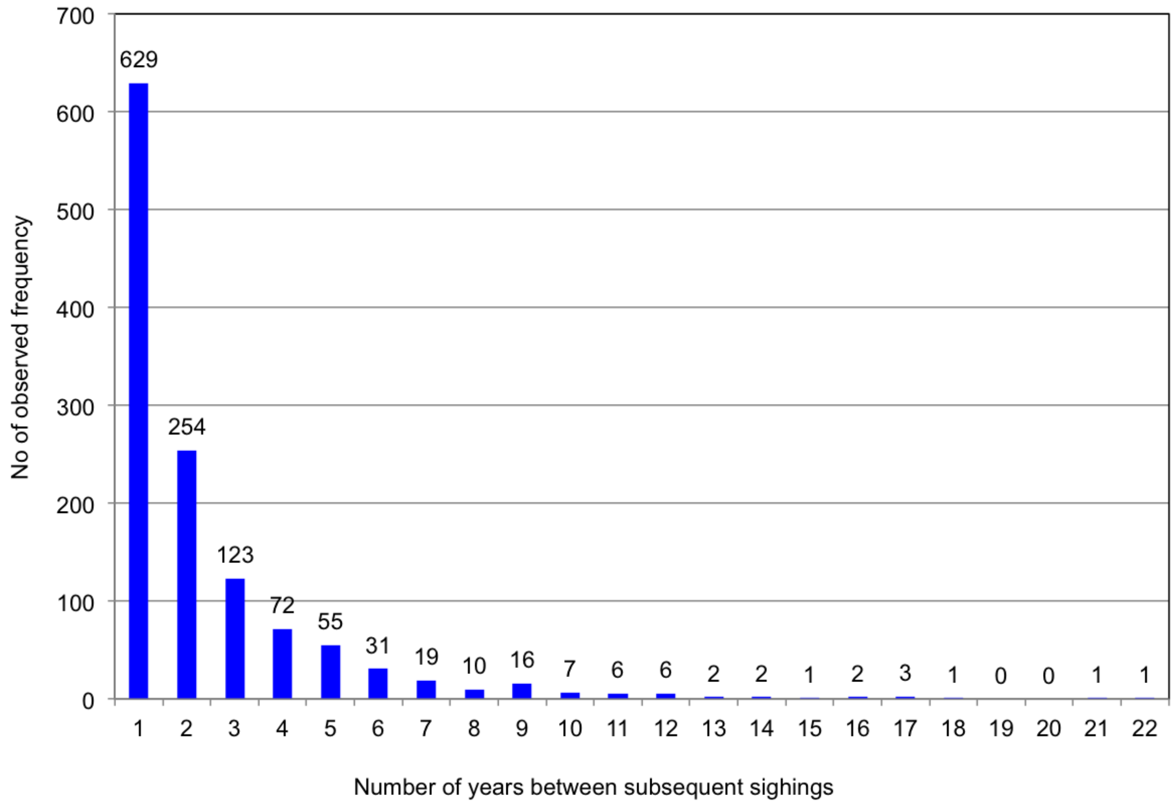

Figure 18. Distribution of the intervals between two subsequent (annual) sightings of individual blue whale sighted twice of more often.

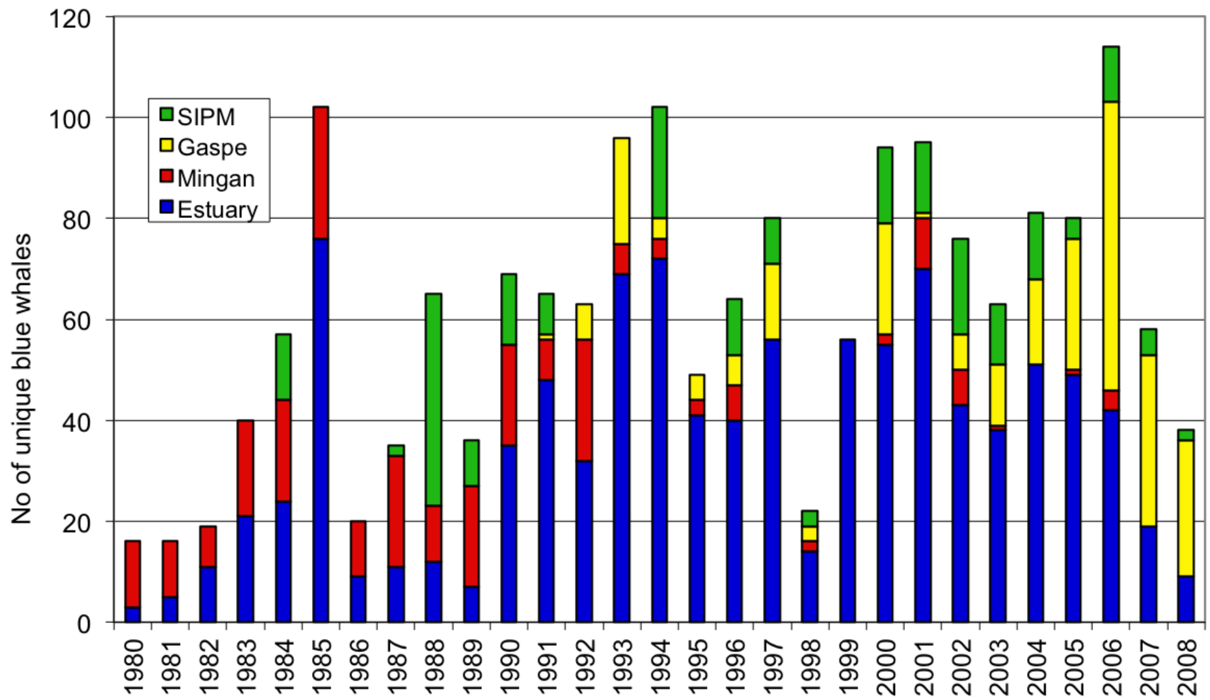

Figure 19. Number of identified blue whales per region pooled over the entire study period. Animals seen in two or more areas in one year were counted once in each, thus the numbers do not represent the total annual number of unique whales as in Figure 16.

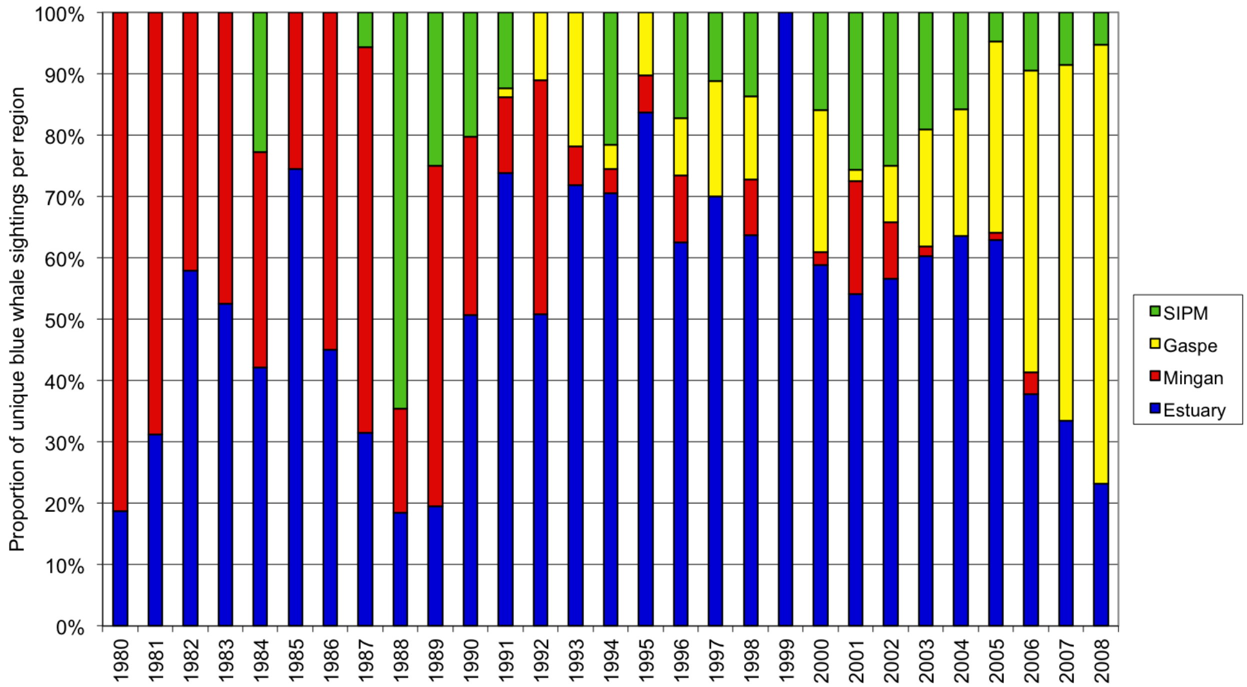

Figure 20. Proportion of individual blue whales per region (based on the data in Figure 18).

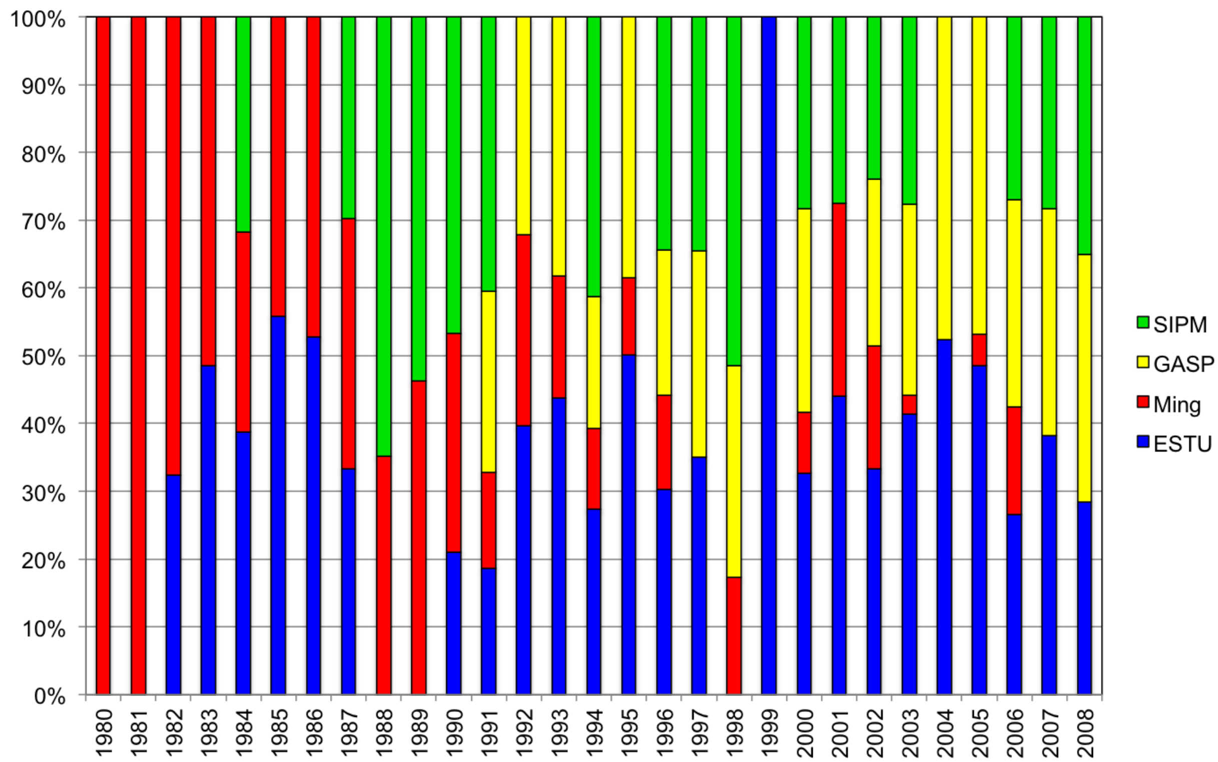

Figure 21. Proportion of first sightings per observation day per region. The number of first sightings was divided by the number of observation days per region and transferred to a logarithmic scale to counter-balance the influence of low effort in some areas and/or years. All data (MICS and opportunistic) are included.

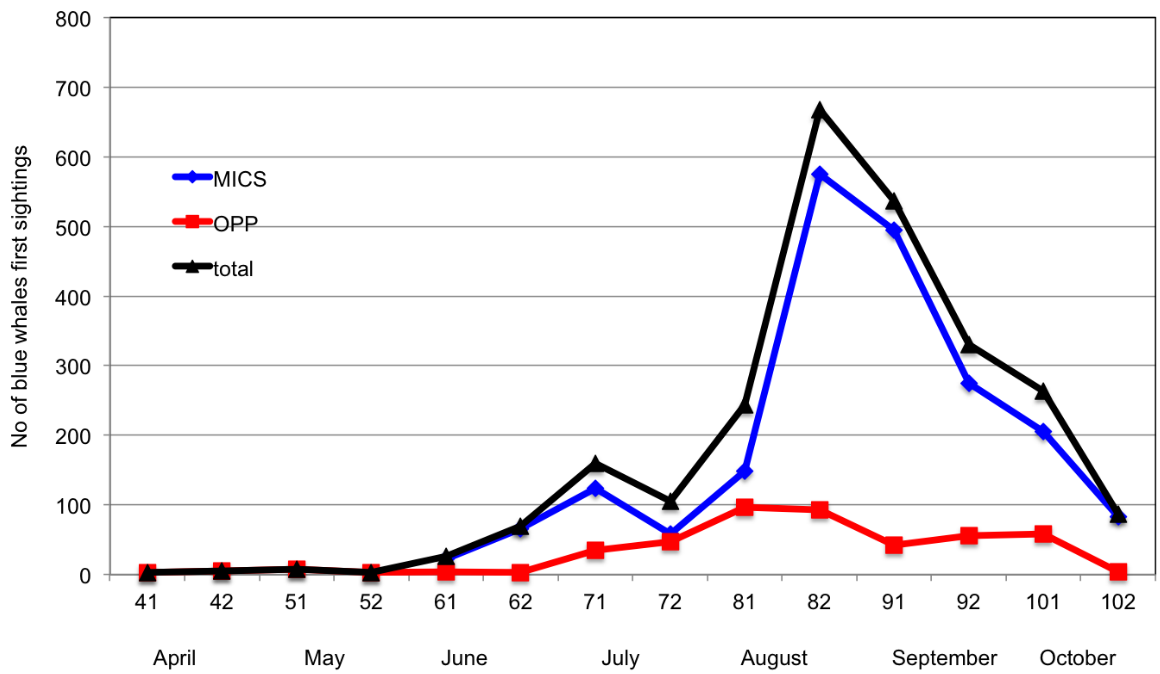

Figure 22. The seasonal distribution of all first sightings of identified blue whales over the season. Months are divided in halves, for example 41= 1-15 of April, 42 = 16-30 April.

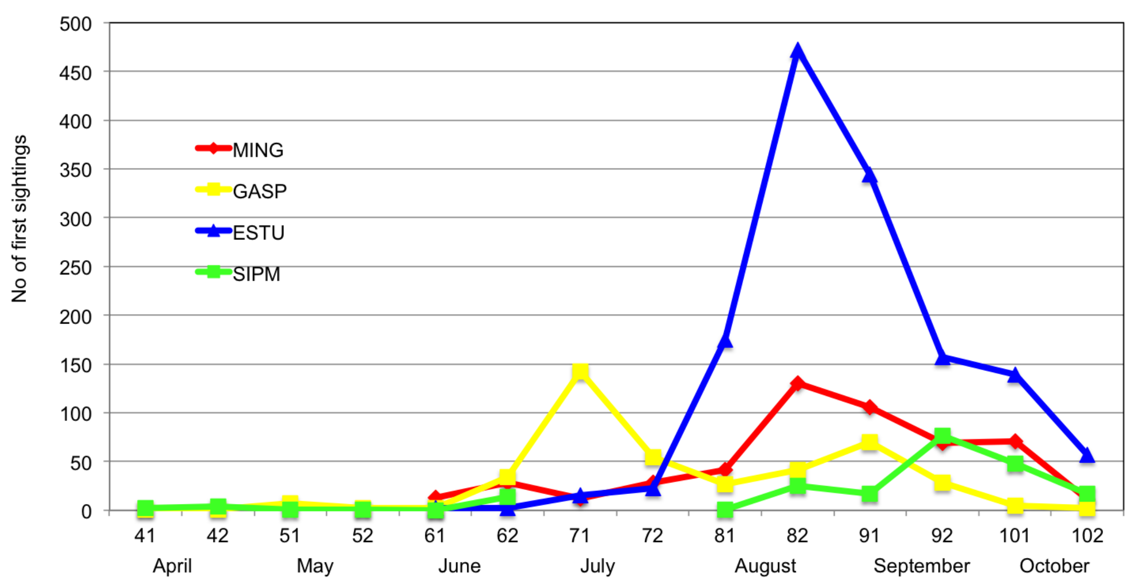

Figure 23. All first sightings of blue whales over the season (half months) divided by research regions from April to October.

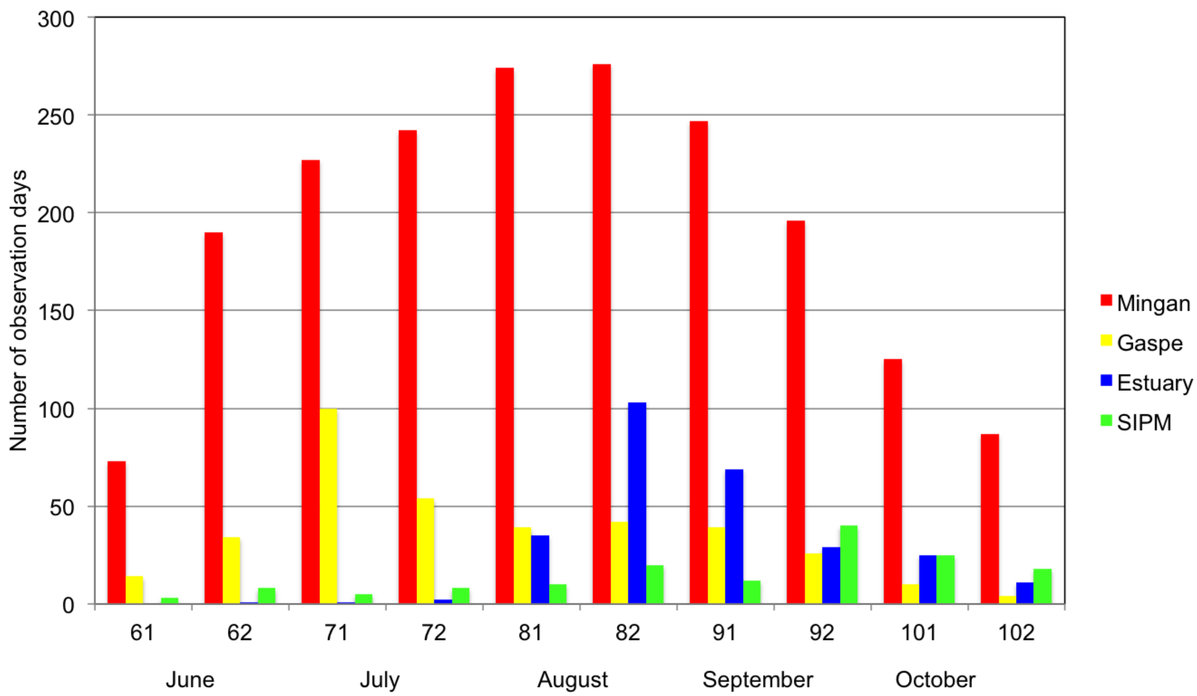

Figure 24. Number of observation days by region (opportunistic and MICS data) over the season pooled over the study period 1980-2008.

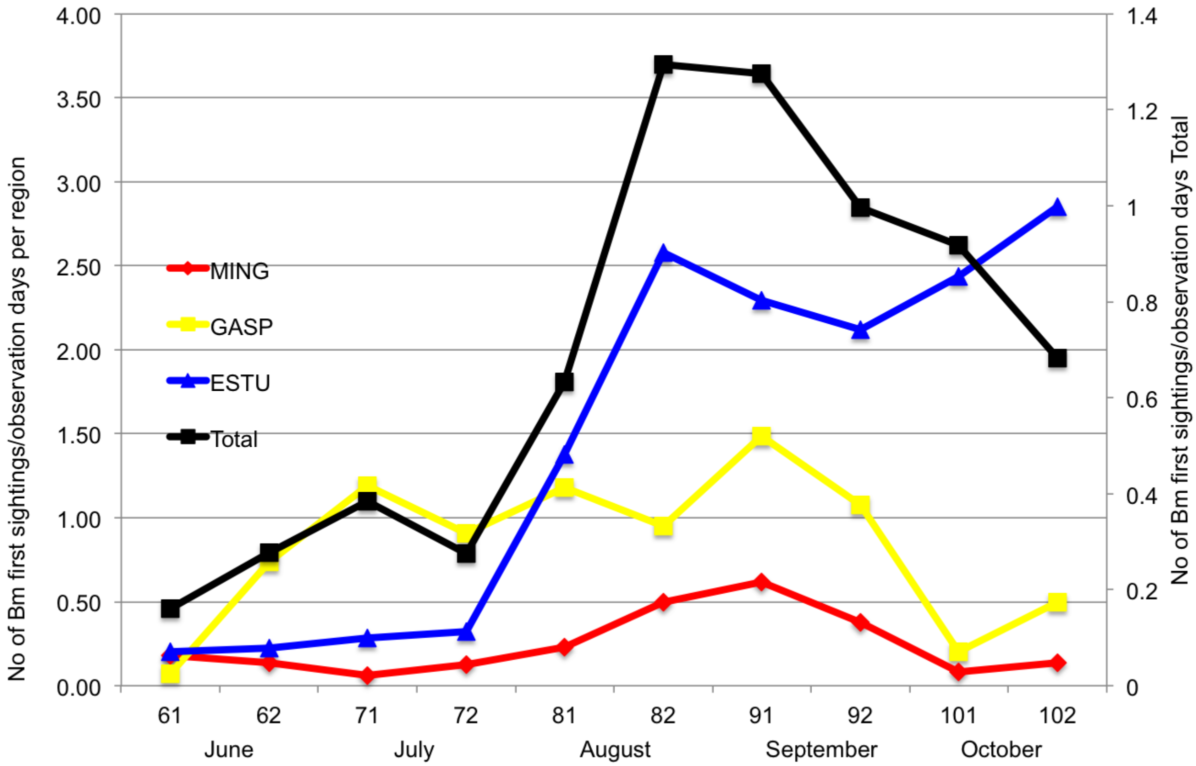

Figure 25. Number of blue whale first sightings per observation day, divided by the three main regions over the season (half months). SIPM was left out for clarity due to the highly variable effort. Includes both MICS and opportunistic data.

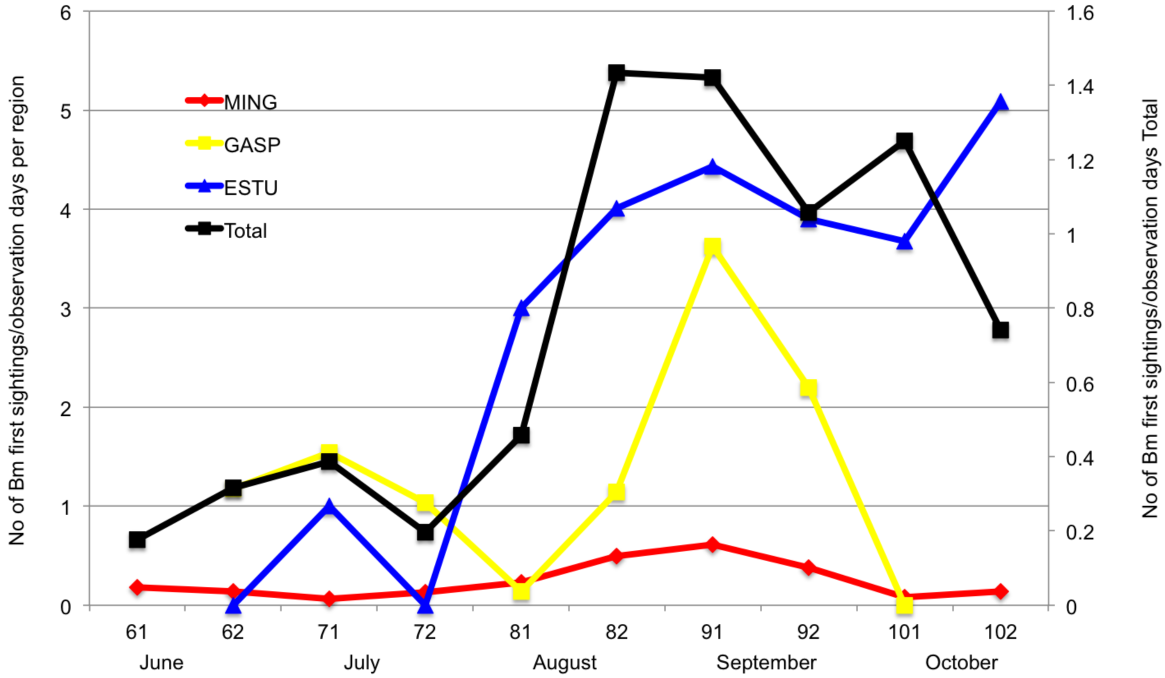

Figure 26. Number of first sightings per observation day categorized by research areas over the season (half months) – MICS data exclusively.

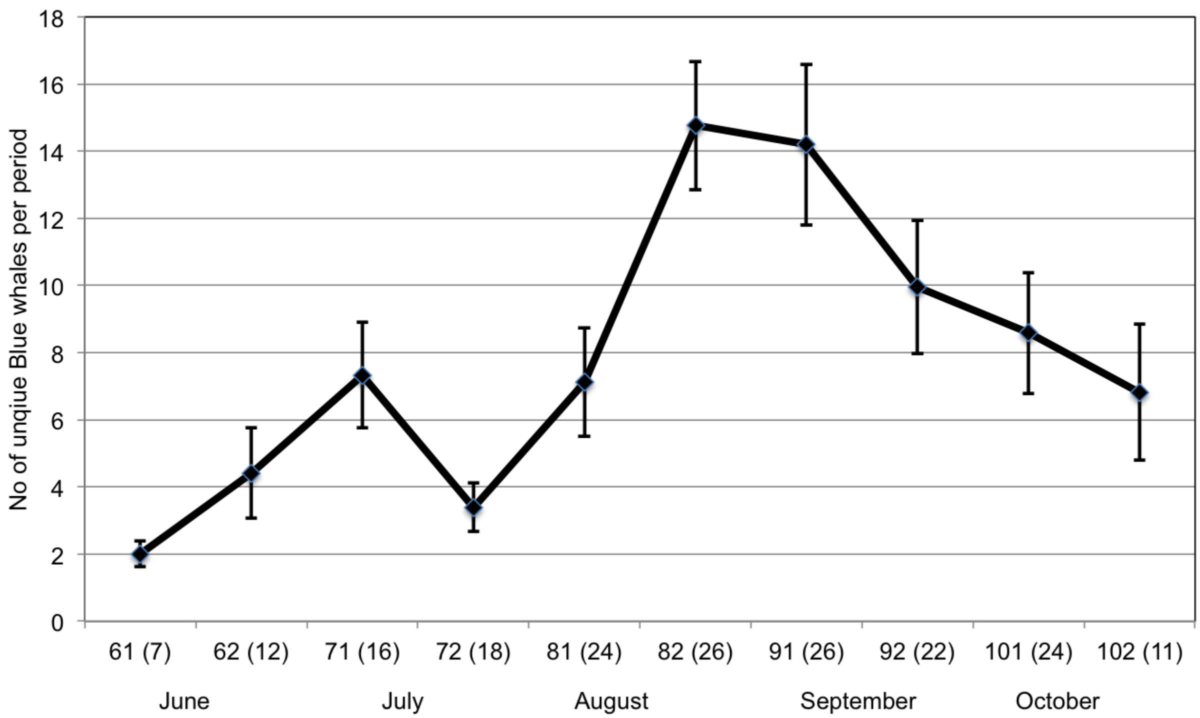

Figure 27. Number of unique blue whales (with SE) per half-month period averaged over the study period 1980-2008.

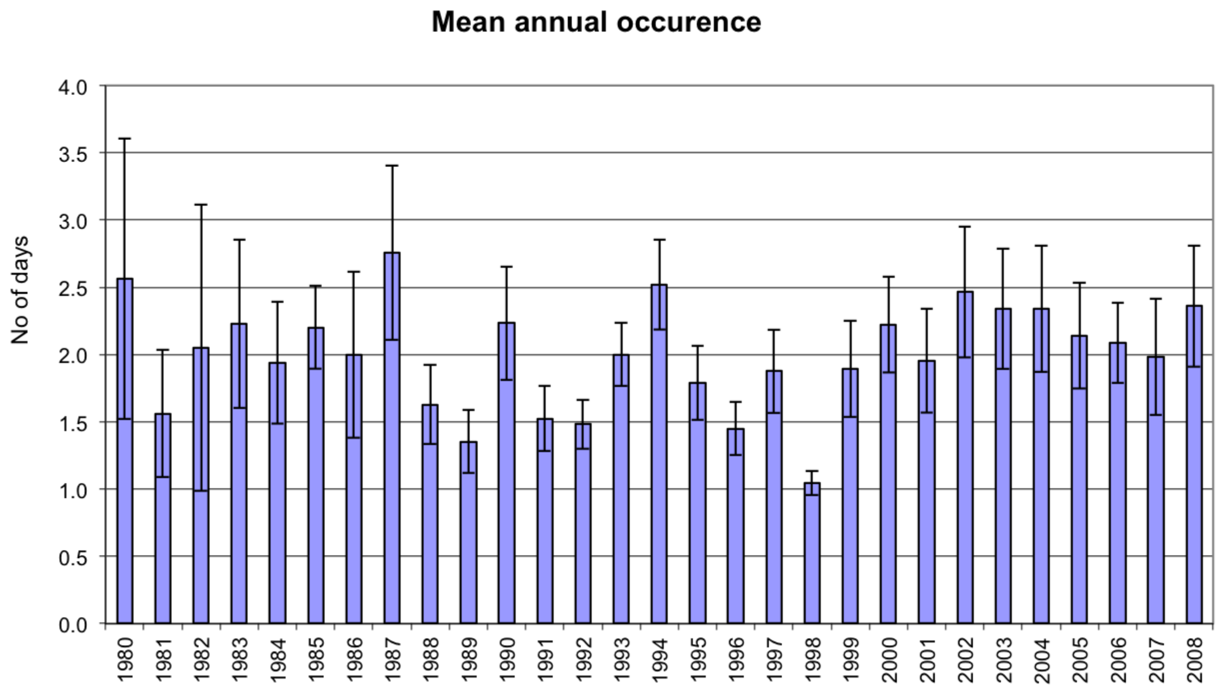

Figure 28. Mean annual occurrence (with SE) of individual blue whales in the Gulf of St. Lawrence (GSL).

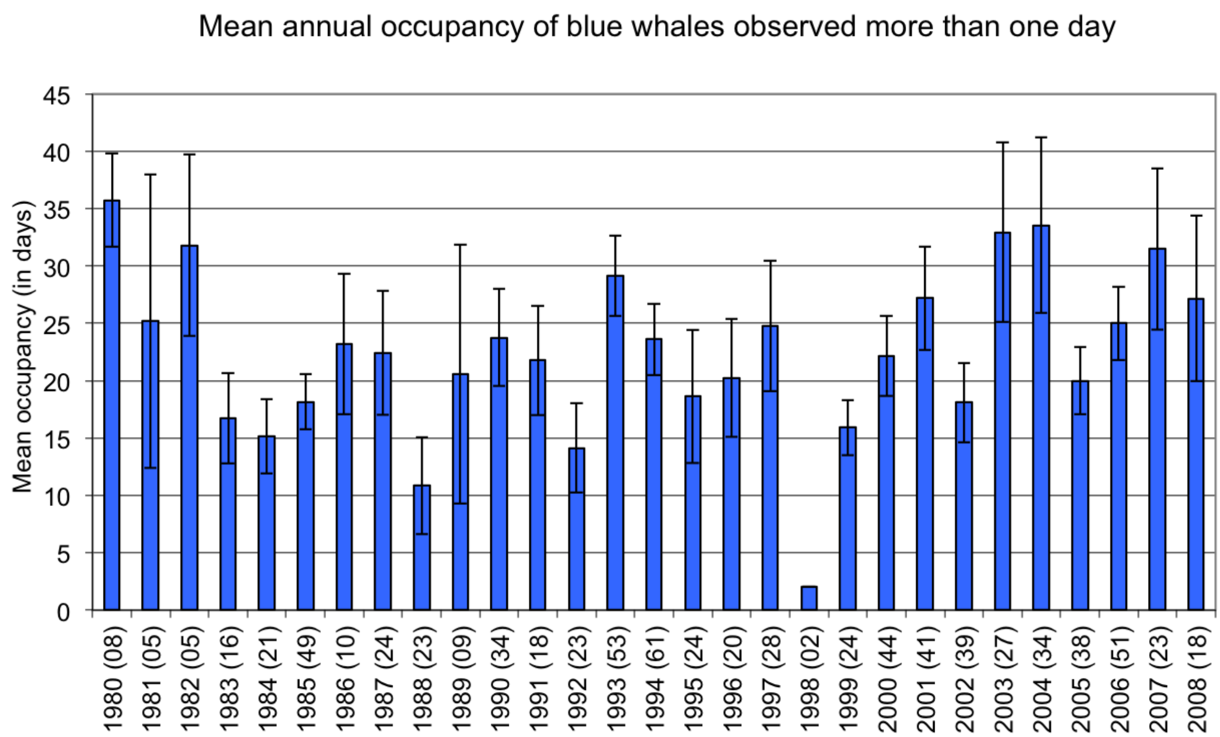

Figure 29. Annual occupancy (with SE) of identified blue whales with an occurrence of greater than 1 day. Sample size is in parenthesis.

Table 1. Blue whale sightings in the Estuary from 2000-2008. The second column shows the number of first sightings. The next column shows the number of unique individuals involved in these sightings. The next columns show the number of observation days and the survey effort. The ratio first sightings per km survey gives an indication about the encounter rate over the years. The last column shows the number of unique animals sighted in the Estuary, including the ones without positions (opportunistic sightings).

Year	MICS first sightings	Bm ID's	No of observation days	Survey effort in km	First sighting per km	Total Bm
2000	158	36	32	2,492	0.0634	55
2001	164	69	62	3,239	0.0506	70
2002	119	39	20	1,423	0.0836	43
2003	45	31	16	1,066	0.0422	38
2004	54	39	18	1,067	0.0506	51
2005	99	40	25	1,917	0.0516	49
2006	30	26	15	1,179	0.0254	42
2007	27	16	10	762	0.0354	19
2008	10	9	5	464	0.0215	9
Total	706	305	203			

Table 2. Blue whale sightings along the Gaspé Peninsula in 2000-2008 (no data 2001). The second column shows the number of first sightings (Figure15). The next column shows the number of unique individuals involved in these sightings. The next columns show the number of observation days and the survey effort. The 6th column shows the ratio first sightings/km surveyed. The last column shows the number of unique animals sighted in the Estuary, including the ones without positions (opportunistic sightings).

Year	MICS first sightings	Bm ID's	No of observation days	Survey effort in km	First sighting per km	Total Bm
2000	31	22	11	580	0.0534	22
2002	6	6	7	369	0.0136	7
2003	3	1	6	513	0.0058	12
2004	11	8	5	415	0.0265	17
2005	22	21	4	214	0.1028	26
2006	116	56	36	1,808	0.0642	57
2007	24	13	13	963	0.0249	34
2008	32	19	17	1,434	0.0223	27
Total	245	146	99			

Appendix 1. The number of blue whale first sightings and total on-effort observation days for the Gulf of St. Lawrence per year and region. Values include both MICS and opportunistic data.

	Number of First Sightings					**Total Effort Observation Days**				
Year	Estuary	Mingan	Gaspé	SIPM	**Total**	Estuary	Mingan	Gaspé	SIPM	**Total**
1980		23			23	2	23		0	25
1981		17			17	3	25		6	34
1982	1	23			24	11	23	6	9	49
1983	8	45			53	14	61		4	79
1984	25	43		12	80	10	64	2	13	89
1985	65	44			109	42	82	1	2	127
1986	8	26			34	18	87	1	9	115
1987	10	67		2	79	16	68		5	89
1988	0	22		40	62	14	75	11	8	108
1989	0	26		6	32	5	83	1	11	100
1990	4	55		14	73	25	78		3	106
1991	3	5	1	8	17	26	79	3	4	112
1992	39	30	6		75	31	97	12	3	143
1993	114	8	26		148	46	83	21	2	152
1994	46	5	8	41	100	54	73	34	5	166
1995	54	3	6		63	26	89	10	0	125
1996	30	11	4	16	61	12	88	8	3	111
1997	73	0	27	14	114	29	89	22	6	146
1998	0	3	3	3	9	9	81	28	6	124
1999	91				91	32	59	3	2	96
2000	161	3	25	17	206	53	63	13	12	141
2001	177	23		3	203	76	68	8	10	162
2002	125	15	6	9	155	31	57	7	12	107
2003	89	1	3	4	97	52	71	9	13	145
2004	77		8		85	55	61	9	11	136
2005	105	1	21		127	37	59	9	7	112
2006	45	11	103	11	170	40	64	45	9	158
2007	32		37	2	71	22	49	46	5	122
2008	10		89	2	101	24	44	73	2	143
Total	1392	510	373	204	2479	815	1943	382	182	3322