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Distribution and Preliminary Abundance Estimates for Cetaceans Seen During Canada's Marine Megafauna Survey - A Component of the 2007 TNASS

Répartition et estimations préliminaires de l'abondance des cétacés vus lors du relevé de la mégafaune marine du Canada - un élément de l'édition 2007 du TNASS

Jack W. Lawson[1] and Jean-François Gosselin[2]

[1] Science Branch
Department of Fisheries and Oceans
PO Box 5667
St. John's, NL A1C 5X1

[2] Maurice-Lamontagne Institute
Department of Fisheries and Oceans
PO Box 1000
Mont-Joli, Quebec G5H 3Z4

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ABSTRACT

The Canadian Department of Fisheries and Oceans (DFO) conducted a large-scale aerial survey of marine megafauna in the northwest Atlantic during the summer of 2007. This is the first systematic effort to provide coverage for much of the eastern Canadian seaboard, and the first in more than two decades to survey the continental shelf along the Labrador and Newfoundland coasts for marine mammals, sea turtles, and other species that intermittently reside near the surface. The Canadian survey is a component of the multinational Trans North Atlantic Sightings Survey (TNASS) that extends from the northeastern U.S.A. to the U.K. The Canadian survey included three initiatives that covered different geographic areas: 1) Labrador Shelf and Grand Banks, 2) Gulf of St. Lawrence and 3) Scotian Shelf. Using a deHavilland Twin Otter and two Cessna 337 Skymaster aircraft, and multiple trained observers, we flew transects at altitudes of 183 and 198 m, respectively, to gather data on the distribution and abundance of a variety of marine megafauna at the ocean surface. Using Distance-based analytical techniques, with covariates such as group size, sighting cue, depth, sea state and sea surface temperature (collected in real time from the Twin Otter), we estimated the abundance and distribution of mysticete species such as blue, fin, humpback, and minke whales, as well as large (sperm, pilot and killer whales) and small (white-beaked, common and Atlantic white-sided dolphins, and harbour porpoises) odontocetes, leatherback sea turtles, sunfish, and basking sharks. Here we present the cetacean data, uncorrected for perception and availability biases. The most abundant species was the common dolphin (54,625; 95% CI: 35,179-81,773), with lower numbers of other small cetaceans (e.g., Atlantic white-sided dolphin: 5,796; 95% CI: 2,261-13,088, and harbour porpoise: 4,955; 95% CI: 2,254-8,971). Pilot whales were the most abundant medium-sized species (5,612; 95% CI: 3,020-10,867), while there were an estimated 2,149 humpback (95% CI: 1,347-3,169), and 1,360 fin whales (95% CI: 825-2,241). These abundance estimates are negatively biased due to the lack of correction factors for availability and perception biases. Once corrected, the results will be integrated with concurrent data from other international components of the TNASS to produce the first estimate of abundance in the North Atlantic. These data will greatly improve our understanding of marine populations whose summer home ranges extend across international boundaries and improve our ability to provide advice for these species within Canada.

RÉSUMÉ

Le ministère des Pêches et des Océans (MPO) du Canada a effectué au courant de l'été 2007 un relevé aérien à grande échelle de la mégafaune marine dans le nord-ouest de l'Atlantique. Il s'agit du premier travail systématique en vue de couvrir une grande partie du littoral maritime de l'est du Canada. Il s'agit aussi du premier relevé de la plate-forme continentale le long des côtes de Terre-Neuve-et-Labrador qui est effectué depuis plus de deux décennies en ce qui concerne les mammifères marins, les tortues de mer et les autres espèces qui résident de façon intermittente près de la surface. Le relevé canadien constitue un élément du Trans North Atlantic Sightings Survey (TNASS) multinational qui s'étend du nord-est des États-Unis jusqu'au Royaume-Uni. Le relevé canadien consistait en trois initiatives qui couvraient diverses régions géographiques : 1) le plateau continental du Labrador et Les Grands Bancs de Terre-Neuve, 2) le golfe du Saint-Laurent, et 3) le plateau néo-écossais. À bord d'un avion deHavilland Twin Otter et de deux avions Cessna 337 Skymaster, accompagnés de plusieurs observateurs formés, nous avons survolé des transects à des altitudes de 183 m et de 198 m, respectivement, afin de recueillir des données sur la répartition et l'abondance de diffèrentes espèces de la mégafaune marine à la surface de l'océan. Par des techniques d'analyse fondées sur la distance, avec des covariables comme la taille des groupes, l'objet détecté, la profondeur, l'état de la mer et la température de la surface de la mer (indiquée en temps réel par le Twin Otter), nous avons estimé l'abondance et la répartition des espèces mysticètes comme le rorqual bleu, le rorqual commun, le rorqual à bosse et le petit rorqual, ainsi que des gros odontocètes (grand cachalot, globicéphale et épaulard) et des petits odontocètes (dauphin à nez blanc, dauphin commun, dauphin à flancs blancs et marsouin commun), de la tortue luth, du poisson-lune et du requin-pèlerin. Nous présentons ici les données sur les cétacés, non corrigées pour les biais de détection et de disponibilité. Les espèces les plus abondantes étaient le dauphin commun (54 625; IC de 95 % : 35 179-81 773), avec un nombre moins élevé pour les autres petits cétacés (p. ex., dauphin à flancs blancs : 5 796; IC de 95 % : 2 261-13 088 et marsouin commun : 4 955; IC de 95 % : 2 254-8 971). Les globicéphales étaient l'espèce de taille moyenne la plus abondante (5 612; IC de 95 % : 3 020-10 867), tandis qu'on a estimé à 2 149 le nombre de rorquals à bosse (IC de 95 % : 1 347-3 169) et à 1 360 celui des rorquals communs (IC de 95 % : 825-2 241). Il y a un biais négatif pour ces estimations de l'abondance en raison du manque de facteurs de correction pour les biais de disponibilité et de détection. Une fois corrigés, les résultats seront intégrés avec les données concurrentes provenant des autres éléments internationaux du TNASS afin de donner les premières estimations de l'abondance dans l'Atlantique Nord. Ces données amélioreront considérablement notre compréhension des populations marines dont le domaine vital pendant l'été dépasse les frontières internationales et permettront d'améliorer notre capacité à donner des avis pour ces espèces au Canada.

INTRODUCTION

Two of the key types of information needed to assess the status and risks to marine fauna under DFO jurisdiction are reliable measures of abundance and distribution. While DFO has conducted relatively small-scale aerial surveys of nearshore areas in Atlantic Canada (e.g., Gulf of St. Lawrence surveys dating back 10 years (Kingsley and Reeves 1998), and SARCEP-funded aerial surveys in 2002 and 2003), better coverage was needed – particularly in offshore waters and during the time of year when a number of species of interest to DFO (e.g., blue whales, beluga whales, harbour porpoise, and leatherback turtles) should be at their most numerous. For populations with ranges extending over wide areas of the north Atlantic, evaluation of status and resulting management decisions within DFO jurisdictions would also benefit from a more comprehensive and synoptic study extending beyond Canada's borders.

Such an approach has been utilized by a number of European countries to cover much of the central and northeast Atlantic. The North Atlantic Sightings Surveys (NASS) were co-ordinated international surveys carried out using aircraft and vessel platforms (e.g., Sigurjónsson et al. 1991, Buckland et al. 1992). These large-scale surveys were designed to provide updated data for use in the continued monitoring and assessment of the distribution and abundance of whale stocks and other megafauna. NASS surveys were carried out in 1987, 1989, 1995 and 2001, but have suffered a lack of completeness for the north Atlantic area by not having coverage in adjacent Canadian waters.

The discontinuity is all the more striking since the National Marine Fisheries Service (NMFS) in the United States also conducted complementary surveys to the south of Atlantic Canada at the same time as the NASS (e.g., Palka 2000). Further effort to the southeast of the NASS studies in 2007 was a large-scale vessel and aerial survey, the Cetacean Offshore Distribution and Abundance (CODA) survey, of the western European shelf.

The DFO aerial survey yielded new data that will be integrated with the European and American surveys to provide coverage for virtually the entire north Atlantic - in particular the Scotian Shelf and Grand Banks - with data extending far to the north. Canada has been asked a number of times to participate in these multinational surveys and 2007 provided an excellent opportunity to do this. One of the goals of the resultant Trans North Atlantic Sightings Survey (TNASS) is to estimate the abundance of cetacean populations in the entire north Atlantic from survey data collected during the summer of 2007. It will add to the long-term series of international NASS. After the completion of TNASS in 2007, the NASS-TNASS series will have occurred over a time period of 20 years, which provides a realistic opportunity for detecting changes in abundance over time.

As part of the TNASS effort, we conducted aerial surveys to estimate the distribution and abundance of marine megafauna in Atlantic Canadian waters. The study area extended from Cape Chidley, northern Labrador, down to the Scotian Shelf to meet a similar U.S. effort extending north into the Bay of Fundy. The Canadian components of the TNASS provided full coverage of the Atlantic Canadian coast for the first time, covering areas of the eastern coast of Canada that have not been surveyed completely in earlier surveys, or in some cases, at all. This document provides an overview of what was accomplished during the survey, and results for the analyses of cetacean sightings data.

METHODS

SURVEY PLANNING AND PLATFORMS

The TNASS was planned under the auspices of the Scientific Committee of NAMMCO in a series of several meetings between 2005 and 2007. To maintain consistency with surveys in other areas in the western Atlantic, it was decided that the survey methodology of the Canadian survey would remain as similar as possible to that used previously in Canada, and the adjacent U.S. NOAA survey area (e.g., Palka 2005).

For logistical reasons, aircraft used and observer arrangements differed between the Newfoundland and Labrador (NL), Cape Breton (CB), Gulf of St. Lawrence (Gulf), and Scotian Shelf (SS) survey areas. A single DeHavilland DH-6 Twin Otter 300 was used in the NL survey, while two Cessna Skymaster 337s, were flown simultaneously in the CB, Gulf, and SS surveys.

The Otter had two forward bubble side windows immediately behind the cockpit bulkhead, plus a bubble door window on the right rear. Observers were acoustically and visually isolated from each other, with the fourth DFO team member acting as navigator and data recorder in an intermediate position with control over what audio channel each observer could hear. The Skymasters had one observer at the left rear bubble window, a second in the right front seat next to the pilot that was also acting as a navigator. Both types of aircraft had twin engines and high-wings, with the Skymaster having retractable landing gear.

OBSERVER TRAINING

All observers were highly-experienced, and had participated in training and practice aerial and shipboard surveys prior to the TNASS effort. The pilots in each aircraft were also experienced in operations at low altitudes and over water.

The NL survey flight crew was trained the previous fall and spring during preliminary flight trials around Newfoundland using the Twin Otter aircraft and planned survey equipment. The observers were able to fly for several days during each trial using the planned survey protocols, and improvements to the methodology resulted (e.g., during the TNASS each observer had a USB keypad to trigger automatic entry of a sighting record on the data recorder’s laptop computer). The Skymaster teams consisted of two observers, including one in each plane that had previous experience gained during beluga surveys using the same aircraft and methodology. Both teams conducted a single day of flight familiarization prior to the TNASS effort by conducting 700 km of survey effort in the estuary of the St. Lawrence River as part of a beluga whale survey.

TARGET SPECIES

All aquatic megafauna species encountered were recorded, although in the NL survey area pinnipeds sightings were rarely recorded as they were infrequent, and their abundance had been estimated previously using other means by DFO. Sightings of marine megafauna included whales, dolphins, porpoises, seals, sea turtles, large sharks, tuna, and other species. In this paper we present the results for cetaceans only.

TRANSECT DESIGN, DATA COLLECTION, AND ANALYTICAL METHODS

The abundance of marine megafauna in Newfoundland and Labrador was estimated for three different strata extending out to the edge of the continental shelf: the south coast, the east and north coasts of Newfoundland, and Labrador (Fig. 1). Using the boundaries of the desired survey strata and the survey effort to be apportioned to each, the Distance programme (Distance 5.0 Release 2; Thomas et al. 2006) was used to design a line transect survey in which the transects were oriented across bathymetry gradients. Greater effort was allocated to the southern stratum of the NL survey since higher densities were recorded during previous aerial surveys of this area (Lawson and Gosselin 2003; Lawson unpubl. data).

The NL portion of the TNASS was conducted in an equal-angle, zigzag pattern[1], with no spatial overlap with the TNASS components of Cape Breton, the Gulf of St. Lawrence, and the Scotian Shelf, discussed below (Fig. 1). The Otter aircraft completed 23,361 km of on-effort trackline. The observers noted weather conditions (sea state, glare from the sun, cloud cover) and sightings of marine megafauna. These sightings were recorded using a specialized software programme (VOR) operated by a fourth observer acting as data recorder and navigator. Observers rotated positions at the ends of transect lines, or at proximately 30-min intervals during approximately half of the long transects. The Twin Otter flew at an altitude of 183 m (600 ft), as determined with a radar altimeter aboard the aircraft, and monitored by the flight crew and the DFO navigator, and groundspeed of 204 km/h (110 kt). Aircraft position, obtained from a GPS receiver, was recorded automatically every 2 s. The distance of each sighting from the trackline was derived using angle measurements from an inclinometer (Suunto) when the sighting locations of individuals or groups were passing abeam.

Around Cape Breton, in the Gulf of St. Lawrence, and on the Scotian Shelf the survey transects were arranged in parallel (Figs. 1 and 2). Stratification was based on the areas where concentrations of marine mammals had been detected in previous surveys and so that these areas could be covered in the shortest time period. Lines in the St. Lawrence estuary (SLE) from Rimouski to Île-aux-Coudres were 4 nmi apart and perpendicular to the main axis of the estuary, similar to previous visual surveys for belugas in the area. All remaining lines were 10 nmi apart and arranged to be generally perpendicular to the isobaths (Fig. 2). The design had a total of 23,443 km of lines, including 9,111 km over the Scotian Shelf. The two Skymaster aircraft flew alternating lines of the systematic design, except in the SLE where they flew the same transects in an in-line configuration, separated by 0.5-7.8 km (9 s to 2.4 min flying time). Two observers recorded conditions (sea state, glare intensity from the sun, subjective visibility) and sightings on audio tape recorders. Aircraft flew at a target altitude of 198 m (650 ft) and airspeed of 185 km/h (100 kt). Aircraft position and altitude from the GPS was recorded every 10 sec with electronic map software (Fugawi). The GPS altitude output was used in the estimation of the perpendicular distance (note: average difference between GPS altitude reading in the aircraft and actual airport elevation was 1.7 m (n=637, SD=7.4 m, max=36.7 m). Distance of sightings from the trackline was derived using angle measurements from an inclinometer (Suunto) as individuals or groups were passing abeam.

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Line transect density and abundance analyses were completed using the programme Distance 5.0 (Thomas et al. 2006). Distant sighting outliers were right-truncated using the approach

[1] This design was modified in two locations on the Labrador coast to accommodate range limitations of the Twin Otter aircraft.

recommended in Buckland et al. (2001) whereby approximately 15% of the most distant sightings were omitted from further analyses. Model selection and inclusion of covariates followed the stepwise procedure of Marques and Buckland (2003). The detection function was fitted a) without considering model covariates to investigate sighting distance variation and other data qualities, and b) considering model covariates such as stratum, weather conditions, observer, and sighting cue. Half-normal, hazard-rate, or uniform models without adjustment terms were fitted to the truncated distribution of sightings for each species or species groups and the best model was selected using AICc. Using the best key function from the global distribution of pooled sightings for a given species or group of species, we examined the effect of sea surface temperature, water depth, group size, observers (four levels), and three variables of conditions that are correlated and therefore examined separately {i.e., sea state (Beaufort = 0 to 4 in 0.2 increments), glare intensity (none; light; moderate; severe), sightability (poor, moderate, good, excellent)} as covariates for deriving the best detection function (Buckland et al. 2004, Marques and Buckland 2003, Marques et al. 2007). The three variables of sea state, glare intensity, and visibility are correlated and therefore were never combined in a model. The overall density in the northeastern and southern survey areas was estimated as the mean density of the strata weighted by stratum area. The density and abundance indices, variance, and confidence intervals were estimated empirically when the key function was the selected model and using bootstrapping when a model with covariate was selected.

GULF AND SCOTIAN SHELF

The probability of detection under the plane and near the trackline is limited by the position of the observers and the window's lower edge. The overall distribution of perpendicular distances was examined and the closest perpendicular distance showing a marked increase in frequency of detected sighting was chosen as the close truncation distance for the estimation of the detection function (i.e., left truncation). The truncation to the distant end of the distribution of perpendicular distances (i.e., right truncation) was limited to distant outliers. The distance of the outermost sighting kept for detection function estimation rounded up to the nearest meter was used as the value for right truncation (*w*). Model selection and inclusion of covariates followed the stepwise procedure of Marques and Buckland (2003). Half-normal or hazard-rate models without adjustment terms were fitted to the truncated distribution of ungrouped perpendicular distances of sightings for each species or species groups and the model with the lowest AICc was selected as key function. Using the selected key function, we examined, as the next step, if AICc could be reduced further by the addition of one of the following covariates: group size, observers (four levels), planes (two levels), sea state (Beaufort = 0 to 4), glare intensity (none; unlikely reducing visibility; likely reducing visibility; intense) and visibility (excellent; good, fair; reduced). If AICc was reduced by the addition of the covariate, less than 5% of the estimated probabilities of detection of sightings were less than 0.2 and none were less than 0.1, then the model with the additional covariate was retained. Models with additional covariates were selected in subsequent steps if the addition of a covariate further reduced AICc and if the conditions of estimated probabilities of detection of sightings were respected. The three variables of sea state, glare intensity, and visibility are correlated and therefore were never combined in a model.

The group size of sightings for each species in each geographic stratum was estimated using the size bias regression method of the natural logarithm of group size [i.e., $\ln(s)$] against the detection function value [$g(x)$], or using the mean cluster size when the regression was not significant (p>0.15). In the St. Lawrence estuary where each transect was surveyed by the two airplanes within minutes from each other, the encounter rate was estimated using the addition of the counts of the two planes on twice the transect length. This facilitated maintaining the transect, and not the passage of each plane, as the sampling unit. The overall density in the Gulf and on the Scotian Shelf was estimated as the mean density of strata weighted by stratum area. The density and abundance indices, variance and confidence interval were estimated empirically when the key function was the selected model and using bootstrapping when a model with covariate was selected.

On the final day of the survey, all three aircraft flew in an in-line formation along a pair of transects on the south coast of Newfoundland. The two Skymaster aircraft followed the Twin Otter along the lines as closely as possible (within a kilometre) and at their previous survey altitudes. Observers recorded sightings as they had during the surveys and these data were compared in an effort to investigate whether there were differences in the detection qualities of the two aircraft types. However, it was difficult to maintain the formation due to crosswinds and wake turbulence from the Otter. It was also difficult for the observers in the Skymasters to estimate declination values due to the increased instability of the Skymasters when following the Otter.

National Oceanographic and Atmospheric Administration (NOAA) personnel conducted concurrent aerial and shipboard surveys as far north as the Canadian side of the Bay of Fundy, but these cetacean abundance estimates are not yet available for inclusion in the results of the Canadian TNASS (D. Palka, NOAA, pers. comm.).

SEA SURFACE TEMPERATURE DATA

An electronic temperature probe mounted in the belly of the Twin Otter aircraft recorded sea surface temperature data into the survey programme every two seconds (with data averaged from samples taken at 300 ms intervals by the probe, and output to the nearest degree C). Sea surface temperature readings ranged between 4°C and 14°C, and were validated against same-day POES satellite data in the NL region of the survey. The temperature probe system was calibrated before and after the survey using a known heat source in the laboratory and found to be within specifications for the device (model IX-6B15RS2, Linear Laboratories).

RESULTS

NEWFOUNDLAND AND LABRADOR

Effort

Most of the planned transect lines were flown (realized coverage was 84% of the original planned amount; Tables 1 and 2), and most in good to very good sea states and sightability conditions (Fig. 1), with effort conducted from 17 July to 24 August, 2007. During the survey, several modifications to the Distance-based survey design were required for logistical purposes. Primarily, we had to reduce survey coverage in several areas off the Labrador coast and off the Newfoundland southeast coast due to range limitations of the aircraft. Transect lines were re-drawn to maximize coverage while staying within operational limits. For example, the north-south orientation of the southeast coast offshore transects was changed to west-east to allow the team to cover more of the offshore areas than originally planned while on effort, rather than transiting off-effort.

Sightings

While on effort, we recorded 710 non-replicate sightings of 18 species totalling almost 4,000 individual animals (Tables 3 and 4; Fig. 1). Of these, most (n=584 sightings; n=3,691 individuals) were cetaceans. The most commonly-sighted cetacean was the humpback whale, with relatively large numbers of sightings of Atlantic white-sided dolphins, fin whales, and white-beaked dolphins.

Most sightings, and a higher sighting rate, occurred during the southern stratum of the survey area, with relatively few (n=19 sightings) along the Labrador coast (Tables 3 and 4; Fig. 1). More sightings were made during the latter part of the survey, even when adjusted for the increased effort on the south coast stratum flown towards the end of the survey period.

Abundance Estimates

Abundance estimates for the most commonly-sighted species in the Newfoundland and Labrador survey strata were obtained with Distance, with truncation and detection functions chosen to minimize AIC values (Table 5, Figs. 3 and 4). Too few sightings were made in the Labrador stratum to obtain reliable abundance estimates. Examination of the distribution of sightings showed that the probability of detection decreased from the trackline, but that sightings were made directly below the aircraft as facilitated by the large bubble windows and the rear bubble door. Thus left truncation was used only in (rare) cases where there was a significant reduction in the proportion of sightings immediately adjacent to the trackline for estimation of detection curves. Right truncation was applied when outlier values were present.

The cetacean most commonly encountered during the NL portion of the survey was the humpback whale with 144 sighting events (Table 3). These provided a combined abundance estimate of 1,427 (95% CI: 952-2,140; Table 6). Minke whales, with a combined abundance estimate of 1,315 (95% CI: 855-2,046), were sighted in all of the NL strata. No obvious mother-calf pairs were seen amongst the 53 minke whales encountered, as most were seen alone. Fin whales, with a combined abundance estimate of 890 (95% CI: 551-1,435), were sighted in the all of the NL strata as well. Only two mother-calf pairs were seen amongst the 98 fin whales encountered. Relatively few small cetaceans were sighted in the NL strata, despite good sighting conditions and much effort.

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Effort

Coverage was extremely good over this survey area (Figs. 1 and 2, Tables 1 and 2), with effort conducted from 21 July to 23 August, 2007. All of the 23,443 km of lines of the design were flown, including 9,111 km over the Scotian Shelf. Most of the lines were also surveyed in good to very good sea states and sightability conditions (average recorded Beaufort of 1.8).

Sightings

The two Skymaster teams reported more than 1,706 sightings, of 28 identified species, including 20 species of cetaceans and three species of seals. The Scotian Shelf evidenced a higher diversity (27 species) and higher encounter rate (0.13 sighting/km) than the Gulf (16 species, 0.04 sightings/km). The St. Lawrence estuary is the only stratum within the Gulf that provided a higher encounter rate value (0.14 sightings/km) than the Scotian Shelf, primarily due to the presence of belugas (0.13 sighting/km). In this document, detailed abundance results are only presented for the 20 species of cetaceans (Tables 7 and 8).

Abundance Estimates

Examination of the overall distribution of sightings showed that the probability of detection increased rapidly 70 m away from the trackline, then remained stable and decreased further away (e.g., Fig. 5). This value was used as the left truncation value for estimation of detection curves for all species. Only distant outliers were truncated for each species or species group which provided distant truncation (i.e., right truncation) that varied from 434 m for harbour porpoise (1 sighting) to 2,616 m for beluga (3 sightings). There was no right truncation applied to perpendicular distances of fin whales, humpback whales, and common dolphins.

Estimates of abundance were only presented for species with more than 20 sightings. Results from the fitting of key functions and some covariates providing the lower AICc are presented in Table 9. For seven of the ten species or species group the key function was amongst the three models with the lowest AICc (Table 9).

Common dolphins were the most abundant species with 200 sightings (2,985 individuals) made on the Scotian Shelf and along the outer part of the shelf to provide an abundance of 54,000 (95% CI: 35,000-82,000) without considering availability or perception corrections (Table 10). This is nine times higher than the estimate of 5,729 (95% CI: 3,020-10,867) for pilot whales and ten times the estimate of 5,354 (95% CI: 2,180-8,777) for white sided dolphin the second and third most abundant species of cetaceans in the area. Pilot whales were also detected along the outer part of the shelf, the Laurentian channel and in the Cape Breton through. White-sided dolphins were detected on the Scotian Shelf and in the eastern part of the Gulf, similarly for harbour porpoise that were detected closer to shore on the Scotian Shelf and further west in the Gulf. White-beaked dolphins were sighted north of Sable Island in the Laurentian channel in Cabot Strait but mostly in the Belle Isle Strait. Eight groups of killer whales were all sighted on the Scotian Shelf.

The minke whale was the most abundant rorqual, with an estimated abundance on the Scotian Shelf of 1,526 95% CI: 1,021-2,279). Abundance of fin whales and humpback whales were almost similar on the Scotian Shelf with estimates for the stratum of 442 (95%CI: 255-769) and 434 (95% CI: 366-531), respectively. However, only six fin whales, the same number as blue whales, were detected in the Gulf.

The estimated abundance of beluga whales in the Gulf during this survey was 893 whales (CV=0.24, 95% CI: 520-1,143), derived from the 203 sightings. The beluga was the second most commonly sighted cetacean in the Gulf and Scotian Shelf strata after unknown dolphins (Table 7).

SUMMARY FOR CANADIAN TNASS SURVEY AREA

Abundance Estimates

Twenty cetacean species were sighted during the Canadian component of the TNASS, with the most common being dolphins (common dolphin: 53,625 [95% CI: 35,179-81,773], unknown dolphin sp.: 34,462 [95% CI: 20,560-57,862], along with 6,134 pilot whales (95% CI: 2,774-10,573), 3,242 minke whales (95% CI: 2,051-4,845), 2,080 humpback whales (95% CI: 1,337-3,172), and 1,352 fin whales (95% CI: 821-2,226) (Table 11).

None of these estimates have been corrected for perception or availability biases inherent in aerial survey studies.

DISCUSSION

OVERALL CONCLUSIONS

The large-scale DFO aerial survey of marine megafauna in the northwest Atlantic in the summer of 2007 was extremely successful from logistical and results perspectives. Since this is the first systematic effort of this extent to provide coverage for much of the eastern Canadian seaboard, this new information will greatly improve our understanding of those marine populations whose summer home ranges extend across the north Atlantic.

The vast survey areas covered in the Canadian portion of the TNASS required multiple survey platforms (Twin Otter and Cessna 337 aircraft), and multiple trained observers, so combining data from all survey effort requires care. In particular, there are platform- and observer-based differences in fauna detectability for which we have partly accounted for during the Distance modelling process.

Twenty cetacean species were sighted in the Canadian portion of the TNASS survey area, with the most common being dolphins, and humpback, minke, fin, and (in the Gulf) beluga whales. Given that the survey conditions were generally good, and species as cryptic as sunfish and sharks were sighted, it is unlikely that we missed sighting any species present in the survey areas.

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The abundance estimates for the smaller cetaceans, such as the common dolphin (n=576) and harbour porpoise (n=1,195), are much lower than those from nearshore surveys carried out in 2002-03 (Lawson and Gosselin 2003). While the current estimates will increase following the application of correction factors for perception and detectability biases, it is likely the estimates will still be lower than previous. At this stage we are not sure why this might be, but it appears (based on reports from fisheries officers, fishermen, and tour boat operators) that marine fauna were later arriving in the survey area than in previous years. For instance, relatively fewer cetaceans were sightings during the early survey effort on the Labrador Shelf, despite very good sighting conditions, than were reported by colleagues working on the south coast of the island at the same time.

Further evidence comes from the fact that more marine mammal sightings were made later in the survey period than initially; this confounding factor was not due to survey locality as fisheries officers, fishermen, and whale watchers reported a later arrival of marine mammals into the Newfoundland and Labrador regions. Such a delayed arrival of animals into the survey area would explain why the number of sightings in the Labrador stratum was lower than observed during previous surveys by DFO and NGOs (e.g., Hay 1982, McLaren et al. 1982, Sergeant 1966). A much earlier report suggested that fin whales did not arrive on the Labrador coast until mid-July and were most numerous in August (Kellog 1928 in Sergeant 1966) – in 2007 the Labrador stratum had been surveyed prior to this time of year.

CAPE BRETON, GULF OF ST. LAWRENCE, AND SCOTIAN SHELF

There were fewer harbour porpoises in the Gulf than estimated from earlier surveys. The estimate of 3,629 harbour porpoises for both the Gulf and Scotian Shelf in 2007 is much lower than the estimates of 12,100 and 21,720 from partial aerial surveys of the Gulf conducted with similar planes and protocol in 1995 and 1996 (Kingsley and Reeves 1998). The estimate of abundance of fin whales (n=28), minke whales (n=360), and white sided dolphins (n=1,044) in the Gulf in 2007 were all lower than the estimates in 1995 of 380, 1,020 and 11,740 for the respective species. However, surveys in 1995 and 1996 were restricted to the Gulf and the large estimates for the Scotian Shelf in 2007 could account for most of these differences.

Northern right whales were not seen during the effort on the Scotian Shelf, although they do occur within its southern boundary (e.g., Mellinger et al. 2007). As expected given their relatively low abundance in the northwest Atlantic (Sears 2002, Lesage et al. 2007), only 16 blue whales were seen during the entire 2007 Canadian survey.

The 2007 estimate of abundance of beluga whales in the Gulf of 893 (CV=0.24, 95% CI: 520-1,143) is almost equal to the 2003 combined estimate from five visual surveys (n=934, CV=0.11, 95%CI: 749-1,165) which was the highest estimate we had for this population. Note that the observation of single individuals in the north-eastern Gulf (esq) and the Gulf (g) strata only represent bootstrap estimated stratum abundances of 6 and 10, respectively. These are negligible compared to the total estimate or the estimate from the section of the estuary considered to main summer area for belugas in the St. Lawrence (sle) with an abundance for the stratum of 668 (cv=0.27, 95% CI: 3,68-1,050). However, the 17 sightings (27 animals) in the lower estuary stratum (est) provided an important contribution to the 2007 total abundance estimate with a bootstrap stratum abundance of 208 (CV=0.49, 95% CI: 44-428). This suggests that we will have to consider extending the area covered for future beluga surveys in the St. Lawrence estuary.

TOTAL ABUNDANCE OF CETACEANS IN ATLANTIC CANADA

Once we receive the abundance estimates for the aerial and shipboard sightings carried out concurrently by NOAA (D. Palka, Fig. 1) in the Bay of Fundy, we will be able to estimate total abundance of cetaceans in Atlantic Canada.

NEXT STEPS

Data from these surveys will have a significant impact on our understanding of cetaceans, some listed under SARA, in the northwest Atlantic. However, first the estimates will have to be adjusted by incorporating correction factors for detectability biases for the two different survey platforms. This may necessitate an additional tandem trial survey with two Skymasters and a Twin Otter, where platform-related detection biases have not yet been assessed.

If this survey is conducted in the future, Canada should consider using platforms with greater range to cover areas to the edge of the shelf break in Newfoundland on the Grand Banks (e.g., the Flemish Cap), the offshore areas between Canada and Greenland, and further off the Scotian Shelf. This could be possible using a Twin Otter with an additional fuel tank, such as NOAA operates. Additionally, the Department of National Defence's Arcturus patrol aircraft deserves further study as a possible platform for such offshore work, despite its greater airspeed (170 kt) and cost.

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Table 1. Canadian TNASS planned and realized survey effort, subdivided by aircraft type and the three survey blocks.

		Trackline km			Surveyed Area
Survey Platform	**Planned Survey Strata**	**Planned**	**On Effort**	**%**	**km^2**
Twin Otter	Newfoundland & Labrador (3 strata)	23,811	23,361	98.1	741,699
Skymaster 337	Gulf of St. Lawrence (8 strata)	13,696	13,696	100.0	234,832
Skymaster 337	Scotian Shelf and Cape Breton (2 strata)	9,762	9,747	99.8	179,536
	Overall	47,269	46,803	99.0	1,156,067

Table 2. Canadian TNASS planned and realized survey effort (coverage), subdivided by stratum.

Stratum	**Stratum Area (km^2)**	**Trackline Length On Effort (km)**	**Coverage On Effort (km/1000 km^2)**
Labrador (Lab)	239,546	5,363	22
NL East (NLE)	284,415	7,611	27
NL South (NLS)	217,738	10,387	48
St. Lawrence Estuary (SLE)	5,231	1,438	275[a]
Lower Estuary (EST)	6,840	365	53
Northwest Gulf (NW)	22,333	1,226	55
Jacques-Cartier St. (JC)	28,890	1,502	52
Esquiman Channel (ESQ)	42,063	2,244	53
Gulf (G)	72,120	3,883	54
Gulf, east-west lines (EW)	48,134	2,557	53
Northumberland Strait (NS)	9,221	482	52
Cape Breton (CB)	11,791	635	54
Scotian Shelf (SS)	167,745	9,111	54
Overall	1,156,067	46,804	54

[a] These transects were conducted with two Skymasters flying in-line, separated by 0.5-7.8 km.

Table 3. Cetacean sighting events in the Newfoundland and Labrador survey area, subdivided by survey strata. Sightings of pinnipeds (mostly harp seals) and replicate sightings by the paired right side observers are not included.

	Stratum			
Species Name	**Lab**	**NLE**	**NLS**	**Total**
Beluga Whale	4	1		5
Blue Whale		1	3	4
Common Dolphin	2	1	25	28
Fin Whale	1	17	55	73
Harbour Porpoise		1	35	36
Humpback Whale		59	85	144
Killer Whale		1		1
Unk. Large Whale	1		5	6
Minke Whale	4	21	28	53
Northern Bottlenose Whale	1	1	8	10
Pilot Whale	3		7	10
Sei Whale			1	1
Small Whale			2	2
Sperm Whale		2	9	11
Unk. Dolphin	2	8	30	40
White-beaked Dolphin		15	53	68
White-sided Dolphin	1	7	84	92
Total	**19**	**135**	**430**	**584**
Sightings/km^2	**0.0001**	**0.0005**	**0.002**	**0.0008**

Table 4. Total number of individual animals sighted in the Newfoundland and Labrador survey area, subdivided by survey strata. Sightings of pinnipeds (mostly harp seals) and replicate sightings by the paired right side observers are not included.

	Stratum			
Species Name	**Lab**	**NLE**	**NLS**	**Total**
Beluga Whale	89	1		90
Blue Whale		1	5	6
Common Dolphin	16	7	443	466
Fin Whale	1	26	69	96
Harbour Porpoise		1	57	58
Humpback Whale		88	116	204
Killer Whale		1		1
Unk. Large Whale	1		6	7
Minke Whale	4	22	31	57
Northern Bottlenose Whale	1	4	38	43
Pilot Whale	39		65	104
Sei Whale			1	1
Small Whale			2	2
Sperm Whale		2	9	11
Unk. Dolphin	5	32	176	213
White-beaked Dolphin		63	474	537
White-sided Dolphin	4	32	1,759	1,795
Total	**160**	**280**	**3,251**	**3,691**
Animals/km^2	**0.0007**	**0.0010**	**0.0149**	**0.0050**

Table 5. Models from the AIC procedure of Distance 5.0, release 2, for species with more than 20 sightings in the Newfoundland and Labrador survey area. The key function of half-normal (HN) or hazard-rate (HR) that provided the best fit according to AIC was then used to add covariates such as cluster size, sighting cue, observer, flight day, Beaufort, sea surface temperature, intensity of sun glare, and subjective visibility. The effective strip widths (m) were not used to select the model, but illustrate consistency between models. The model with the lowest AIC value was used for density and abundance estimation.

Species	**Model**	**AIC**	**Delta AIC**	**ESW**	**ESW %CV**
Minke Whale	HN+Flyday+SwimDir	635.9	0.0	552	13
	HN+Flyday+SwimDir+Beaufort	638.2	2.3	551	14
	HN+Flyday+SwimDir	639.0	3.1	595	13
Fin Whale	HN+Cue+Flyday+Beaufort	1,058.4	0.0	1,093	16
	HN+Cue+Flyday+Beaufort+Podsize	1,060.4	2.0	1,096	17
	HN+Cue+Flyday	1,070.8	12.4	1,397	13
Humpback Whale	HN+Observer+SwimDir	444.6	0.0	1236	8
	HN+SwimDir	448.4	3.8	1318	7
	HN+Observer	557.7	113.1	1400	7
Harbour Porpoise	HN+SwimDir	117.0	0.0	279	16
	HN+Flyday	117.1	0.1	194	51
	HN	118.1	1.1	275	16
White-beaked Dolphin	HN+SwimDir+Observer	197.5	0.0	426	14
	HN+SwimDir	207.6	10.1	553	11
	HN+SwimDir+Flyday	209.6	12.1	552	11
Common Dolphin	HN+Beaufort	107.3	0.0	600	21
	HN+Podsize	107.4	0.1	604	16
	HN+Flyday	108.3	1.0	573	36
White-sided Dolphin	HN+Sight	16.3	0.0	730	8
	HN+Beaufort+Vis	18.5	2.2	728	15
	HN+Observer	37.4	21.1	713	8
Unk. Dolphin	HN+SwimDir	128.9	0.0	1441	43
	HN+Flyday	168.3	39.4	1102	18
	HN+SST	177.5	48.4	1396	13

Table 6. Estimated density of individuals (D), abundance (N), coefficient of variation (CV) and model degrees of freedom (DF) using the model providing the best fit according to AIC for species with more than 20 sightings in the Newfoundland survey strata. Results were obtained with Distance 5.0, release 2, using multivariate modelling, with truncation and detection functions chosen to maximize Akaike Information Criterion values using all sighting data, then post-stratified. Too few sightings were made in the Labrador stratum (yellow polygon in Fig. 1) to obtain reliable abundance estimates.

Species	**D**	**N**	**%CV**	**95% CI**	**DF**
Minke Whale	0.0024	1,315	22.5	855-2,046	86.8
Fin Whale	0.0037	890	24.5	551-1,435	128.0
Humpback Whale	0.0019	1,427	20.4	952-2,140	104.0
White-sided Dolphin	0.0020	1,507	22.5	968-2,347	64.2
Common Dolphin	0.0010	576	31.2	314-1,056	77.1
White-beaked Dolphin	0.0077	1,842	22.4	1,188-2,854	105.1
Harbour Porpoise	0.0016	1,195	32.2	639-2,235	75.3
Unk. Dolphin	0.0038	276	52.8	102-748	51.7

Table 7. Sighting events subdivided in the Cape Breton, Gulf of St. Lawrence, and Scotian Shelf survey strata, showing the number of animal groups with missing distance or missing cluster size in brackets.

Species	**SLE**	**EST**	**NW**	**JC**	**ESQ**	**G**	**NS**	**EW**	**CB**	**SS**	**Total**
Beluga	184	17			1	1					203
Blue Whale	2				1	1		1	1	4(1)	10(1)
Fin Whale	2			1	1					44	48
Harbour Porpoise		1		3	13	5	2	1		4	29
Humpback Whale	2	2	5		19	2	1	1		51	83
Minke Whale	4	1	1		9	2		6	1	86	110
Pilot Whale								5	2	36(1)	43(1)
White-beaked Dolphin					12(1)				3	2	17(1)
White-sided Dolphin					3	2		8		15	28
Bottlenose Dolphin										8	8
Common Dolphin									2	198(3)	200(3)
Cuvier's Beaked Whale										1	1
Killer Whale										7	7
Mesoplodon sp.										9	9
Northern Bottlenose										3	3
Pygmy Sperm Whale										1	1
Risso's Dolphin									1	5(1)	6(1)
Sei Whale										2	2
Sperm Whale										11	11
Striped Dolphin										1	1
Unk. Dolphin				1(1)	40	15		33(2)	13	192(9)	294(12)
Unk. Large Whale	2		9	2	2	2				68(2)	85(2)
Unk. Small Whale				1				2		12	15
Unk. Beaked Whale										3(1)	3(1)
Total	**196**	**21**	**15**	**8(1)**	**101(1)**	**30**	**3**	**57(2)**	**23**	**763(18)**	**1,217(22)**

Table 8. Total number of individual animals sighted in the Cape Breton, Gulf of St. Lawrence, and Scotian Shelf survey strata.

Species	SLE	EST	NW	JC	ESQ	G	NS	EW	CB	SS	Total
Beluga	426	27			1	1					455
Blue Whale	2				1	1		1	1	5(2)	11(2)
Fin Whale	4			1	1					45	51
Harbour Porpoise		5		10	26	6	5	15		28	95
Humpback Whale	3	2	6		27	2	1	1		73	115
Minke Whale	4	1	1		9	2		6	1	89	113
Pilot Whale								15	9	290(10)	314(10)
White-beaked Dolphin					45(10)				9	26	80
White-sided Dolphin					120	5		34		358	517
Bottlenose Dolphin										35	35
Common Dolphin									11	2,974(112)	2,985(112)
Cuvier's Beaked Whale										1	1
Killer whale										19	19
Mesoplodon sp.										35	35
N. Bottlenose Whale										6	6
Pygmy Sperm Whale										10	10
Risso's Dolphin									14	31(4)	45(4)
Sei Whale										2	2
Sperm Whale										12	12
Striped Dolphin										4	4
Dolphin Sp.				3	136	72	0	99(5)	131	2,303(90)	2,744(95)
Unk. Large Whale	3		14	2	2	2				84(2)	107(2)
Unk. Small Whale				1				5		21	27
Unk. Beaked whale										20(7)	20(7)
Total	**442**	**35**	**21**	**17**	**368(10)**	**91**	**6**	**176(5)**	**176**	**6,471(227)**	**7,803(232)**

Table 9. Results of the stepwise selection of the model with the lowest AICc that was used to estimate density and abundance indices using Distance 5.0 for species with more than 20 sightings in the Gulf of St Lawrence, and Scotian Shelf. The three models with lower AICc are shown with key function between hazard-rate (HR) and half-normal (HN) then used to add covariates such as pod size, plane, observer, sea state (Beaufort), intensity of sun glare (Gla_int), glare coverage (Gla_cov), subjective visibility. The effective strip widths were not used to select the model, but illustrate consistency between models. The model with the lowest AICc was used to estimate density and abundance, except for white-sided dolphin where the half-normal model was used.

Species **Right truncation (m)**	**Model**	**AIC**	**Delta AIC**	**ESW**	**ESW %CV**
Beluga	HR+Observer	3044.71	0.00	1277	6
2616	HR+Observer+Beaufort	3046.59	1.88	1271	6
	HR+Observer+Visibility	3048.24	3.53	1257	6
Common Dolphin	HR	2615.25	0.00	505	7
None	HR+Plane	2616.15	0.90	486	6
	HR+Observer	2617.51	2.26	477	6
Fin Whale	HR	698.06	0.00	953	18
None	HN	698.74	0.68	914	12
	HR+Beaufort	700.14	2.08	968	10
Harbour Porpoise	HR+Podsize	316.81	0.00	214	15
434	HR+Podsize+Beaufort	318.48	1.67	216	15
	HR+Podsize+Plane	318.67	1.87	220	14
Humpback Whale	HR+Observer	1321.77	0.00	1596	10
None	HR	1324.49	2.72	1253	21
	HR+Beaufort	1324.95	3.18	1573	9
Minke Whale	HR+Glare_cov	1354.88	0.00	483	7
812	HR	1355.39	0.51	509	9
	HN	1355.46	0.58	441	10
Pilot Whale	HN+Gla_cov	520.77	0.00	463	12
987	HN	521.21	0.44	484	15
	HN+Plane	521.49	0.73	470	12
White-sided Dolphin	HN+Gla_int	349.20	0.00	329	22
754	HN+Podsize	350.84	1.64	407	15
	HN	350.98	1.78	447	18
Unk. Dolphin	HR+Observer	4183.91	0.00	561	6
1970	HR	4195.62	11.71	602	11
	HR+Visibility	4201.48	17.57	580	5
Unk. Large Whale	HN+Gla_cov	1428.29	0.00	2782	8
None	HN+Visibility	1428.40	0.12	2664	11
	HN	1429.76	1.47	2853	9

Table 10. Estimated indices of density of cluster (DS), density of individuals (D) and abundance (N) using the model selected with the stepwise procedure for species with more than 20 sightings for the combined Gulf of St. Lawrence and Scotian Shelf blocks.

Species	DS	D	N	%CV	95% CI
Minke Whale[b]	0.0046	0.0047	1,927	21	1,196-2,799
Fin Whale	0.0011	0.0011	462	28	270-791
Pilot Whale[b]	0.0019	0.0148	6,134	32	2,774-10,573
Harbour Porpoise[b]	0.0029	0.0088	3,667	35	1,565-6,566
Humpback Whale[b]	0.0013	0.0016	653	26	385-1,032
Common Dolphin	0.0086	0.1280	53,049	21	34,865-80,717
White-sided Dolphin	0.0014	0.0104	4,289	49	1,713-10,741
Unk. Dolphin[b]	0.0109	0.0825	34,186	36	20,458-57,114
Unk, Large Whale	0.0007	0.0008	346	21	222-495
Beluga[b]	0.0011	0.0022	907	31	509-1,583

[b] Estimates using covariates were obtained from bootstrapping (n=999).

Table 11. Estimated total abundance (N) and 95% confidence intervals for species with more than 20 sightings in the Canadian TNASS survey. The number of animals, if any, for those strata with less than 20 sightings for a single species, were added to the appropriate estimated abundance values from strata where there were sufficient samples.

Species	N	95% CI
Minke Whale	3,242	2,051-4,845
Fin Whale	1,352	821-2,226
Humpback Whale	2,080	1,337-3,172
Pilot Whale	6,134	2,774-10,573
White-sided Dolphin	5,796	2,681-13,088
Common Dolphin	53,625	35,179-81,773
White-beaked Dolphin	1,842	1,188-2,854
Harbour Porpoise	4,862	2,204-8,801
Unknown Dolphin	34,462	20,560-57,862
Beluga[a]	907	509-1,583

[a] Estimates using covariates from bootstrap (n=999).

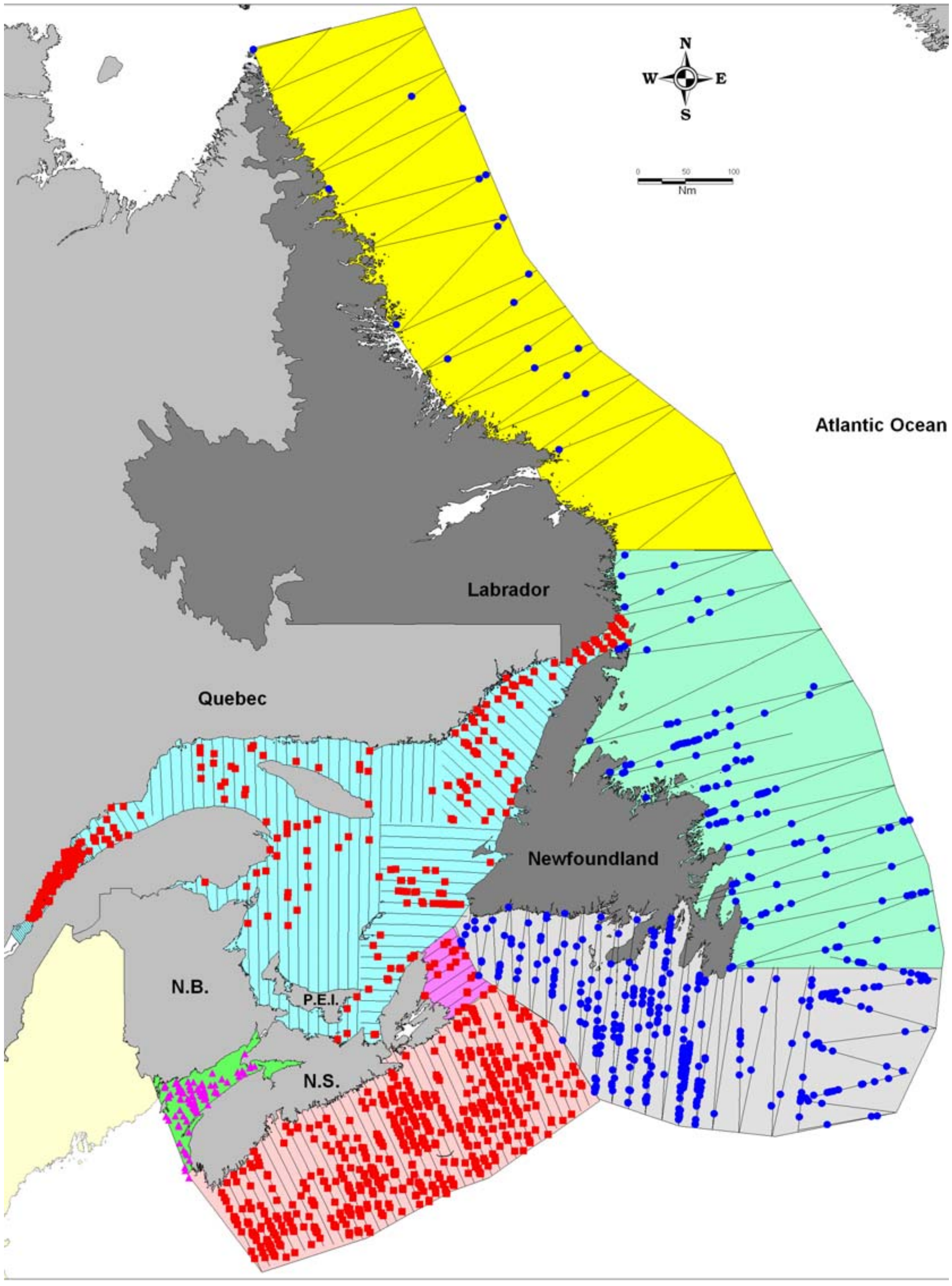


Figure 1. Aerial survey effort. Newfoundland and Labrador (yellow, light green, and light grey), Cape Breton (purple), Scotian Shelf (pink), and Gulf (light blue) blocks. Marine megafauna sightings made during the Canadian aerial survey effort are indicated with blue circles (Newfoundland and Labrador) and red squares (Cape Breton, Scotian Shelf, and Gulf). The darker green survey block in the Bay of Fundy was flown by NOAA; sightings collected during the NOAA survey are indicated with purple triangles.

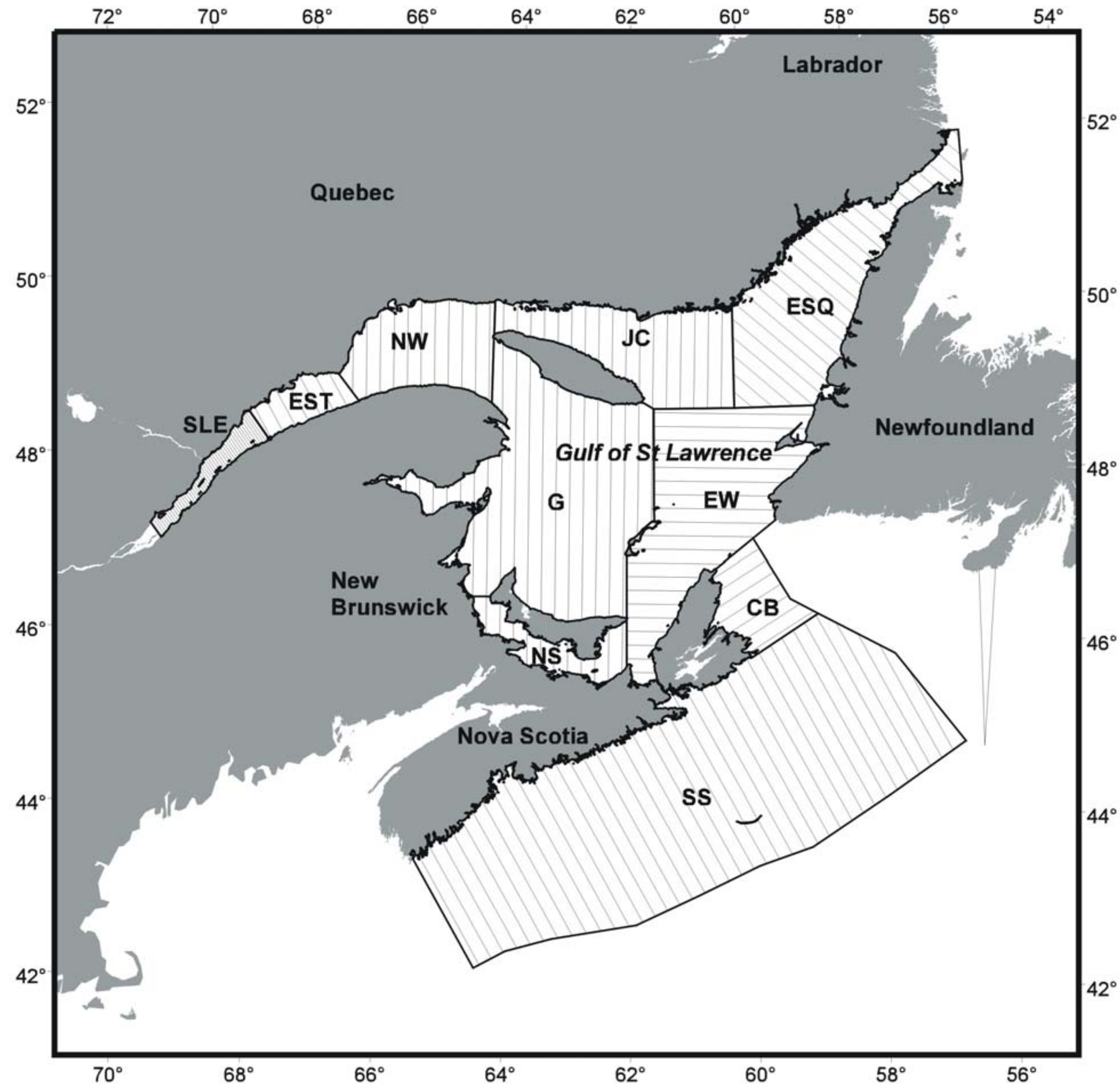
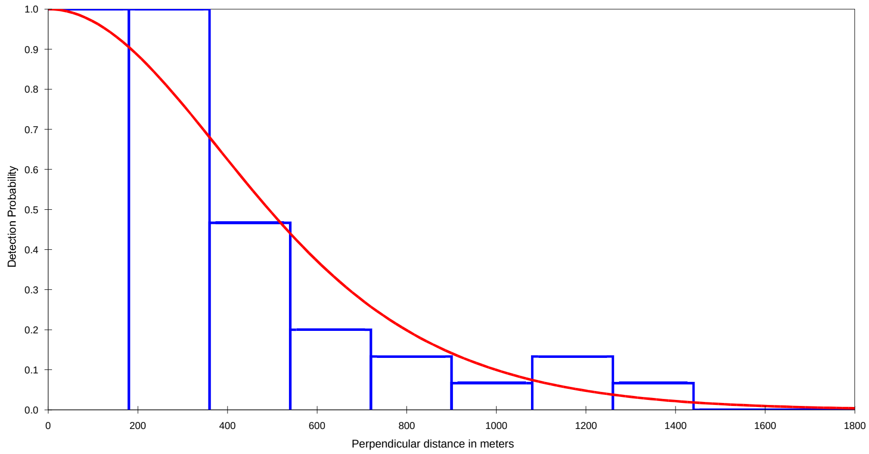
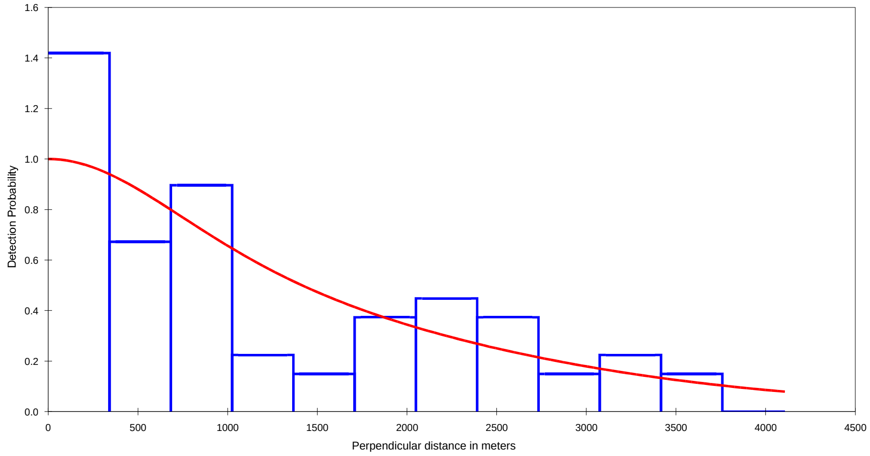


Figure 2. Stratification of the Gulf of St. Lawrence and Scotian Shelf areas showing parallel survey lines. The two in-line formation flight comparative transects are also shown on the south coast of Newfoundland.

Minke Whale (half-normal + flyday + swimdir)



Fin Whale (half normal + cue + flyday + seastate)



Humpback Whale (half normal + swimdir)

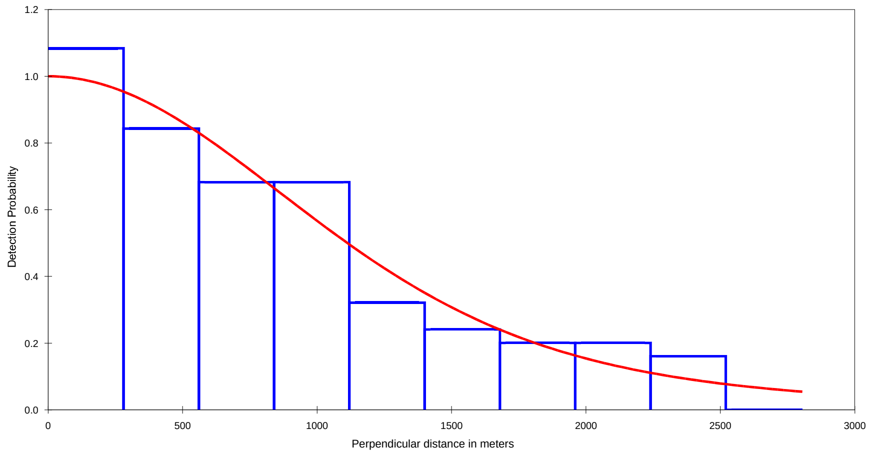
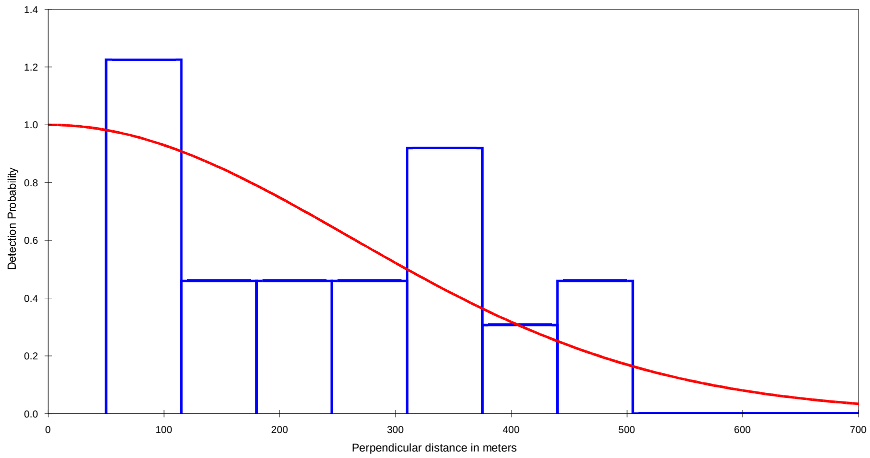
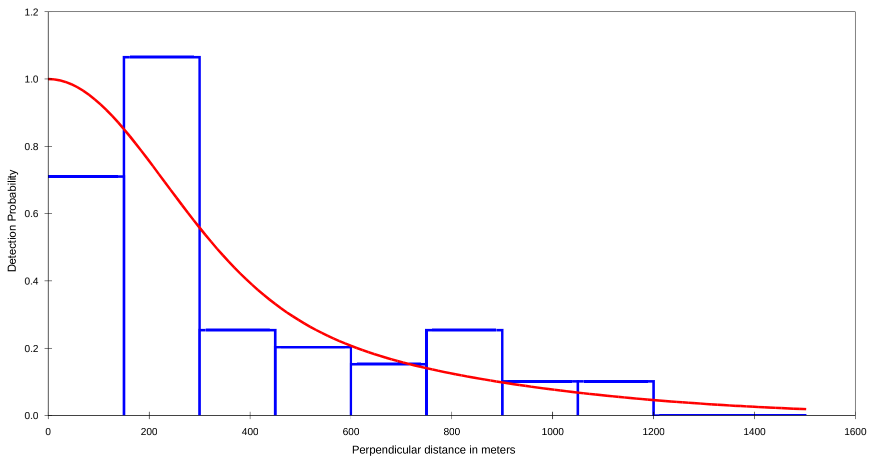


Figure 3. Detection curves for the best-fitting model as determined in Distance for minke, humpback, and fin whales in the Newfoundland and Labrador strata. Details of the analysis are presented in the Results section.

Harbour Porpoise (half-normal + swimdir)



White-beaked Dolphins (half-normal + swimdir + observer)



Common Dolphins (half-normal + seastate)

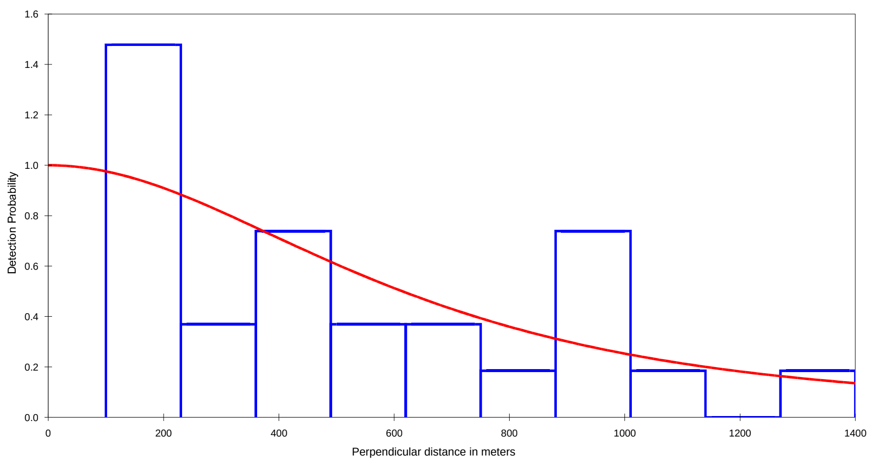


Figure 4. Detection curves for the best-fitting model as determined in Distance for harbour porpoise, white-beaked dolphins, and common dolphins in the Newfoundland and Labrador strata. Details of the analysis are presented in the Results section.

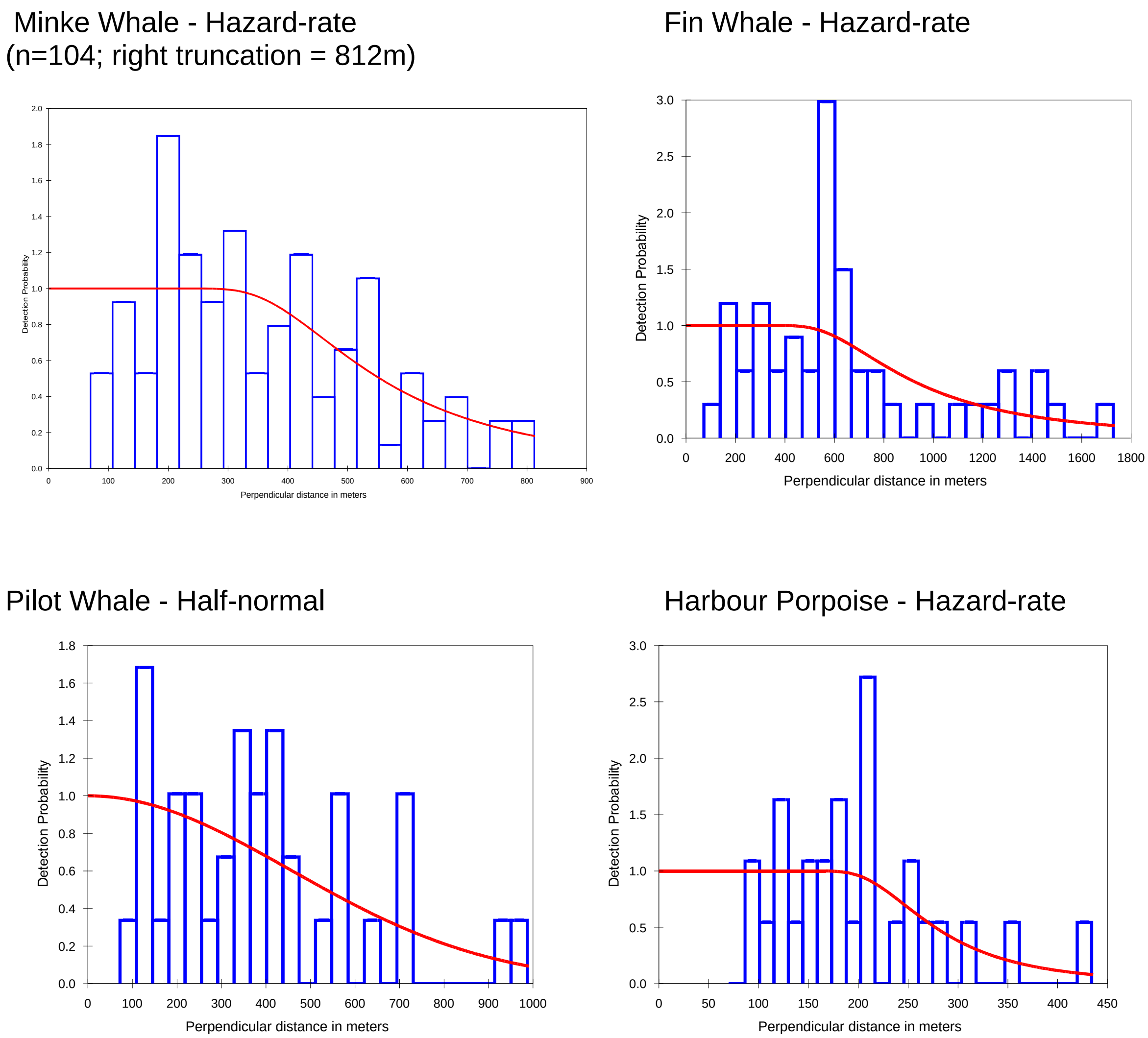
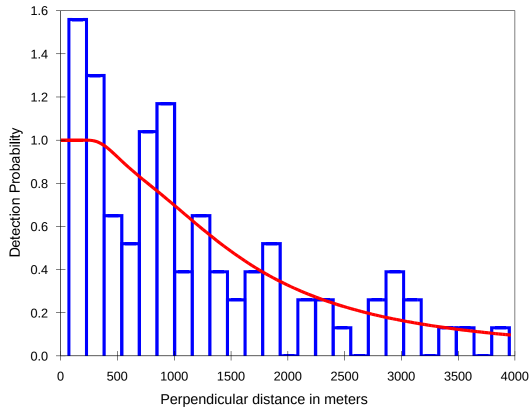


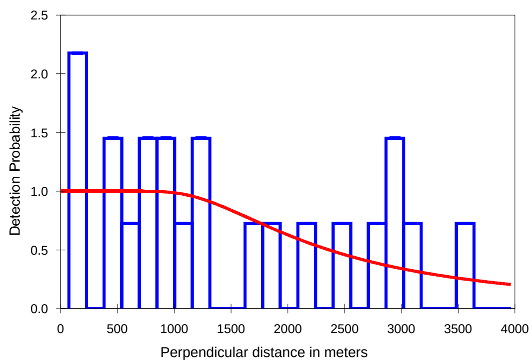
Figure 5. Detection curves for the best-fitting model shown in Table 10 as determined in Distance for species with more than 20 sightings in the Gulf and on the Scotian Shelf. When a simple key function with no covariate provided the best fit, a single graphic is shown. When covariates were used, the levels of factor covariates are shown in different graphs. For non-factor covariates a single graph shows the evaluated detection probability at the 25th, 50th and 75th percentile of the covariate.

Figure 5. Cont'd.

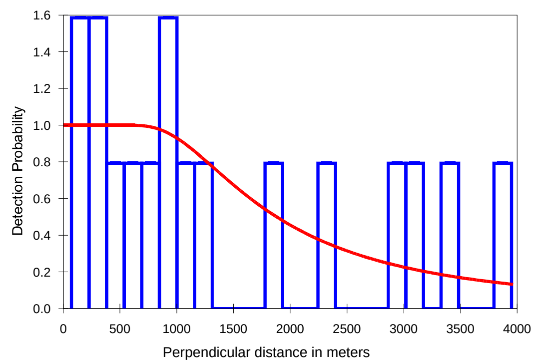
Humpback Whale - Hazard-rate + Observer (factor)



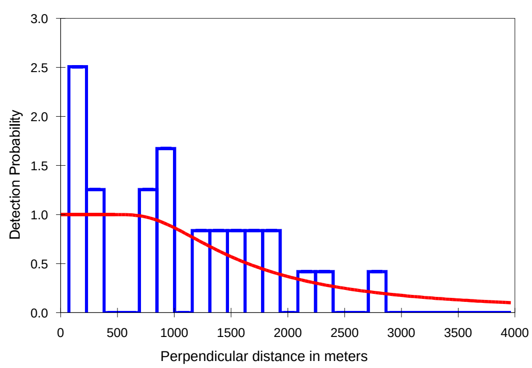
Factor combination 1: OBSERVER=JFG



Factor combination 2: OBSERVER=PC



Factor combination 3: OBSERVER=TDV



Factor combination 4: OBSERVER=YM

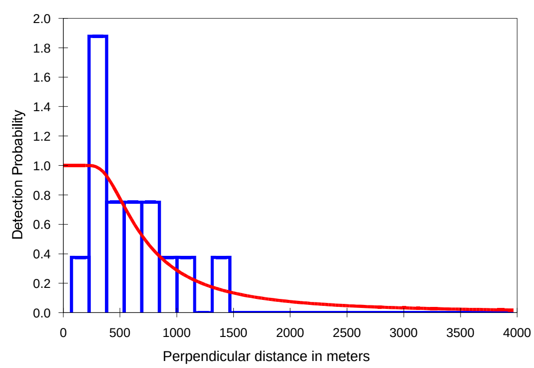
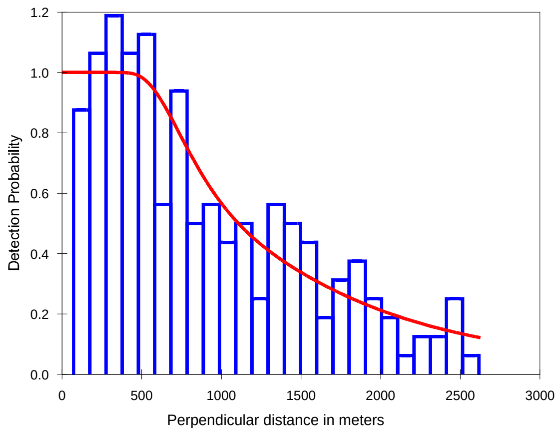
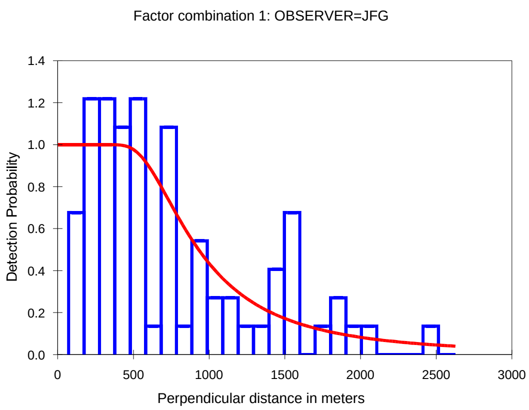
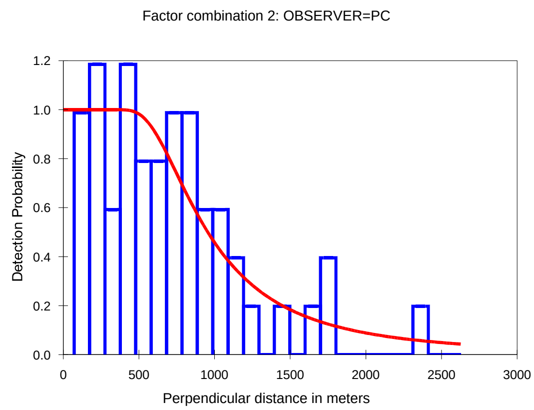


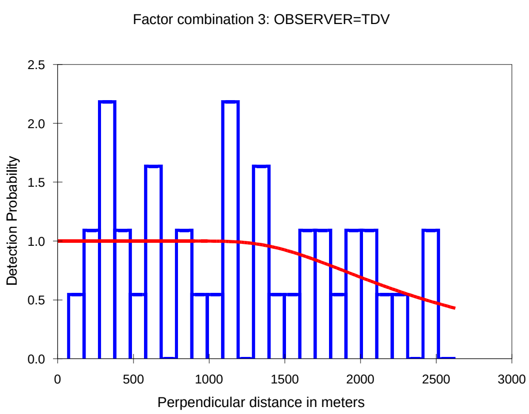
Figure 5. Cont'd.

Beluga - Hazard-rate+Observer (factor)









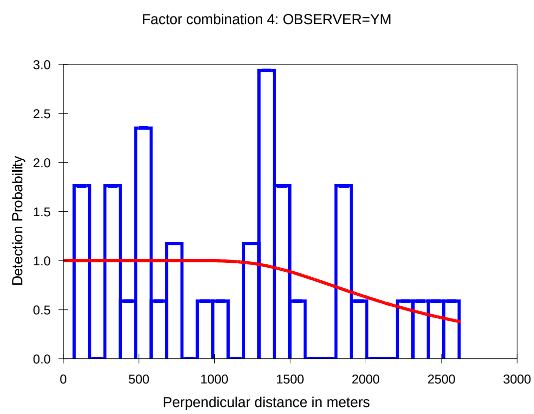
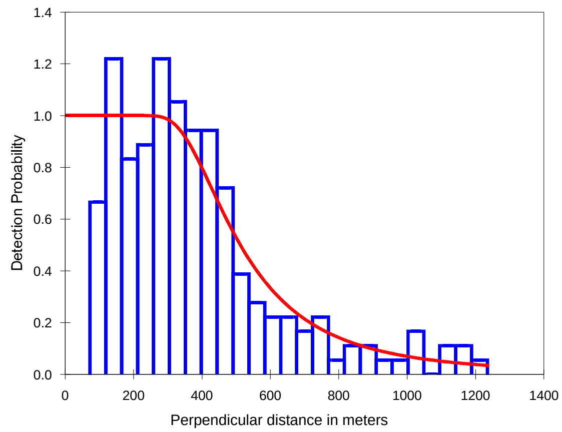


Figure 5. Cont'd.

Common Dolphin - Hazard-rate



White-sided Dolphin - Half-normal + Cluster size