Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2016/036

Québec Region

Estimating abundance and total allowable removals for walrus in the Hudson Bay-Davis Strait and south and east Hudson Bay stocks during September 2014

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June 2016

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Hammill, M.O., A. Mosnier, J-F Gosselin, J.W. Higdon, D.B. Stewart, T. Doniol-Valcroze, S.H Ferguson and J.B. Dunn. 2016. Estimating abundance and total allowable removals for walrus in the Hudson Bay-Davis Strait and south and east Hudson Bay stocks during September 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/036. v + 37 p.

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ABSTRACT

Aerial surveys to determine abundance of walrus from the Hudson Bay-Davis Strait, and south and East Hudson Bay stocks, were flown in September 2014. Surveys covered the areas of Hudson Strait, south Baffin Island, Southampton Island and as far south as Cape Henrietta Maria in Ontario. A total of 2,144 hauled out animals were counted in the Hudson Bay-Davis Strait stock, and 58 animals in the South and East Hudson Bay stock. Adjusting the counts for the proportion of animals hauled out at the time of the survey, using haulout data from several different studies, results in an abundance estimate of 7,100 (95% Confidence Limit, CL = 2,500–20,400) (rounded to the nearest 100) in the Hudson Bay-Davis Strait stock. Counts from 2007 along the southeast coast of Baffin Island estimated 2,500. Adding the two counts together is not recommended because the two areas were surveyed at different times and there is some movement between areas. Total abundance for the South and East Hudson Bay stock is 200 (95% CL = 70–570) (rounded to the nearest 10) animals. PBR estimates range from 90 to 180 animals for the northern Hudson Bay-Hudson Strait component of the Hudson Bay-Davis Strait stock and from 2–6 animals from the South and East Hudson Bay stock, depending on PBR model assumptions.

Estimations de l'abondance et prélèvements totaux admissibles pour les stocks de morse de l’Atlantique de la baie d'Hudson et du détroit de Davis et de la partie sud et est de la Baie d'Hudson

RÉSUMÉ

Des relevés aériens ont été réalisés en septembre 2014 pour déterminer l'abondance du stock de morses du détroit de Davis et de la baie d'Hudson, et celle du stock du sud et de l'est de la baie d’Hudson. Les relevés couvraient le détroit d'Hudson, le sud de l'île de Baffin et l'île de Southampton, et allaient aussi loin au sud que Cape Henrietta-Maria, en Ontario. Au total, 2 144 animaux sortis de l'eau ont été comptés pour le stock du détroit de Davis et de la baie d'Hudson, et 58 animaux pour le stock du sud et de l'est de la baie d’Hudson. L'ajustement des données pour la proportion de la population qui se trouve dans une échouerie au moment du relevé, en utilisant les données d'échouerie de différentes études, donne une estimation d'abondance de 7 100 animaux (intervalle de confiance [IC] de 95 % = 2 500-20 400) (arrondie à la centaine près) pour le stock du détroit de Davis et de la baie d'Hudson. Les dénombrements de 2007 le long de la côte sud-est de l'île de Baffin ont donné une estimation de 2 500 morses. Il n'est pas recommandé de regrouper les deux dénombrements parce que les deux zones ont été étudiées à différents moments et qu'il peut y avoir des transferts entre les zones. L'abondance totale du stock du sud et de l'est de la baie d'Hudson est de 200 individus (IC de 95 % : 70-570) (arrondie à la dizaine près). Les estimations du prélèvement biologique potentiel (PBP) varient de 90 à 180 animaux pour la composante du nord de la baie d'Hudson et le détroit d'Hudson du stock du détroit de Davis et de la baie d'Hudson, et de 2 à 6 animaux pour le stock du sud et de l'est de la baie d'Hudson, selon les hypothèses du modèle du PBP.

INTRODUCTION

The walrus family contains only one extant species, which is divided into two subspecies: the Pacific walrus (*Odobenus rosmarus divergens*) and the Atlantic walrus (*Odobenus rosmarus rosmarus*) (Riedman 1990). Atlantic walruses were once widely distributed in Canada and common south to the Gulf of St Lawrence and Sable Island, but were extirpated from these areas by the late 1700s (Born et al. 1995, Stewart et al. 2014a; Clark undated unpublished manuscript). Walruses have a comparatively narrow ecological niche (Born et al. 1995). Successful populations appear to depend on:

1) the availability of large areas of shallow water (80 m or less) with suitable bottom substrate to support a productive bivalve community,
2) the presence of reliable open water over rich feeding areas, particularly in winter when access to many feeding areas is limited due to ice cover, and
3) the presence of haul-out areas in close proximity to feeding areas (Wiig et al. 2014).

Walruses are harvested for subsistence, and in addition there is a limited sports hunt in Canada. The Committee on Species of Endangered Wildlife in Canada (COSEWIC) has assessed Atlantic walrus as 'Special Concern' (COSEWIC 2006). They are also listed under Appendix III of the Convention on International Trade in Endangered Species (CITES), which means that a permit from the Canadian CITES authorities is required to export walrus parts from Canada.

In Canada, Atlantic walruses can be divided into two populations, a High-Arctic population and a central Arctic population based on analysis of microsatellite DNA (Shafer et al. 2014). A total of seven stocks have been identified, based on a combination of genetic, distributional, telemetry, stable isotope and Traditional Ecological Knowledge, with three stocks occurring within the High Arctic population: the Penny Strait-Lancaster Sound, West Jones Sound and Baffin Bay (shared with Greenland) stocks and four stocks occurring in the central Arctic population: the Hudson Bay-Davis Strait (shared with Greenland), Northern Foxe Basin, and Central Foxe Basin. For management purposes the two Foxe Basin stocks are combined. Although not sampled, walrus from the south and east Hudson Bay area have been considered a separate stock because it was considered to be largely isolated from other stocks (Fig. 1) (Stewart 2008; DFO 2013; Shafer et al. 2014).

Walrus are considered data poor and the Potential Biological Removal (PBR) approach has been used to estimate sustainable removals (Stewart and Hamilton 2013). PBR is an invention of the United States *Marine Mammal Protection Act of 1972*, where the stated management objective is to manage populations above the Maximum Net Productivity Level, which is roughly the same as Maximum Sustainable Yield (Wade 1998). In Canada, there is a different legislative framework, where marine mammals are managed under the *Fisheries Act*, which does not identify a specific management objective. However, Canada signed The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. The agreement commits Canada to managing fisheries resources to maintain or restore stocks to levels capable of producing maximum sustainable yield and to apply the precautionary approach with stock specific reference points. A precautionary approach framework has been developed and implemented for Atlantic seals (e.g., Hammill and Stenson 2003, 2007, 2013); Departmental guidelines were developed in 2006 (DFO 2006), and some additional discussions on the precautionary approach within the marine mammal peer review group have occurred (e.g., Doniol-Valcroze et al. 2012; Stenson et al. 2012). Within northern communities, harvesting is also governed by the different land-claim agreements, which involve co-management of resources, identify conditions when the Minister can limit harvesting, and commit harvesters to respecting the principles of conservation.

In this study, we report on an aerial survey flown in central and western Hudson Strait, as well as results from a survey of the South and East Hudson Bay stock flown between 5–20 September 2014. Survey estimates are corrected for animals not hauled out at the time the surveys were flown using published correction factors. Total allowable removals are estimated using the PBR approach.

MATERIALS AND METHODS

In Nunavik, a researcher visited seven villages during February 2014, to obtain information on haulout locations and survey timing. Haulout sites identified by hunters were added to sites that were known from the literature (Fig. 2). In each community, a range of dates was identified: Inukjuak (August-September), Puvirnituq (late August-early September), Akulivik (August to November, September best), Ivujivik (September ok, October better), Salluit (September), Kangiqsujuaq (late September-early October) and Quaqtaq (migration occurs November-December).

Based on the community consultations, September appeared to be the best time to complete the surveys. Day length is also longer in September, than later in the fall, and weather tends to be better. The camera equipment was installed on the Twin Otters in Iqaluit in early September, and surveys began on the 5 September with some practice flights and continued until 20 September. One plane flew the south Baffin Island coast, part of Southampton Island and the Repulse Bay area. The second plane flew the south coast of Hudson Strait, portions of eastern Hudson Bay and east side of Southampton Island (Fig. 2).

The survey area included portions of southeastern Foxe Basin, northwestern Hudson Bay, and Hudson Strait occupied by the Hudson Bay-Davis Strait stock, and portions of eastern Hudson Bay occupied by the South and East Hudson Bay stock (Figs. 1 and 2).Walruses are highly social, and tend to form few, but large aggregations of animals. Consequently, surveys for walruses, do not follow the more traditional parallel transect surveys flown for some pinnipeds and cetaceans (but see Heide-Jørgensen et al. 2014). Instead, all known haulout sites are identified, then survey track lines are planned to fly over these sites and obtain counts of animals hauled-out at these sites. To account for the possibility that animals may haulout outside of the traditional sites, flights also visited other islands or flew along the coast between sites. Information on the location of haulout sites was obtained from the literature (Orr and Rebizant 1987; Born et al. 1995; Reeves 1995; Gaston and Ouellet 1997). In addition, communities in Nunavik and Nunavut were consulted prior to the survey to obtain additional information on walrus haulout locations, and optimal time to fly aerial surveys.

The aerial survey was initially flown at an altitude of 1,000 feet (305 m) and a target speed of 100 knots (185 km/h) using two deHavilland Twin Otter 300 aircraft. Each aircraft was equipped with bubble windows, two on each side at the 2nd seat row and at the last seat row. The survey crew consisted of two full time observers and a navigator / camera operator. Depending on the shoreline landscape the full time observers were stationed on each side of the aircraft at the 2nd seat row bubble windows allowing them to view the track line below and towards the shoreline or the open water. The navigator/camera operator made observations on the right hand side when conditions and time allowed. Additional local observers, when available, sat primarily in the last seat row bubble window on the shoreward side to enhance sightings at haulout sites. In some cases, and dependent on the landscape conditions, it was decided to have both full time observers stationed at the bubble windows on the shoreward side to enhance sightings at haulout sites. In these situations the navigator/camera operator was responsible for observations on the offshore side.

As the aircraft flew along the coast, approximately 500–750 m offshore, the position and altitude were recorded every second with a GPS device (Garmin model GPSMap78s) to record the track log. If walruses were spotted, the observer recorded the time of sighting, for later geo-referencing, and an estimate of the number of animals they saw. If many animals were sighted the aircraft would circle back over the haulout site to take photos with the belly cameras.

In addition to visual observations, the aircraft was equipped with a large camera belly port to allow the collection of continuous photographic records below the aircraft for the duration of the survey. The camera system was comprised of two digital cameras (Nikon D-800 with Zeiss 35mm lenses) which were mounted in a custom frame and aimed downwards along the track line through the belly window in the rear of the aircraft. A GPS unit (GPSMap 78s) was connected to each camera which in turn was connected to a laptop. Geo-referenced images were thus saved on the laptop in real time (GMT). The cameras were oriented widthwise (long side perpendicular to the track line), and at a flying altitude of 305 m the swath width of the photos taken was 420 m.

Owing to the large number of images, a triage approach was used to identify imagery to be examined for walruses. Highest priority was given to photographs taken around known occupied haulout sites and from locations where observers reported seeing walruses, followed by imagery from islands and the south Baffin coast. Photographs from the southern Baffin Island coast, to the west of Kimmirut were re-sampled following an adapted cluster sampling method for populations displaying a contiguous distribution: 175 series of 20 photographs were randomly chosen among those covering the area. When animals were identified in a series, the 20 preceding and 20 following images of the time series were examined, until no animal was identified in a series. Images from haulout sites were counted at least twice and the highest count was retained. If counts differed by more than 3%, the image was re-counted and the highest count was retained.

After counting, the positions of the visual observations and the photographed animals were compared and matched to determine what counts overlapped between methods. Unique sightings (i.e., detected either on the photographs or visually) were summed to provide a best estimate of total abundance.

Surveys were not flown every day mostly due to poor survey conditions. Little is known about walrus movements in the area, but animals could move between sites between counts, resulting in being counted twice (or completely missed due to occupying a site immediately after it was surveyed). A distance criterion of 45 km/d was used to minimize the probability that animals were counted twice (Stewart et al. 2014b). Distances between haulout sites were measured using Garmin Base Camp (version 4.4.7).

The survey was designed to count walruses at haulout sites. These counts were summed when we were confident, based on the time and distance separating counts, that they had not been included in the previous counts. This provides an estimate of the hauled out population, which is negatively biased due to two factors:

(1) not all animals hauled out are available or detectable for counting, and

(2) the proportion of the population at haulout at the time of the survey is unknown (Stewart et al. 2013).

Several different methods have been used to estimate walrus abundance. The methods we used here are referred to as Simple Counts (SC), Minimum Counted Population (MCP) and

Bounded Counts (BC). The Simple Count (SC) is the sum of all counts from all of the haulout sites. It takes into account the distance criterion if closely situated sites were counted on separate days. If more than one estimate is available for a haulout site, then the average number of animals counted at that site is used for that site and included in the total. This provides an estimate of the total hauled out population, which is then corrected for the number of animals not present at the site when the survey plane passed. The Minimum Counted Population (MCP) (Stewart and Hamilton 2013; Stewart et al. 2014c) is similar to the SC but where more than one count is available for a haulout site, the largest count for that site is used and the smaller count is excluded from the dataset. The total number of walruses hauled out is then corrected for animals in the water at the time the survey aircraft passed overhead. The Bounded Count Method (BC) assumes that possible count values (C) are distributed uniformly between 0 and the total number of individuals in the population (N) (Robson and Whitlock 1964; Johnson et al. 2007). Within this distribution, k random deviates are drawn, which divide the range of values into k+1 segments, whose expected values are identical. Thus, in expectation, the difference between N and C(k) is the same as the difference between C(k) and C(k-1). Numerically, the bounded-count estimator is simply twice the largest count minus the second-largest count.

$$\widehat{BC} = 2\mathrm{C}_{\max} - \mathrm{C}_{max-1} \qquad [1]$$

Where C_{max} is the highest count and C_{max}-$_1$ is the second highest count.

The lower confidence limit is C_{max} and the upper CL at α is:

$$\mathrm{C}_{\max} + (1-\propto)(\mathrm{C}_{\max} - \mathrm{C}_{\max-1}) \, / \propto \qquad [2]$$

where α = 0.05 for 95% confidence limits.

The proportion of the population counted is:

$$\mathrm{P_x} = \bar{\mathrm{C}} \, / \, (2\mathrm{C}_{\max} - \mathrm{C}_{\max-1}) \qquad [3]$$

where is the mean of the replicate counts (Stewart et al. 2014c). The BC method assumes that at some point all animals will be hauled out, and this will be reflected in the sampling, so theoretically no correction for animals not hauled out is needed.

For the SC and MCP methods, it is recognized that counts will be negatively biased because not all walruses are hauled out at the same time. Haulout counts were corrected by dividing the number of walruses recorded at the site by the estimated proportion of the population that was hauled out. We used three correction factors. All correction factors were taken from haulout information in the literature (Tables 1-2). The first correction factor used the mean proportion (p) of animals hauled out from several different studies and estimated the variance, assuming a binomial distribution (Zar 1999):

$$\mathrm{Var} = p \cdot (1-p)/(n-1) \qquad [4]$$

We assumed that the SC reflected the proportion of hauled out animals under average conditions, and combined the average proportion of animals hauled out from several published studies to obtain a single factor with which to adjust the haulout counts. The second correction factor used to adjust the SC was obtained from a study of walruses in Svalbard (northeast Atlantic) (Lydersen et al. 2008). The third correction factor was developed by Stewart et al. (2014c) who argued that the MCP best reflected the numbers of walruses hauled out under favourable conditions. They used an overall weighted proportion based on the average maximal proportions of animals hauled out in several different studies.

Several studies have examined the proportion of animals hauled out at any one time using satellite telemetry in Alaska, Canada, and on Svalbard (Tables 1–2). The proportion of walruses hauled out from these studies has varied from as low as 0.17 to as high as 0.74 if optimum conditions are assumed. The proportion of animals hauled out based on transmitters deployed during summer/early fall was used to develop a correction factor for animals that were not hauled out when the survey was flown. This resulted in an average haulout proportion of 0.3 (standard error, SE = 0.173, N = 7 studies) (Table 2). In a more detailed analysis, Lydersen et al. (2008) estimated that the proportion of 23 tagged animals that were in the water when surveys were flown was 0.75 (SE = 0.088, 95% CL = 0.717–0.781)(Table 2). A correction factor from the Svalbard data was determined by subtracting from 1, resulting in a mean haulout proportion of 0.25 (95% CL = 0.219–0.283).The values 0.3 and 0.25 were applied to the SC to obtain an estimate of the population. The MCP uses the highest count recorded at haulout sites monitored more than once. It assumes that counts were collected under more favourable haulout conditions (Stewart et al. 2014d). For these counts, it was assumed that the proportion of animals hauled out was 0.74 (SE = 0.053)(Table 1). The BC method assumes that all animals could be hauled out at a sampling period, so no correction factor was applied.

The variance from the corrected counts was estimated after Thompson and Seber (1994), as presented in Stewart et al. (2013).

$$var(Count_{corr}) = \frac{var(Count)}{p^2} + Count\ \frac{1-p}{p} + \frac{Count_{corr}^2}{p^2} var(p) \quad [5]$$

TOTAL ALLOWABLE HARVESTS

Total allowable harvests were calculated using the Potential Biological Removal (PBR), which is calculated from:

PBR= 0.5 R_{max} F_R N_{min}; [6]

R_{max} is the maximum rate of population increase, F_R is a recovery factor (between 0.1 and 1), and N_{min} is the estimated population size using the 20-percentile of the lognormal distribution (Wade 1998). In previous assessments, an R_{max} of .07 has been used (e.g., Stewart and Hamilton 2013), However, in the most recent assessments, of Pacific walrus in the United States, an R_{max} of 0.08 is used as the default. We present estimates of PBR using an R_{max} of 0.07, but also estimated PBR using an R_{max} of 0.08 for consistency with past use of American defaults for R_{max} by the National Marine Mammal Peer Review Committee.

CATCH DATA

Catch data from 1960 to 2014 were obtained from Stewart et al. (2014a), and DFO Fisheries Management. The harvest data suffer from three sources of bias. In all hunts, some animals may be killed or wounded, but not all of these animals are recovered. This is referred to as struck and lost or struck and loss. Information on struck and loss rates from harvesting in Canada is limited. Loss rates of 20–30% have been reported for Greenland (Witting and Born 2005). Some early hunts observed during the 1950s in Canada reported loss rates of 30-60% (Loughrey 1959). More recent estimates from the 1970s and 1980s range from 30-38% (Mansfield 1973; Orr et al. 1986; Freeman 1974/75 in Stewart et al. 2014a). NAMMCO assumes a struck and loss of 30% unless there is more specific information available (NAMMCO 2006). Hunters report much lower loss rates of only 5% (DFO 2000). A second source of bias is non-reporting of harvests by individual hunters. In years where reported harvest data are lacking, data were interpolated by taking the average of the adjoining five years of harvest around the missing year. The third source of bias is the non-reporting of community harvest statistics, such that no data are available for the community in a given year.

RESULTS

The cameras were initially set to photograph downwards, such that when flying 500 m off the coast, the coastline was not visible to the cameras. If animals were located, the aircraft circled over the animals to photograph them. Aligning the aircraft to photograph groups of walruses after they were detected was difficult and by the time the plane was properly oriented the groups might have dispersed. Consequently, on the second plane, the angle of the cameras was altered to 25 degrees. At the same time, survey altitude was reduced to 800 ft, which resulted in a swath width of 314 m towards the coast. Distance from the coast was adjusted, so that the coastline was always in view, consequently animals were photographed directly as the aircraft passed. The cameras in the first plane remained pointed straight down due to the varied topography the survey was flown in (e.g., the left side was not always the shoreward side).

The survey area for the Hudson Bay-Davis Strait stock comprised Hudson Strait between Kimmirut on Baffin Island and Port Burwell in the east and the mainland, near Repulse Bay, to the west of Southampton Island (Fig. 1). The southern limit was located at Smith Island, near the village of Akulivik and the northern limit included southern Foxe Peninsula. The area of the South and East Hudson Bay stock that was surveyed included haulout sites south of Smith Island, as far as Cape Henrietta Maria on the Ontario coast.

A total of 85 haulout sites were identified in the planned survey area for the Hudson Bay-Davis Strait stock. Five sites were not visited, one at the extreme eastern end of the survey zone because this area was covered by Stewart et al. (2014b), and four sites to the east and north of Repulse Bay due to poor weather conditions (Fig. 2). Twenty-seven haulout sites were identified for the South and East Hudson Bay stock. Six sites along the eastern Hudson Bay coast were not visited due to limited survey time. A total of 122,512 images were recorded, of which 27,900 were examined for walruses. Walruses were sighted at 22 locations (Fig. 3-5), including haulout sites surveyed twice and animals that may have moved. A total of 4,120 animals were counted using both the photographic and visual counts. A total of 3,859 animals were counted on the photographs but the visual counts only reported 794 animals (Table 3). Counts were extremely clumped, with the majority of animals being counted at three haulout sites in the Hudson Bay-Davis Strait Stock, and at one site in the South and East Hudson Bay stock. Some of these high aggregation sites were visited twice: Walrus Island, which accounted for 69% of the walruses detected (Total = 248 + 2579) and Nottingham Island which accounted for 21% of the walruses detected (Total = 331 + 547). The next most important site was Bushnan Island (66°09’ N, 84°35’ W) with 185 animals, followed by the Sleeper Islands (South and East Hudson Bay stock) (57°29’N, 79°49’ W), which were also visited twice with a total of 106 (99 + 7) animals.

HUDSON BAY-DAVIS STRAIT STOCK

Salisbury Island and Nottingham/Fraser Islands were surveyed twice (Table 1). The first survey flew over these islands on 9 September 2014. One animal was seen on Salisbury Island and 337 animals were counted at Nottingham and Fraser islands. The area was surveyed again on 11 September; Mill Island, located just to the north of Salisbury/Nottingham/Fraser Islands was surveyed the same day. On Salisbury Island 11 animals were observed, with 548 walruses on Nottingham\Fraser islands and six animals at Mill Island (Table 1). Taking this group of islands together, the second survey provided the highest and most complete count, resulting in a MCP of 565 walruses. Walrus Island was also surveyed twice. The first survey was flown on 11 September, with 248 animals being counted. On the second flight, flown 16 September, 2,579 animals were counted. Walrus Island is located 265 km in a straight line from Nottingham Island. Using a daily distance travelled of 45 km/d, as a cutoff, animals would have required 5.9 days to swim to Walrus Island. This is slightly greater than the 5-day interval between surveys flown at Nottingham/Fraser/Salisbury/Mills Island haulouts (11 September), and Walrus Island

(16 September), making it unlikely that animals moved between the two haulout sites during the interval between surveys. Similarly, distances were too great for animals to move between locations on Walrus Island and the haulout (N = 58 walruses) to the west of Southampton Island, or to Bushnan (N = 185) and Vansittart (N = 15) Islands north of Southampton Island—all of which were surveyed on 18 September. Five animals were spotted on the north side of Southampton Island on 16 September but not photographed. They would only have been 85 km from the observations of walruses made at Bushnan (N = 185) and Vansittart (N = 15) Islands on 18 September. Consequently, the 5 visual observations were excluded to minimize the possibility of double counting.

Taking the average of two counts (SC) or highest counts from haulout sites visited twice (MCP), and excluding observations that may represent duplicate counts results in a SC = 2,144, MCP = 3,418 animals for the Hudson Bay-Davis Strait stock. Bounded count estimates were 778 (90% CL=558–2,538, $P_x = 0.58$) for Nottingham/Salisbury and Fraser Island combined, and 4,910 for Walrus Island (90% CI = 2,579–23,558, $P_x = 0.29$). Adding in unique counts from the other sites results in a total BC of 5,969 (95% CL = 3,137–51,646). Mills Island counts were excluded because the site was not visited on 9 September and animals may have moved between Nottingham/Salisbury/Fraser islands between the 9 and 11 September surveys..

SOUTH AND EAST HUDSON BAY STOCK

Both the Ottawa and the Sleeper islands were surveyed twice. The first flight flew over the area on 13 September. The survey flew the area around the Belcher Islands (Sanikiluaq) on 14 September, then flew to Cape Henrietta Maria at the northwest tip of James Bay, and returned to fly over the Sleeper Islands a second time. The Ottawa Islands were surveyed a second time on 15 September. A total of 112 animals were seen during the survey of the South and East Hudson Bay stock. The largest group of 99 animals was photographed on the Sleeper Islands during the 14 September survey (Table 1).

Walruses were seen on the Ottawa, Sleeper, and Driftwood islands and among the southern islands. The Ottawa and Sleeper islands sightings were separated by 226 km, making it unlikely that animals moved between the two sites during the survey. Taking the counts, and excluding possible duplicates, results in a SC of 58 and an MCP of 101 walruses. Two surveys of the Sleeper Islands result in a BC of 191 (95% CL = 99-1,847), with an estimated proportion of the population sampled of 0.28. Adding in the number of observed animals hauled out to the BC, results in an estimate of 196 animals for the South and East Hudson Bay stock.

Counts adjusted for animals in the water

Correcting for animals not hauled out at the time the survey was flown results in estimates ranging from a low of 4,600 (SE = 300) using the MCP method to a high of 8,600 using SC for the area of the Hudson Bay-Davis Strait stock covered in this survey and the adjustment factor of 0.25 from Lydersen et al. (2008) (Table 4a). Estimates for the South and East Hudson Bay stock range from a low of 100 using the MCP to a high of 200 using the SC and BC methods.

PBR estimates using the SC for the Hudson Bay-Davis Strait stock are 79 to 180, using a haulout proportion of 0.3 and depending on whether the recovery factor is 0.5 or 1.0 and R_{max} is 0.07 or 0.08 respectively. Using a haulout proportion of 0.25 increases the PBR to 93 to 218 for a recovery factor of 0.5 or 1.0, respectively and R_{max} of 0.07 or 0.08 respectively (Table 4b). For the South and East Hudson Bay stock the PBR would be 2 to 6, using a haulout proportion of 0.3, an R_{max} of 0.07 or 0.08 and F_R of 0.5 and 1.0, respectively. The PBR would increase to 3 to 6 for a haulout proportion of 0.25 and a recovery factor of 0.5 and 1, respectively.

Catch data for communities harvesting from the Hudson Bay-Davis Strait stock and from the South and East Hudson Bay stock are presented in tables 5 and 6, respectively. Overall, reported harvests appear to be declining, but assessing trend is problematic because data are missing from several communities for several years throughout the time series, Reporting rates are somewhat higher from Coral Harbour and these data suggest a drop in harvests occurring during the mid-1990s, with little change since then (Fig. 6). Reported harvests from the Hudson Bay-Davis Strait stock have averaged 85 (SE = 10.5, N = 5) animals per year over the last five years. Reported harvests from the South and East Hudson Bay stock were relatively constant from the beginning of the time series in the early 1970s (Fig. 7), until the beginning of the new century, with an average of 12 (SE = 1.59, N = 27) animals reported killed every year. Since 2009, fewer animals have been reported harvested with the annual mean dropping to 2.4 (SE = 0.9, N = 5) animals per year. We have assumed that Inukjuak hunters have harvested from this stock during the last 5-year period. If their harvests were taken from the Nottingham Island area instead, then this will reduce the harvest from the South and East Hudson Bay stock and will increase slightly the harvest from the Hudson Bay-Davis Strait stock.

DISCUSSION

Walruses are a challenging species to enumerate due to a combination of factors including a highly clumped distribution; movements between haulout sites; variability in detection probabilities depending on whether animals are hauled out on land, on the ice, or are in the water; and uncertainty in the fraction of the population hauled out at the time of the survey (Heide-Jørgensen et al. 2014; Lydersen et al. 2008; Stewart et al. 2014c). Two approaches are generally used to assess their abundance. One approach is to survey along parallel lines and record walruses sightings using line-transect or strip-transect methods. Such surveys are usually flown during the spring (April-May), when walruses may be hauled-out on the ice (e.g., Udevitz et al. 2001; Heide-Jørgensen et al. 2014). A second approach, which was used here, involves coastal surveys that visit haulout sites and floating ice in areas where walruses are known to occur during summer or early fall.

Previous studies have concluded that aerial surveys which provide a vertical view of hauled out animals are superior to lateral/oblique views obtained from boat surveys because animals are often very tightly packed, and animals in the back of the group are frequently blocked from view by animals in the front (Stewart et al. 2014c). Others (e.g., Mansfield and St Aubin 1991; Stewart et al. 2014c) have found good agreement at low numbers between visual and photographic counts but that observers are rapidly overwhelmed as numbers of hauled out animals increase such that visual counts become increasingly negatively biased.

In this study, we conducted extensive consultation to determine where walruses might be hauled out and at what time of the year would be most effective time for surveys. We identified from the literature and from community consultations where walruses were likely to be seen, and concluded from consultations that an appropriate time for surveys would be in September. Our objective was to fly coastal areas, remaining about 500 to 750 m off the shore and over islands, particularly where haulout sites had been identified, to use the visual observers to detect animals, and then to circle around and photograph aggregations. However, during the survey we found that once animals were detected, it was difficult to line the aircraft up over the haulout site to photograph them, and by the time the aircraft was suitably aligned animals had begun to disperse. We adjusted for this by altering the camera angle on plane #2 from vertical, shooting just under the aircraft, to a 25-degree angle to ensure coverage of the coast as we flew along. This adjustment was made prior to the second counts being made at both the Fraser/Nottingham Salisbury and Walrus Island sites. After the survey we counted imagery according to priority, beginning with places where animals were detected visually, followed by reported haulout sites, and then coastal areas and islands. An exception to this approach was made for the extensive islands off the south coast of Baffin Island (Fig. 1). Using this approach some animals were not detected visually but were picked up on the photographs. Sightings from Charles Island and the Sleeper Islands are notable examples of detecting animals using the photographic component.

Bias during surveys arises from two main sources: not all animals are detected by observers or on photographs (detectability bias) and not all animals are available to be detected (availability bias). Using vertical photographs and multiple counts of these photographs, detectability bias can be considered to be quite low in walrus surveys (Stewart et al. 2014c; this study). However, several studies have identified that the proportion of the population hauled out at any one time may fluctuate (e.g., Stewart et al. 2014b,c,d; Udevitz et al. 2009; Lydersen et al. 2008). This is clearly illustrated by the variability in repeated counts reported by Mansfield and St. Aubin (1991) from the Coats-Southampton Island area, indicating that availability bias will be a much more important factor affecting estimates of abundance (Tables 7 and 8). This issue is not limited to walrus studies that focus on haulout counts, for example, among harbor seals (*Phoca vitulina*), 68% of variance in abundance estimates is due to the telemetry data, while only 31.5% was associated with the counts. Among walruses in Foxe Basin, 79% of the variance was associated with the proportion of animals hauled out, while only 21% was due to counts. Obviously, future research efforts should focus to improve our understanding of walrus haulout behaviour (Doniol-Valcroze et al. 2016; Hammill et al. 2016).

MCP and BC represent two approaches to compensate for availability bias (e.g., Stewart et al. 2013, 2014b,c,d) and both approaches will be less negatively biased than the SC method. However, both approaches pose challenges for statistical treatment and to decide on what correction factor should be applied, if any, to the counts, to correct for animals in the water at the time surveys were flown (Doniol-Valcroze et al. 2016). In using MCP, the highest of two or more counts at a haulout are selected, so that the sample is no longer random. If it is accepted that higher counts at haulout site(s) represent more favourable haulout conditions, then presumably a different correction factor should be assigned to sites counted repeatedly, than to sites where only single counts are available. The challenge is then to decide what more favorable factor should be applied-should it be the tail of a distribution of haulout proportions, and if so, what proportion of this tail should be used (Doniol-Valcroze et al. 2016)? In this study we divided the MCP by 0.74, the maximum proportion of animals considered to be hauled out that has been used elsewhere (Stewart et al. 2014c).

The BC estimator assumes that a series of estimates are drawn from a uniform distribution, such that the difference between the true number and the first draw is the same as the difference between the first draw and the second draw (Johnson et al. 2007). The BC estimator will be biased high if some animals are counted twice. It performs poorly if there is only one good count (i.e., close to the true number) and the remaining counts are very low (i.e., the probability of detection is very low) and the assumption of a uniform distribution is obviously not met (Johnson et al. 2007; Routledge 1982). Bias can be reduced if the number of surveys or counts of the haulout are increased but logistically repeated surveys may not be feasible (Routledge 1982). The absence of a means to obtain a variance estimate from the BC method is also of concern. BC estimates will also be negatively biased low if some animals do not haul out at the same time as other animals (Thompson et al. 1997; Johnson et al. 2007). In this case, the BC estimator will need to be corrected for the number of animals in the water when the survey was flown, but the correction needed is uncertain.

Ideally, satellite transmitters would be deployed on animals during the survey, and the proportion of animals hauled-out during the survey would be used to correct counts for animals that are in the water. Unfortunately, transmitters were not deployed in this study, which means we applied estimates of the hauled-out proportion of animals from other studies (Table 2) to our counts as is done with other surveys, such as the Nunavik beluga and High Arctic narwhal surveys. This resulted in an average proportion of animals hauled out of 0.30 (SE = 0.173, N = 7). The low value of 0.17 from a study by Gjertz et al. (2001) appeared be an outlier and so was excluded from the calculation. Including this latter value would have reduced the proportion of animals hauled out to 0.28 (Table 2) and would have increased slightly our overall population estimate. The correction factor of 0.3 and a correction factor of 0.25 developed by Lydersen et al. (2008) were applied to the SC estimates, which are considered to represent a sample of animals hauled out at the time our surveys were flown. It is assumed that the proportion of animals hauled-out follows a binomial distribution with variance calculated accordingly.

The large differences observed between the first and second counts of walruses hauled out at Walrus Island and in the Sleeper Islands, as well as the observed variability between counts reported by Mansfield and St. Aubin (1991) (Tables 7 and 8), indicate much more variability in walrus haulout behaviour than would be represented from a binomial distribution and that we underestimate the variance associated with walrus haulout behaviour (Doniol-Valcroze et al. 2016). We compensated somewhat for this in an ad-hoc manner in our estimation of the variance by using a sample size of 7, which is the number of studies we used to calculate our mean haulout proportion of 0.3. This was correct in that we estimated the average of the average proportion hauled out in each study, which resulted in a high variance, and survey coefficients of variation (CV) of 0.58. If we had used the actual number of transmitters deployed in these seven studies (Table 1), this would have reduced the variance, and produced a survey CV of 0.19, which would have had an impact on our estimate of minimum population size, a component of the PBR calculation (see below). Some studies have reported that high winds, cool temperatures and time of day are important factors affecting walrus haulout behaviour (Mansfield and St. Aubin 1991; Garlich-Miller and Jay 2000), although these effects may be weak compared to other apparently random factors (Udevitz et al. 2009). Other studies have not identified any relationship with time of day (Mansfield and St. Aubin 1991) or weather variables (Lydersen et al. 2008). Walruses do haul out for long periods at a time (Gjertz et al. 2001; Jay et al. 2001; Stewart et al. 2014c; Lydersen et al. 2008) and previous haulout state is one factor that has an important effect on continued haulout state, which may be due to physiological, social or environmental conditions outside of the normal environmental variables considered (Udevitz et al. 2009). Lydersen et al. (2008) found that animals that were marked together tended to haulout at similar times, but not necessarily at the same place and took into account overdispersion in the development of their correction factor, which estimated that only 0.25 of the population would be hauled out at any one time.

We used the SC to estimate total allowable harvests because they represent a random sample of counts of animals hauled out when surveys were flown. As outlined earlier, both MCP and BC should in theory be less negatively biased than SC, but it is not clear what proportion of the availability bias can be allocated to MCP and BC and what proportion of the remaining availability bias can be allocated to correcting for animals not hauled out during the survey using the telemetry data. The BC approach is also not appropriate when the proportion of animals detected is low, and limited simulation information (on harbor seals) suggests that simple counts performed better than maximum counts in detecting population trend (Routledge 1982; Adkison et al. 2003; Johnson et al. 2007).

We obtained estimates of 7,100 to 8,600 animals in the Hudson Bay-Davis Strait stock using SC and a mean haulout proportion of 0.3, or an estimated haulout proportion of 0.25 respectively (Lydersen et al. 2008). These estimates are not significantly different. Owing to the uncertainty associated with the proportion of animals hauled out during the survey, we recommend using the lower estimate. This estimate is similar to the two estimates of 4,675 (95% CL = 1,845–

11,842) and 6,020 (95% CL = 2,485–14,585) obtained from systematically flown line-transect surveys that covered the entire Hudson Strait to as far west as Mansel Island during March–April 2012 (Elliot et al. 2013). However, these estimates may not be completely comparable if there is extensive overwinter mixing between Hudson Bay-Davis Strait walruses, and walruses from other stocks. In the current study, the majority of animals were observed around a complex of islands consisting of Fraser/Nottingham and Salisbury Islands, and at Walrus/Coats/Southampton islands. The high counts of nearly 2,600 animals on Walrus Island, were similar to an estimate of 2,900 animals made in this area in August 1954, counts of 2,650 in 1961, and 2,171 in 1977, but are higher than counts of 1,373 in 1990 (Table 9) while counts in the Fraser/Nottingham/Salisbury islands area of over 500 animals were similar to counts of 461 in 1990, and 714 in 2010 (Table 9), suggesting that this stock remains abundant in the Hudson Strait-Southampton Island area .

Counts of walruses from the South and East Hudson Bay stock were much lower at around 200 animals using SC. These estimates are due largely to a sighting of 99 animals on the Sleeper Islands. No animals were seen at Cape Henrietta Maria, where large numbers have been reported in the past (Table 9). Walrus sightings in this area are more opportunistic. Walruses were distributed as far south as James Bay but had disappeared from this area by the 1950s (Loughrey 1959). Reports in the literature from the 1940-1970s suggest that numbers of walruses in the Sleeper/Belcher/Ottawa islands had declined (Loughrey 1959; Manning 1946, 1976), but our sightings of 99 animals in the Sleeper Islands was similar to reports of 100 animals seen during the 1970s (Table 9) (Manning 1976).

The PBR was developed specifically for dealing with incidental catches in commercial fisheries and for finding acceptable levels of bycatch that would still respect the objectives of the *Marine Mammal Protection Act*. It was not developed for directed harvesting. The benefit of PBR is that it only requires a single estimate of abundance, and it has undergone extensive testing to evaluate how it performs if reasonable assumptions are not respected, but such testing did not consider scenarios involving hunting and potential loss of hunting opportunities due to overly conservative PBR estimates. The PBR is the product of N_{min}, ½ R_{max}, and F_R (Equation 6). N_{min} is a factor that recognizes that abundance estimates have considerable uncertainty associated with them. Using the CV associated with the abundance estimate, N_{min} estimates the 20th percentile of the log-Normal distribution, which means that there is an 80% probability that the population is greater than this number. An estimate with a higher CV has a lower N_{min}. In the United States, where the PBR approach was developed, there has been extensive modeling and discussion in setting defaults for R_{max} and in setting guidelines for the Recovery Factor (F_R). The same formal discussion has not occurred in Canada, where the legislative and management framework is much different. In general, Canada has used the R_{max} defaults identified in the USA for each group. However, the setting of the F_R has been more ad hoc. For data-rich species in Canada, a population model is used to quantify the risk associated with different harvest strategies (Stenson et al. 2012), whereas the PBR method has been used to set allowable removals where stocks are considered data poor (Stenson et al. 2012). To date, the selection of F_R has varied depending on the fishery. For narwhal and walruses, a recovery factor of 0.5 and 1.0 have been used, while under the Atlantic Seal Management Strategy the Recovery Factor is set to 1, unless there is an obvious serious conservation concern (Stewart and Hamilton 2013; Stenson et al. 2012).

In this study, we presented values for R_{max} of 0.07 and 0.08. In earlier work, it was argued that 0.08 was not appropriate because survival rates for walruses were not known, leading to possible bias in estimates of R_{max} for this species (Chivers 1999; Stewart and Hamilton 2013). However, for most species examined in the United States, survival rates are not known so defaults are based on modeling only, which led to walrus R_{max} default being set at 0.08. Some other information provides support for the fact that R_{max} is higher than 0.07. For example, finite estimates of population growth obtained by fitting an exponential curve to Soviet estimates of abundance from 1958 to 1975, when walruses were not considered to be food limited, were 0.07 (Sease and Chapman 1988). This estimated rate of growth is negatively biased, since harvesting continued throughout this period and was not considered in their analysis. Modeling of the dynamics of Atlantic walrus populations in Greenland, resulted in an R_{max} of 7.7% (95% Confidence Interval, CI = 6.7–8.9%) assuming no harvest (Witting and Born 2014). More recent modeling of Pacific walruses during a period where population growth has slowed (1974–2006) suggest that adult survival rates used by Chivers (1999) when she was estimating her R_{max} of 0.08, were conservative since they did not consider harvesting (Taylor and Udevitz 2015).

In the American system, if catches exceed a PBR level, then the population is considered to be depleted and a take-reduction team is established to find ways to reduce takes. A population is also considered depleted if a population is below MNPL or is listed under the *American Endangered Species Act*. In Canada, the term Depleted does not have the same meaning. For the PS-JS walrus stock in the High Arctic walrus population, Stewart et al. (2014c) concluded that a population was not depleted, because there was no obvious decline in abundance over the period 1977 to 2009, based on walrus counts from differing numbers of haulout sites, as well as reports from other studies. As a result, they applied a Recovery Factor of 1. In the current study of walruses in the northern Hudson Bay-Hudson Strait area, synoptic survey data are only available for 2012 and 2014. However, several studies over the last six decades have reported estimates of walrus abundance for the principle haulout areas of Nottingham /Fraser/Salisbury Island complex and for the Southampton/Walrus/Coats Island areas suggesting that this component of the Hudson Bay-Davis Strait population has not shown any temporal trend in abundance (Table 9). Therefore, using a similar approach to that used for the High Arctic (Stewart et al. 2013; Stewart et al. 2014c), we also provided PBR estimates using a Recovery factor of 1.

The SC estimate for the northern Hudson Bay-Hudson Strait portion of the HBDS stock is 7,100 rounded to the nearest 100. A survey flown in 2007 along the east Baffin Island coast portion of the HBDS stock resulted in an estimate of 2,500 animals corrected for the proportion of functioning tags that were dry when the survey was flown and rounded to the nearest 100 (Stewart and Hamilton 2013). The surveys along east Baffin and in northern Hudson Bay-Hudson Strait were flown in different years and although there is some genetic separation between Hudson Strait and east Baffin Island animals, there is also some movement of animals between these two areas as well (Anderson et al. 2014). Therefore, it is not recommended to add the two surveys together. The PBR for the northern Hudson Bay-Hudson Strait component of the HBDS stock lies between 90 and 180 animals for R_{max}=0.08, and F_R of 0.5 and 1.0 respectively. From the 2007 survey, along the east Baffin Island coast, the PBR would be 44 and 88 for an F_R of 0.5 and 1.0, respectively. Using the mean reported harvests over the last five years (N = 85) from communities that are harvesting the HBDS stock and assuming a struck and loss of 30%, total removals from this stock were 121 animals. Current Canadian harvests are below estimated PBR levels for a recovery factor of 1. We have not considered Greenland harvests from this stock.

The information on abundance of the South and East Hudson Bay stock is more anecdotal and would suggest that this population may have declined, but this decline probably occurred prior to the 1970s. Since then, it would appear that low numbers of walruses continue to persist in the Belcher-Sleeper-King George islands (Table 4a, b). Reported harvests from this stock have averaged four animals per year over the last five years. Taking into account struck and loss rates of 30% would result in harvest levels of six animals. These harvest levels are above PBR levels for F_R =0.5 (Table 4b). Interest in harvesting from this stock has been declining in recent years due to an increase in detection of trichinella among harvested animals (D.W. Doidge, Nunavik Research Centre, Kuujjuaq, pers. comm.) and it is not certain if villages continue to hunt in this area or have shifted hunting to the Nottingham Island area.

In this assessment we provided estimates of walrus abundance in the south and east Hudson Bay stock, as well as the northern Hudson Bay and Hudson Strait areas of the Hudson Bay-Davis Strait stock. There are several uncertainties associated with this study, including a lack of understanding of walrus movement patterns between haulout sites, a need to improve our understanding of haulout behaviour, which has probably the most significant impact on our estimates of the proportion of animals hauled out during the survey period (availability bias) and more importantly the uncertainty associated with this haulout proportion adjustment (Doniol-Valcroze et al. 2016). We have also assumed that animals from this stock are not harvested in Foxe Basin, or in the south and eastern Hudson Bay area. The South and East Hudson Bay stock is poorly understood. At one time, walruses extended into James Bay. Unfortunately, walruses from this stock have not been sampled, therefore it is not clear if they do in fact from a unique stock, or represent the southern limits of a stock that we currently identify as the Hudson Bay-Davis Strait stock. Walruses from the Hudson Bay-Davis stock have been recorded in Greenland, but there is little information on the extent of this exchange.

ACKNOWLEDGEMENTS

We thanks Caroline Sauvé, P. Carter, P. Hall, Robert Karetak, Ali Qavavawk, Eli Angyou, and our pilots from Kenn Boreck Air and PCSP staff in Resolute for support. This project was supported by the Nunavut wildlife Management Board, Nunavut Tungavik Inc., DFO Central and Arctic Region and the DFO national marine mammal survey fund.

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TABLES

Table 1. Maximum numbers of tagged walrus hauled out simultaneously (from Stewart et al. 2014c).

Location	Year	Season	Number of tags (dry/total)	Maximum proportion hauled out
Alaska Svalbard	1990	Summer	5/6	0.833
	2003	August	6/9	0.667
	2004	August	9/11	0.818
Alaska	2004	April	8/12	0.667
	2006	April	17/24	0.708
NE Greenland	2009	August	7/8	0.875
Overall weighted average			52/70	0.743
Variance				0.003
Coefficient of Variation				0.07

Table 2. Estimated proportion of animals hauled out or at sea from different studies using satellite transmitters or time depth recorders. Results from Gjertz et al. (2001) were very different from other summer deployments and were excluded from the estimate of average numbers of animals hauled out. Including Gjertz et al. (2001) in the estimate is shown in square brackets. Spring deployments were not included in estimate of average proportion hauled out.

Study	Month	Sex	N	At sea (SE)	95% CL	Hauled-out (SE)
Lydersen et al. 2008	August	Male	28	0.75 (0.088)	0.717-0.781	0.25
Stewart et al. 2013	September.2010		8			0.37 (0.144)
Stewart et al. 2013	September 2011		12			0.36 (0.15)
Stewart et al. 2014d	July-August.2009	2M:1F				0.32 (0.106)
Stewart et al. 2014b	September 2007 (Table 3)	4M:2F				0.25 (0.039)
Jay et al. 2001	August	Male	4	0.766 (0.081)		0.23
Acquarone et al. 2006	August	Male	6			0.33 (0.093)
Gjertz et al. 2001	July-Aug	Male	6			0.17
Heide-Jørgensen et al. (2014)	Mar-April		9			0.365 (0.029)
Udevitz et al. 2009	April					0.17
Average						0.30 (0.173) [0.28 (0.183)]

Table 3. Site, position, survey dates, photographic and visual counts of hauled out walrus. In some cases walruses were counted visually and detected on the photographs, or animals were seen visually, but were not photographed. In these cases duplicates were excluded and the remaining animals were summed.

Site	Latitude	Longitude	Date	Max count	Walrus photo	Visual counts
			Hudson Bay-Davis Strait stock			
Akpatok Island	60°15'59"N	68° 8'50"W	2014-09-08	0	0	0
Back Peninsula	63°42'32"N	80°12'5"W	2014-09-16	0	0	0
Bencas Island	63° 1'33"N	82°37'13"W	2014-09-11	0	0	0
Big Island	62°40'38"N	70°36'00"'W	2014-09-05	3	3	0
Bushnan Island	66°09'24"N	84°35'41"W	2014-09-18	185	185	0
Cape Dorchester	65°28'39"N	77°22'54"W	2014-09-14	2	2	0
Cape Queen	64°42'30"N	78°16'44"W	2014-09-14	1	1	0
Charles Island	62°38'37"N	74°16'46"'W	2014-09-09	2	2	0
Chrobak Inlet	64°27'21"N	74°27'31"W	2014-09-13	0	0	0
Coats Island	62°34'41"N	82°57'25"W	2014-09-11	0	0	0
Digges Island	62°33'14"N	78° 0'27"W	2014-09-09	0	0	0
Digges Island	62°33'14"N	78° 0'27"W	2014-09-12	0	0	0
Duke of York Bay	65°12'43"N	84°51'9"W	2014-09-16	0	0	0
East Bay	64°02'26"N	81°46'53"W	2014-09-16	0	0	0
Fraser Island	63°27'32"N	78°29'25"W	2014-09-09	6	0	6
Fraser Island	63°27'32"N	78°29'25"W	2014-09-11	1	1	0
Leyson Point	63°26'10"N	80°58'56"W	2014-09-16	0	0	0
Lona Bay	64°21'34"N	77°34'40"W	2014-09-13	0	0	0
Mansel Island	61°59'54"N	79°46'02"W	2014-09-12	0	0	0
Mills Island	63°58'38"N	77°46'09"'W	2014-09-11	6	4	3
Native Point	63°43'16"N	82°32'26"W	2014-09-16	0	0	0
Nias Island	65°31'42"N	84°40'48"W	2014-09-16	0	0	0
Southampton Island	65°10'56"N	84° 0'54"W	2014-09-16	2	2	0
Southampton Island	65°12'N	83° 0'58"W	2014-09-16	1	0	1
Southampton Island	65°15'N	84° 12"'W	2014-09-16	2	0	2
Nottingham Island	63°18'32"N	77°58'44"W	2014-09-09	331	267	105
Nottingham Island	63°18'32"N	77°58'44"W	2014-09-11	547	376	313
Okoli Island	64°10'0"N	76°38'31"W	2014-09-13	0	0	0
Prairie Point	63°58'27"N	83° 9'36"W	2014-09-15	0	0	0
Renny Point	63°49'15"N	83°34'59"W	2014-09-15	0	0	0
RWS IQ4 OS	65°31'56"N	86°49'6"W	2014-09-18	58	58	0
Salisbury Island	63°32'36"N	77°00'02"'W	2014-09-09	1	1	0
Salisbury Island	63°32'36"N	77°00'02"W	2014-09-11	11	1	11
Sea Horse Point	63°46'17"N	80° 8'1"W	2014-09-16	0	0	0
Seeko Island	65°39'51"N	84°31'16"W	2014-09-18	1	1	0
Shuke Islands	64°15'59"N	77° 8'1"W	2014-09-13	0	0	0
Terror Point	64° 6'6"N	80°51'24"W	2014-09-16	0	0	0
Vansitart Island	66° 2'7"N	84°26'10"W	2014-09-18	15	15	0
Walrus Island	63°16'25"N	83°41'15"'W	2014-09-11	248	248	152
Walrus Island	63°16'25"N	83°41'15"W	2014-09-16	2579	2579	200
Weggs Island	62°19'2"N	73° 3'51"W	2014-09-09	0	0	0
West Foxe Island	64°17'24"N	75°47'39"W	2014-09-12	1	1	0
			South and East Hudson Bay Stock			
Belcher Islands	56°12'23"N	79°17'47"W	2014-09-13	3	3	0
Drifwood Island	57°18'16"'N	78°23'42"'W	2014-09-14	1	1	0
Ottawa Islands	59°49'10"N	80°30'W	2014-09-13	1	1	0
Ottawa Islands	59°29'29"N	80°30' W	2014-09-15	1	1	1
Sleeper Island	57°29'35"N	79°49'10"W	2014-09-13	7	7	0
Sleeper Island	57°29'35"N	79°49'10"W	2014-09-14	99	99	0

Table 4a. Simple counts (SC), minimum counted population (MCP), and bounded counts (BC), haulout proportion (SE), adjusted estimates (SE, 95% Confidence limits, L95, U95), coefficient of variation (CV) and PBR estimates from the September 2014 survey of the Hudson Bay-Davis Strait and South and East Hudson Bay walrus stocks. The BC estimates are before the diagonal and adjusted for proportion of animals hauled out follow the diagonal. Confidence limits for BC were not adjusted for the proportion hauled out. Estimates for Hoare Bay are from Stewart and Hamilton (2013) from surveys flown in 2007.

Count		Haulout proportion	Adjusted [1]Estimate (SE)	L95[1]	U95[1]	cv
Hudson Bay Davis Strait stock						
SC	2144	0.30 (0.173)	7100 (4100)	2500	20,500	0.58
SC	2144	0.25 (0.88, 95% CL = 0.219–0.283)	8600	7600	9800	0.35
MCP	3418	0.743 (0.053)	4600 (300)	4600	5300	0.074
BC	5969	0.743 (0.053)	6000/8100	3400	5200	
Hoare Bay (Baffin Island)	1051	0.42 (0.17)	2500 (400)	1800	3500	0.17
South and East Hudson Bay stock						
SC	58	0.30 (0.173)	200 (100)	-	400	0.57
SC	58	0.25 (0.088, 95% CL = 0.219–0.283)	200	200	300	0.35
MCP	101	0.743 (0.053)	100 (12)	100	200	0.07
BC	196	0.743 (0.053)	200/25	100	1800	-

[1] rounded to the nearest 100

Table 4b. Simple counts, adjusted estimates coefficient of variation (CV) and PBR estimates from the September 2014 survey of the Hudson Bay-Davis Strait and South and East Hudson Bay walrus stocks. PBR is calculated using Recovery factors (F_R) of 0.5 and 1. Two values for R_{max} were used: 0.07 and 0.08. Survey estimates for Hoare Bay are from Stewart and Hamilton (2013) from surveys flown in 2007.

Abundance			PBR R_{max}=0.07		PBR R_{max}=0.08	
Hudson Bay-Davis Strait stock						
Count	Adjusted estimate	CV	F_R=0.5	F_R=1.0	F_R=0.5	F_R=1.0
2144	7100	0.58	79	158	90	180
2144	8600	0.35	93	186	109	218
South and East Hudson Bay stock						
58	200	0.57	2	4	2	4
58	200	0.35	3	6	3	6
Hoare Bay						
1051	2500	0.17	38	77	44	88

Table 5. Reported harvest (subsistence and sport harvest) statistics for communities harvesting walrus from the Hudson Bay-Davis Strait for the period 1960-2014(COSEWIC 2006; DFO statistics).

Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Nunavut													
Cape Dorset		1	30	40	20		34	7		6	14	21	
Clyde River	5	3	6	8	10		9				0		
Iqaluit			6	7	26	16	26	16					
Kimmirut		4	4	3	1	1	100			1	0		
Pangnirtung	15	23	1		12	22	12	9		4			4
Qikiqtarjuaq													
Arviat						2	1	1				4	
Chesterfeild In.	18		18		34								
Coral Harbour	194	180			30		20	200					64
Rankin Inlet					31						0		
Repulse Bay		25			30				1				10
Whale Cove		4			2				1				
Nunavut total	232	240	65	58	196	41	202	233	2	11	14	25	78
Nunavik													
Killiniq													
Kangiksualujjuaq													
Kuujjuaq													
Tasiujaq													
Kangirsuk													
Aupaluk													
Quaqtaq													
Kangiksujuaq													
Salluit			30	30	30								
Ivujivik													
Akulivik													
Puvirnituq													
Nunavik total	0	0	30	30	30	0	0	0	0	0	0	0	0
Total	232	240	95	88	226	41	202	233	2	11	14	25	78

Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Nunavut													
Cape Dorset	35	14		20	72	66	67	20	10	35	59	4	15
Clyde River	37			3	2	7	0	2	3		6	1	0
Iqaluit			70	50	32	12	65	65	58	40	25	39	27
Kimmirut		17	6	10	3	4	0	1	5	10	6	0	
Pangnirtung	4		125	3	31	33	0	20	62	12	33	13	6
Qikiqtarjuaq	29	49	20	7	12	12		46	4	35	6	37	5
Arviat													
Chesterfeild In.							0	0	0	0	0	0	1
Coral Harbour			5	3		0	1	5	4	3	5	14	10
Rankin Inlet	103	65	24	43	42	16	41	54	11	39	67	60	24
Repulse Bay			5	3	5	0	0	8	13	15	15	2	4
Whale Cove	6			10	10	0	0	6	33	35	10	5	14
Nunavut total				2		3	6	0	1	3	3	0	0
Nunavik													
Killiniq		1	4	0	2								1
Kangiksualujjuaq		0	1	1	0	0	1	1	0	0	0	0	0
Kuujjuaq		0	0	0	0	0	15	7	0	0	0	0	0
Tasiujaq		0	0	2	0	0	0	0	0	0	0	0	0
Kangirsuk		7	7	7	9	2	1	8	4	5	12	3	15
Aupaluk				1	0	0	0	0	0	0	1	1	3
Quaqtaq		13	9	5	7	0	7	10	3	2	6	9	8
Kangiksujuaq		2	5	4	7	0	0	9	0	0	1	0	17
Salluit		57	59	13	1	0	5	36	30	73	2	27	16
Ivujivik									33	29	57		16
Akulivik		12	15	18	0	0	3	5	24	8	1	0	16
Puvirnituq													
Nunavik total	0	92	100	51	26	2	32	76	94	117	80	40	92
Total	214	237	355	205	235	155	212	303	298	344	315	215	198

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Nunavut																	
Cape Dorset		5	35	24	24	7	11	23	24	10	30	8	4	10	46	11	5
Clyde River	0	3	1	0	1	7	2	0	0	0	1	0	1	0	0	1	0
Iqaluit	4	29	10	8	16	16	16	29	26	25	9	0	27	15	19	7	1
Kimmirut	4	8	4	9	8	22	7		2	0	5	NR	NR	NR	0	0	4
Pangnirtung	0	12	44	8	40	21	3	0	40	8	15	16	4	3	15	19	9
Qikiqtarjuaq	9	9	12	15	10	13	21	0	5	16	13	3	0	0	0	1	33
Arviat	0	0	3	0	0	0		0	0	0	0	NR	0	2	1	NR	3
Chesterfeild In.	20		11	9	9	9		6	0	3	12	NR	0	NR	4	NR	NR
Coral Harbour	43	31	41	45	45	60		55	31	48	26	10	9	8	1	NR	30
Rankin Inlet	2	4	5	5	3	2	3	4	2	6	12	NR	12	NR	7	NR	12
Repulse Bay	9	18	13	11	11	18		25	8	0	7	0	0	2	1	NR	20
Whale Cove	0	0	2	0	0	0		2	0	0	0	NR	0	0	0	NR	1
Nunavut total	91	119	181	134	167	175	63	144	138	116	130	37	57	40	94	39	118
Nunavik																	
Killiniq	0	0															
Kangiksualujjuaq	0	3	0	5	0	0	0	1	1	1	1	3	0	0	0	0	0
Kuujjuaq	0	0	0	3	0	0	4	0	0	0	4	0	0	6	0	0	0
Tasiujaq	9	7	3	5	3	2	0	2	5	3	9	0	0	0	0	0	0
Kangirsuk	3	0	7	5		6	7	2	5	10	9	0	4	0	3	0	7
Aupaluk	0	0	0	0	3	2	5	3	5	2	2	0	0	0	0	1	0
Quaqtaq	7	6	10	4	12	10	9	7	6	20	3	8	11	2	0	0	0
Kangiksujuaq	41	2	0	0	0	3	6	2	3	2	4	0	5	1	0	4	0
Salluit	91	1	8	0	10	3	15	11	19	19	18	20	7	0	0	1	0
Ivujivik	0	19	8	11		13	7	33	0	20	0	23	1	7	0	0	0
Akulivik	1	18	10	1	4	9	12	1	9	0	3	9	10	1	0	0	14
Puvirnituq	11	0	16	0		6	12	12	3	0	4	6	0	0	0	0	0
Nunavik total	163	56	62	34	32	54	77	74	56	77	57	69	38	17	3	6	21
Total	254	175	243	168	199	229	140	218	194	193	187	106	95	57	97	45	139

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Nunavut												
Cape Dorset	1	NR	6	25	NR	NR	NR	1	2	0	0	0
Clyde River	0	2	NR	1	0	NR	NR	NR	0	0	0	0
Iqaluit	1	NR	10	9	11	NR	14	14	14	19	6	1
Kimmirut	7	4	6	2	NR	NR	NR	7	0	1	0	2
Pangnirtung	15	NR	NR	15	NR	10	NR	NR	NA	7	0	4
Qikiqtarjuaq	1	0	NR	9	6	NR	NR	6	5	10	0	0
Arviat	5	NR	1	0	0	NR	NR	0	0	0	0	0
Chesterfeild In.	4	3	3	0	2	0	NR	NR	7	4	0	15
Coral Harbour	10	NR	17	18	4	4	15	8	11	15	22	22
Rankin Inlet	2	2	3	13	6	3	6	2	4	6	0	0
Repulse Bay	NR	3	6	6	12	NR	4	NR	0	5	0	0
Whale Cove	NR	NR	NR	0	0	NR	NR	0	0	0	0	0
Nunavut total	46	14	52	98	41	17	39	38	43	67	28	44
Nunavik												
Killiniq												
Kangiksualujjuaq	0	0	0	0	0	0	0	0	1	0	0	0
Kuujjuaq	0	0	0	5	0	0	0	1	0	0	0	0
Tasiujaq	0	0	2	3	0	0	0	1	0	0	0	0
Kangirsuk	0	0	0	0	1	0	0	0	0	0	7	0
Aupaluk	0	0	0	0	0	0	0	0	0	0	0	0
Quaqtaq	6	11	5	2	3	6	7	6	2	5	10	4
Kangiksujuaq	1	9	0	4	0	0	2	1	2	5	2	0
Salluit	2	10	17	14	24	17	7	14	11	12	0	14
Ivujivik	9	0	8	11	13	8	0	5	5	0	0	0
Akulivik	11	12	4	9	5	9	3	5	5	8	9	10
Puvirnituq	9	0	8	9	21	13	17	9	12	17	3	0
Nunavik total	38	42	44	57	67	53	36	42	38	47	31	28
Total	84	56	96	155	108	70	75	80	81	114	59	72

Table 6. Reported harvest statistics for harvest of the South and East Hudson Bay stock for 1973-2014. (COSEWIC 2006; DFO statistics)

Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Inukjuak		4	7	1	4	3	40	10	7	2	0	15	9	11	12	7	0	8	8
Kuujjuarapik		0	1	2	0	0	0	0	1	0	1	0	1	0	0	0	0	1	0
Sanikiluaq	8		8	7	6	0			2	10	3	7	1	2	10	5	5	5	5
Umiujaq															0	0	1		0
Total	8	4	16	10	10	3	40	10	10	12	4	22	11	13	22	12	6	14	13
Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Inukjuak	5	9	5	10	11	5	8	0	0	0	0	4	0	3	0	0	8	0	0
Kuujjuarapik	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Sanikiluaq					2	4	20	1	1	0	15	3	NR	NR	2	NR	0	2	2
Umiujaq	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	5	10	5	10	13	11	28	1	1	0	15	7	0	3	2	0	8	2	2
Year	2011	2012	2013	2014															
Inukjuak	0	0	5	0															
Kuujjuarapik	0	0	0	0															
Sanikiluaq	2	3	0	0															
Umiujaq	0	0	0	0															
Total	2	3	5	0															

	2010	2011	2012	2013	2014	5 y average
Baffin Region						
Cape Dorset	1	2	0	0	0	0.6
Clyde River	*0*	0	0	0	0	0
Iqaluit	14	14	19	6	1	10.8
Kimmirut	7	0	1	0	2	2
Pangnirtung	*7.2*	*7.2*	7	0	4	7.2
Qikiqtarjuaq	6	5	10	0	0	4.2
Arviat	0	0	0	0	0	0
Chesterfeild In.	*5.2*	7	4	0	15	5.2
Coral Harbour	8	11	15	22	22	15.6
Rankin Inlet	2	4	6	0	0	2.4
Repulse Bay	*1.8*	0	5	0	0	1.8
Whale Cove	0	0	0	0	0	0
Nunavut total	52	50	67	28	44	
Nunavik						
Killiniq						
Kangiksualujjuaq	0	1	0	0	0	0.1
Kuujjuaq	1	0	0	0	0	0.1
Tasiujaq	1	0	0	0	0	0.1
Kangirsuk	0	0	0	7	0	1
Aupaluk	0	0	0	0	0	0
Quaqtaq	6	2	5	10	4	5.4
Kangiksujuaq	1	2	5	2	0	1.5
Salluit	14	11	12	0	14	12.4
Ivujivik	5	5	0	0	0	3.9
Akulivik	5	5	8	9	10	6.7
Puvirnituq	9	12	17	3	0	11.5
Nunavik total	42	38	47	31	28	
Total	94	88	114	59	72	

Table 7. Walrus counts in the Southampton-Coats Island area of Hudson Bay during July-August 1976-77. From Mansfield and St. Aubin (1991).

Date	Walrus Island	Bencas Island	Cape Préfontaine	Cape Pembroke	East Coats	Sea Ice	Total
1976-07-24	297	167	0	240	536	-	1230
1976-07-24	169	0	0	0	561	-	730
1976-07-25	368	0	33	0	1090	-	1491
1976-07-26	103	0	102	30	992	-	1227
1976-07-27	250	0	92	282	773	-	1397
1976-07-28	75	0	103	345	333	-	856
1976-07-29	15	15	12	30	175	-	232
1976-07-30	8	0	75	0	175	-	258
1976-07-31	9	0	20	0	225	-	254
1976-08-01	7	0	195	0	450	-	652
1976-08-03	0	0	160	50	536	-	746
1976-08-04	0	0	7	12	750	-	769
1977-07-20	0	-	0	0	20	6	26
1977-07-21	0	-	-	-	-	800	800
1977-07-22	0	-	-	-	0	300	300
1977-07-23	25	-	-	-	-	675	700
1977-07-24	0	-	0	0	6	-	6
1977-07-26	0	-	25	0	1721	425	2171
1977-07-26	-	-	-	-	-	625	625
1977-07-28	0	-	0	13	125	0	138
1977-07-29	0	-	0	248	179	0	427
1977-08-01	0	-	70	150	1113	0	1333

Table 8. Maximum daily counts from eastern Coats Island during July-August, 1976-77 (Mansfield and St. Aubin 1991).

Date	1976	1977
24-July	-	0
25-July	-	765
26-July	775	1220
27-July	400	1460
28-July	225	700
29-July	110	250
30-July	120	320
31-July	220	1275
01-Aug.	305	1125
02-Aug.	545	-
03-Aug.	495	-
04-Aug.	450	-
05-Aug.	260	160
06-Aug.	250	660
07-Aug.	250	-
08-Aug.	245	400
09-Aug.	140	360
10-Aug.	280	475
11-Aug.	540	990
12-Aug.	600	840
13-Aug.	540	495
14-Aug.	5	830
15-Aug.	0	1010
16-Aug.	0	1605
17-Aug.	140	1795
18-Aug.	385	1235
19-Aug.	335	260
20-Aug.	165	385
21-Aug.	180	460
22-Aug.	105	1090
23-Aug.	55	600
24-Aug.	55	480
25-Aug.	-	575
26-Aug.	125	-
27-Aug.	180	-
28-Aug.	275	-

Table 9. Abundance observations from Nottingham/Fraser/Salisbury island complex and the Walrus – Coats island complex.

Location	Date	Number	Study
Walrus-Coats Island-Southampton Island			
Aerial surveys	August 1954	2900	Loughrey 1959
Aerial/boat surveys	Aug 1961	2650	Fisher 1962
Aerial surveys	July-Aug. 1976	254-1491	Mansfield and St. Aubin 1991
Aerial surveys	July –Aug 1977	6-2171	Mansfield and St. Aubin 1991
Aerial surveys	Aug 1988	757	Richard 1993. unpubl. rep.
Aerial surveys	July 1989	1231	Richard 1993. unpubl. rep.
Aerial surveys	Aug 1990	1373	Richard 1993. unpubl. rep.
Nottingham/Fraser/Salisbury Islands			
Aerial surveys	Aug 1988	92	Richard 1993. unpubl. rep.
Aerial surveys	July 1989	97	Richard 1993. unpubl. rep.
Aerial surveys	Aug 1990	461	Richard 1993. unpubl. rep.
Aerial surveys	Aug 2010	714	Gosselin pers comm.
Hunter interviews	Summer 1985	500-1000+	Orr and Rebizant 1987
South and East Hudson Bay stock			
Sleeper Islands-boat observations	1930	400	Twomey and Herrick (1942)
boat	Summer 1971	100	Manning 1976
Belcher Is-beluga aerial survey	Summer 1993	30	Desrosier in Stewart and Higdon, unpubl. rep.
Cape Henrietta Maria	Spring 1955	1000	Clark in Loughrey 1959
Cape Henrietta Maria	2007	147 (SD=5)	Stewart and Higdon 2014 unpubl. rep.
Cape Henrietta Maria	August 1999	221	COSEWIC 2006
Cape Henrietta Maria	September 1986	330	COSEWIC 2006
Cape Henrietta Maria	September 1983	204	COSEWIC 2006
Cape Henrietta Maria	October 1978	310	COSEWIC 2006

FIGURES

Figure 1. Location of Atlantic walrus stocks in the eastern Canadian Arctic. The stocks are Baffin Bay (BB), West Jones Sound (WJS), Penny Strait-Lancaster Sound (PS-LS), Hudson Bay-Davis Strait (HBDS) and South and East Hudson Bay (SEHB). The North and Central Foxe Basin stocks are surveyed together and are referred to as Foxe Basin (FB).

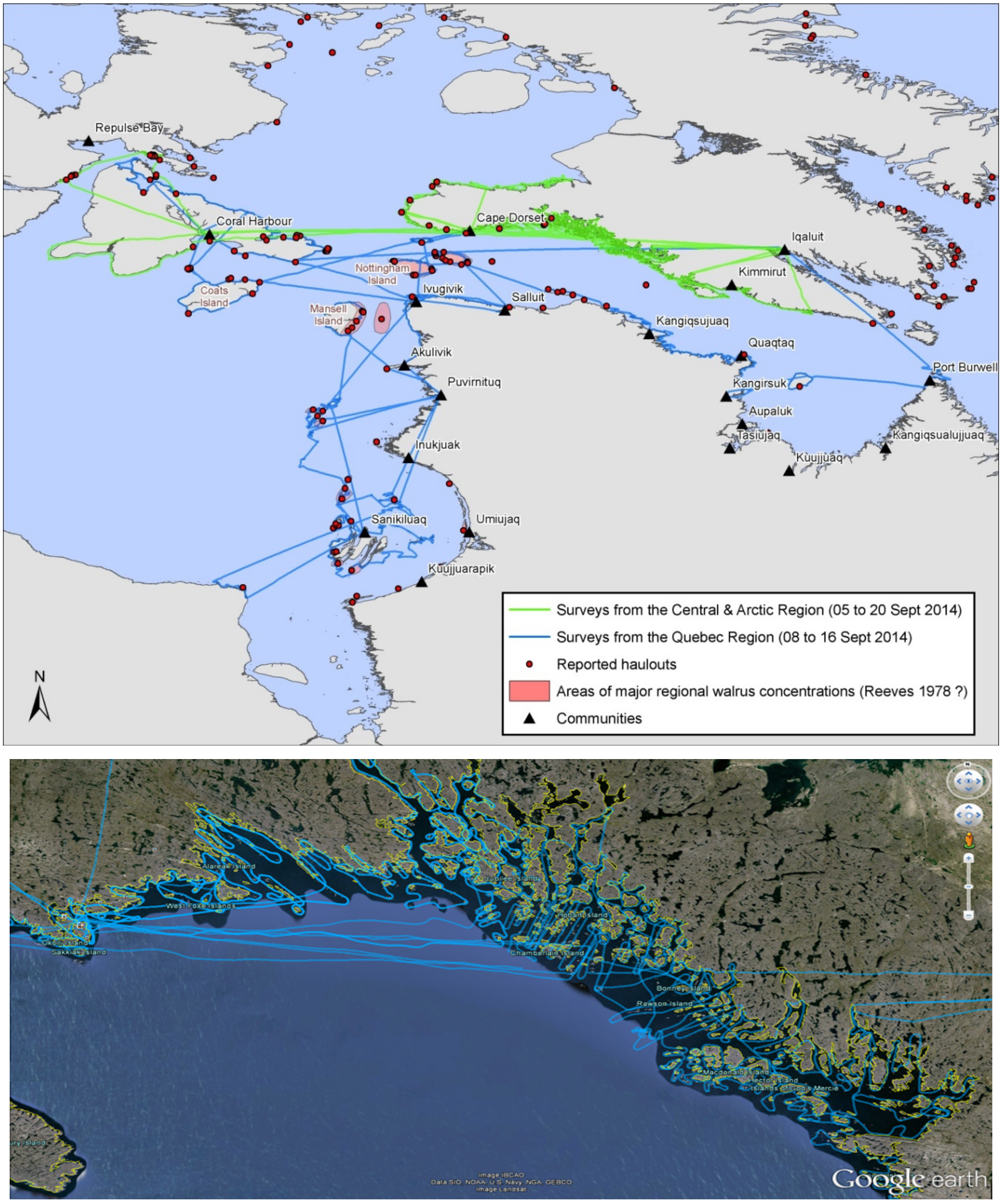

Figure 2. Locations of known walrus haulout sites as recorded from the literature and from discussions with hunters and survey tracks flown by the two survey aircraft during September 2014. The lower figure shows flight lines along south Baffin Island.

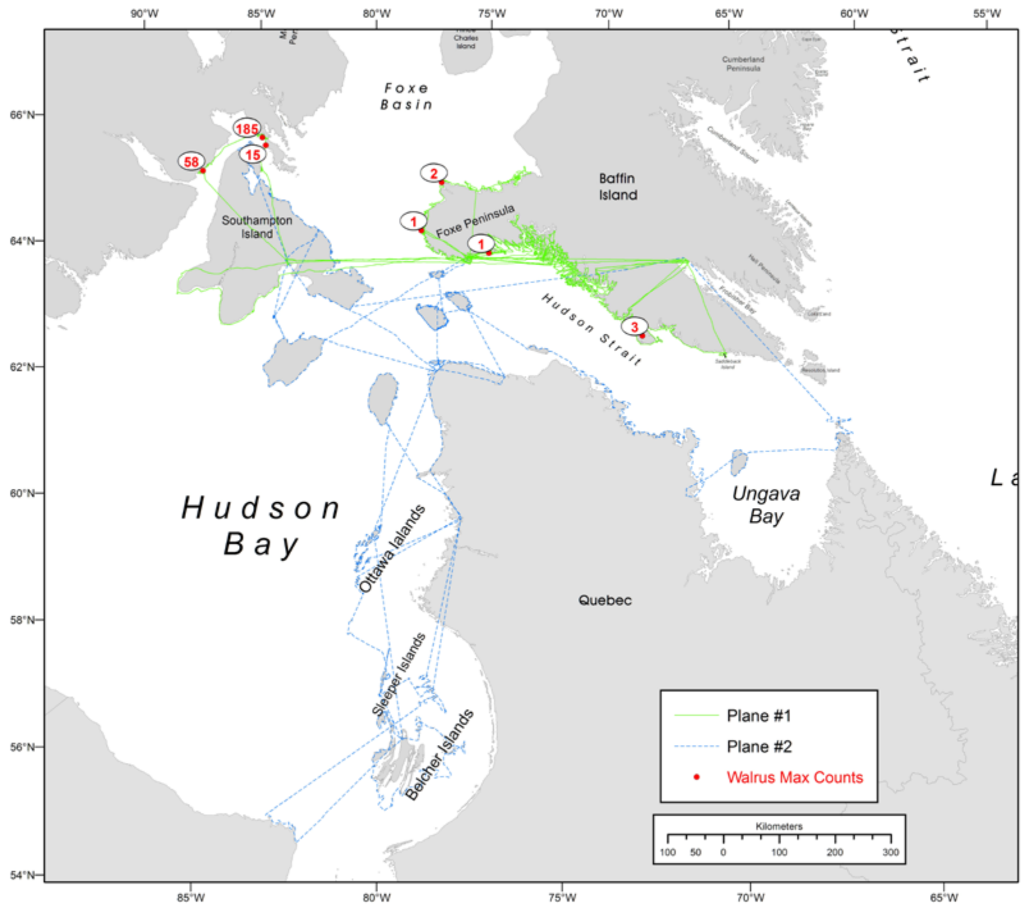

Figure 3. Maximum counts from photographs of hauled out walrus from the area covered by plane 1.

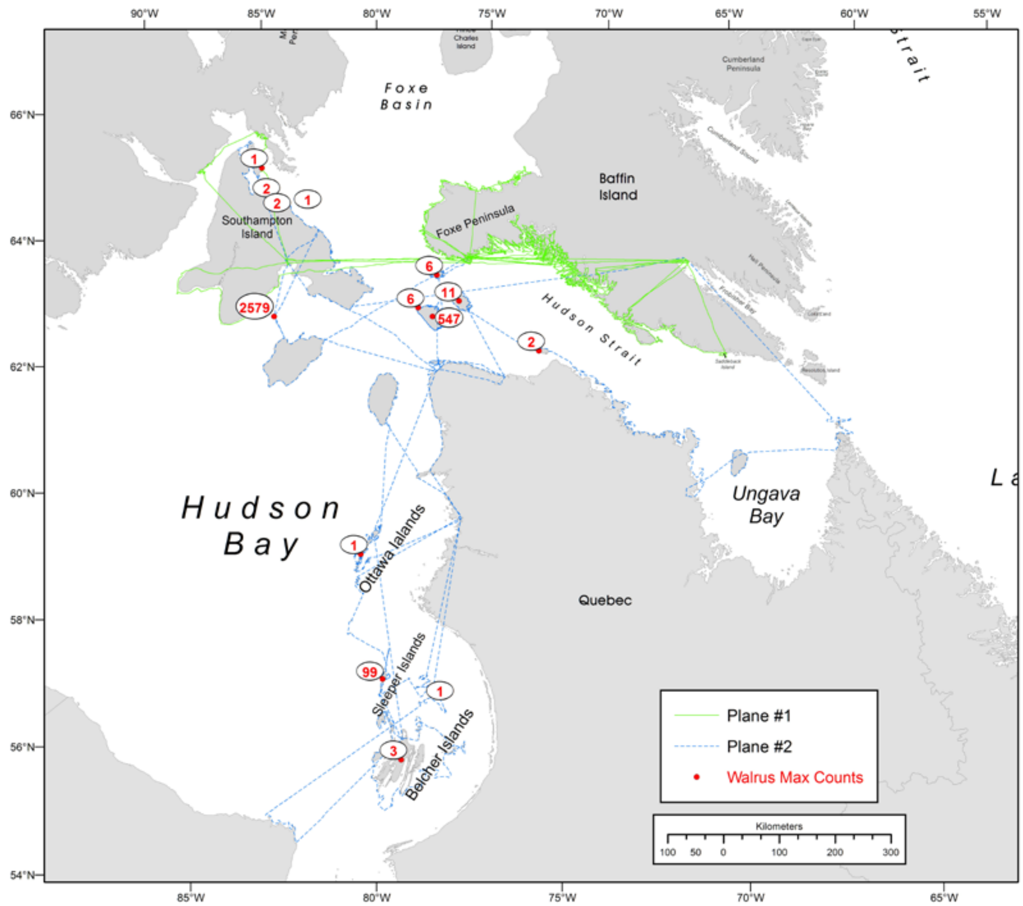

Figure 4. Maximum counts from photographs of hauled out walrus from the area covered by plane 2.

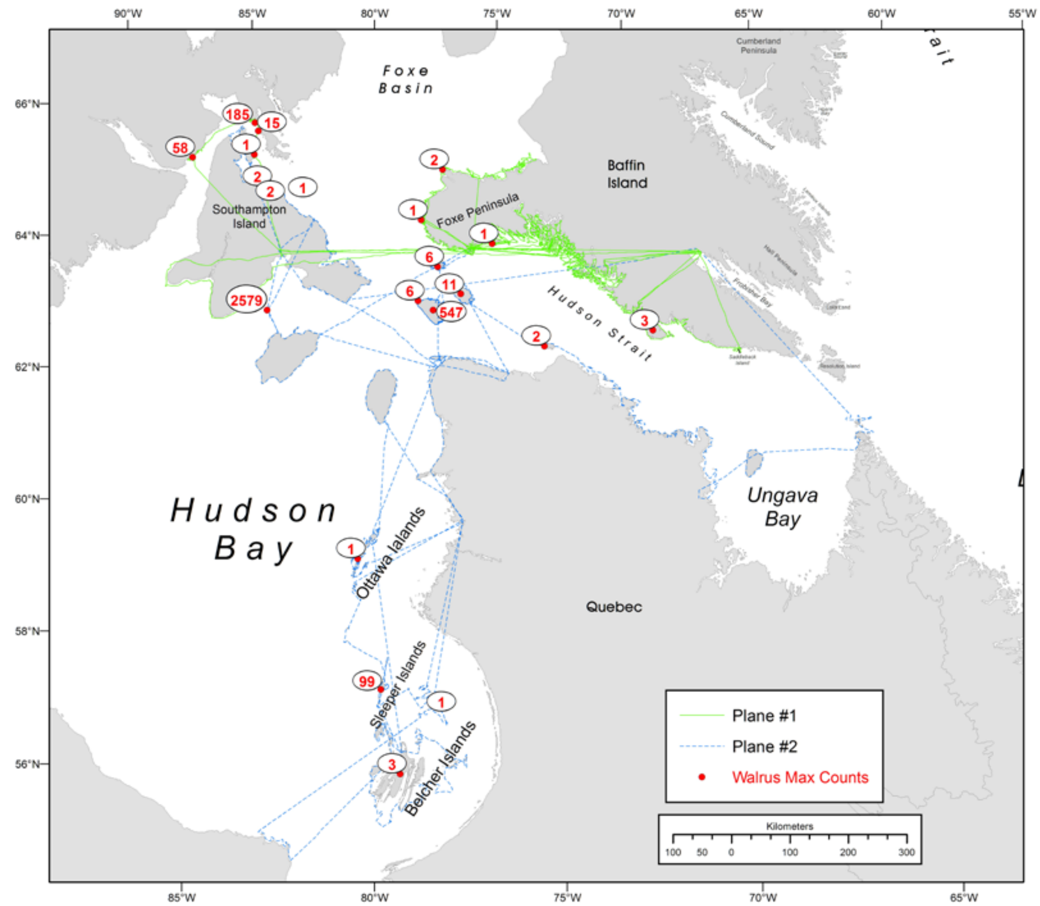

Figure 5. Maximum counts from photographs of hauled out walrus from the study area.

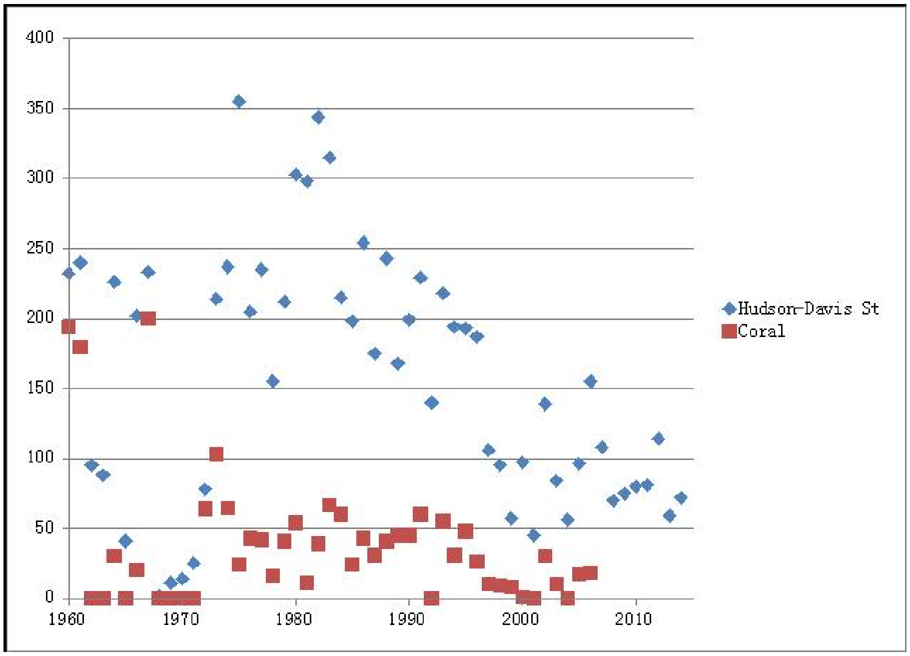

Figure 6. Reported and interpolated harvests from all Canadian communities hunting the Hudson Bay-Davis Strait stock, and reported harvests from the community of Coral Harbour which has a long time series of consistent reporting.

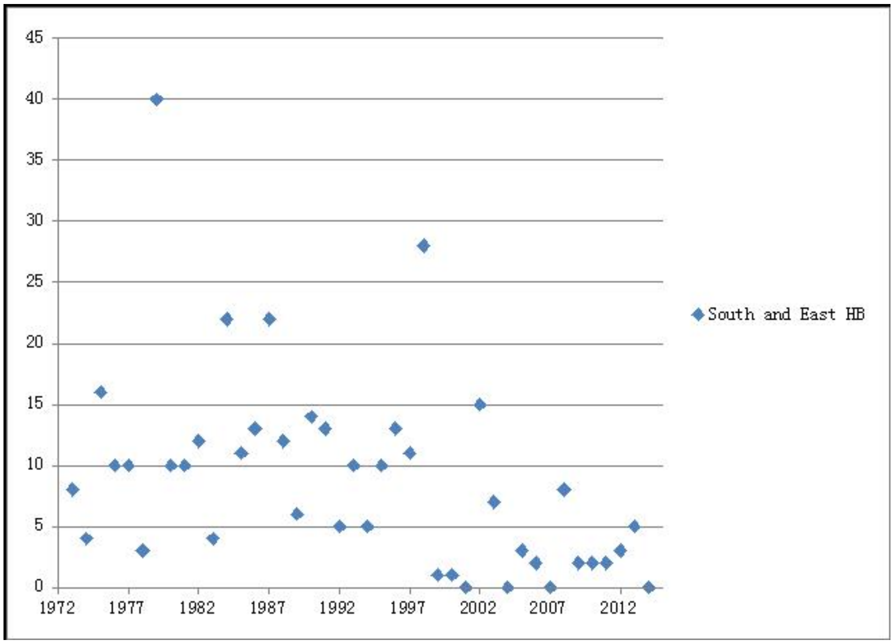

Figure 7. Reported and interpolated harvests from communities hunting the South and East Hudson Bay stock.