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Aerial survey estimates of hauled-out Ringed Seal (*Pusa hispida*) density in western Hudson Bay, June 2009 and 2010

Estimations par relevé aérien des phoques annelés (*Pusa hispida*) hors de l'eau de la côte ouest de la baie d'Hudson, juin 2009 et 2010

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ABSTRACT

We conducted strip-transect surveys in June 2009 and 2010 to estimate density and abundance of Ringed Seals (*Pusa hispida*) in western Hudson Bay, Canada. Ringed Seal density has varied considerably over the 16-year period of aerial surveys. Recent survey results describe a decrease in Ringed Seal density from 1.06 seals/km^2 in 2007, to 0.50 in 2008, and 0.28 in 2009, followed by an increase to 0.73 in 2010. However, estimates from 2009 should be considered cautiously due to an incomplete survey caused by poor weather and ice conditions. Our results add to a long time-series of Ringed Seal density and abundance in the Arctic. A declining, albeit not significant, trend in Ringed Seal density estimates in western Hudson Bay is evident over the past sixteen years based on results obtained from nine aerial surveys which include the 2009 and 2010 surveys. As Ringed Seals are considered to be a good indicator species of long-term changes, continued monitoring of population density will add to an understanding of biological mechanisms of population response to environmental forcing.

RÉSUMÉ

Nous avons effectué des relevés de transects en bande en juin 2009 et 2010 pour estimer la densité et l'abondance des phoques annelés (*Pusa hispida*) de la côte ouest de la baie d'Hudson, au Canada. La densité des phoques annelés a varié considérablement pendant les 16 ans de relevés aériens. Les résultats des récents relevés font état d'une diminution de la densité de phoques annelés, qui est passée de 1,06 phoque/km^2 en 2007 à 0,50 phoque/km^2 en 2008 et à 0,28 phoque/km^2 en 2009, puis d'une augmentation de la densité à 0,73 phoque/km^2 en 2010. Cependant, les estimations de 2009 doivent être interprétées avec prudence, car le relevé était incomplet en raison des intempéries et de la glace. Ces résultats s'ajoutent à une longue série chronologique de données sur la densité et l'abondance des phoques annelés en Arctique. Une tendance à la baisse, mais non significative, des estimations de densité des phoques annelés de la côte ouest de la baie d'Hudson est évidente lorsqu'on regarde les résultats des neuf relevés aériens obtenus au cours des 16 dernières années, y compris ceux de 2009 et de 2010. Comme les phoques annelés sont une espèce considérée comme étant un bon indicateur de changements écologiques à long terme, il faudra continuer de surveiller la densité de cette population pour mieux comprendre les mécanismes biologiques de la réponse de cette population au forçage environnemental.

INTRODUCTION

In Hudson Bay, surface air temperature in spring and summer and the length of the ice-free period have increased significantly, whereas sea-ice extent and winter snow depth have decreased in the last 20-30 years (Gough et al. 2004, Gagnon and Gough 2005, Parkinson and Cavalieri 2008). Likely as a consequence of rising surface air temperature, the break-up of sea ice in western Hudson Bay is now occurring 3-4 weeks earlier than in the 1970s (Stirling and Parkinson 2006). Evidence for impacts of climate warming on marine animal populations has already been documented in Hudson Bay for Thick-billed Murres (*Uria lomvi*; Gaston et al. 2003), Polar Bears (*Ursus maritimus*; Regehr et al. 2007), and Ringed Seals (*Pusa hispida*; Ferguson et al. 2005).

Ringed Seals, an ice-dependent species, have a northern circumpolar distribution, and occur at the southern limit of their range in Hudson Bay (Mansfield 1967). Sexually mature animals use stable land-fast and pack ice with sufficient snow cover to build birth lairs that are critical for pup survival (Hammill and Smith 1991). Ringed Seals are sensitive to variations in sea-ice habitat including early or late ice break-up, heavy/light ice conditions (Stirling et al. 1982, Smith 1987, Harwood et al. 2000) and unusual warm and/or rain events in the spring (Stirling and Smith 2004). Ringed Seals face critical challenges with predicted climate warming and loss of sea ice habitat (Laidre et al. 2008).

Ringed Seals contribute the bulk of the Inuit subsistence harvest of marine mammals and are the main food resource for polar bears. Concerns have arisen over possible declines in Ringed Seal numbers in western Hudson Bay as indicated by hunter knowledge, reduced pregnancy rate (Stirling 2005), reduced pup survival (Holst et al. 1999), older age structure (Vincent-Chambellant 2010), reduced recruitment (Ferguson et al. 2005), and reduced growth and number of polar bears (Regehr et al. 2007). Management concerns arose from a pattern of decreasing Ringed Seal abundance estimates provided from four spring aerial surveys of basking Ringed Seals 1995-2000 that estimated population density declines from 1.60 seals/km2 (104,000 seals) to 0.62 (44,000) (Lunn et al. 2000, Chambellant 2010).

Effects of climate changes on population size require long-term studies to separate changes from concurrent natural variations (Laidre et al. 2008). Aerial surveys of western Hudson Bay were conducted over the 1995 to 2000 period by Environment Canada (Lunn et al. 1997). DFO conducted aerial surveys in western Hudson Bay in 2007 and 2008 (Chambellant and Ferguson 2009, Chambellant 2010). Here we provide density and abundance estimates of 2009 and 2010 Ringed Seal surveys and interpret long-term trends for the 1995-2010 period.

MATERIALS AND METHODS

SURVEY DESIGN

To allow comparison with aerial surveys completed in the 1990s by Lunn et al. (2000) and in 2007 and 2008 by Chambellant and Ferguson (2009) in western Hudson Bay, the flight plan and protocol was replicated in 2009 and 2010. A Cessna 337 “Skymaster” chartered from Wildlife Observation Services was used to fly transects of 800 m wide (400 m on each side) between Churchill, MB and Arviat, NU at 150 m altitude and 260 km/h ground speed. In 2009, a transect width of 1200 m (600 m on each side) was used, however, to be consistent with surveys flown in other years, only the data collected within the 800 m strip were used for analyses. The 16 long transects of previous surveys were to be flown and 20 short transects were added over the area of landfast ice along the coast between Churchill, MB and Arviat, NU, where Ringed Seals are found at higher density (stratified sampling design; Fig. 1).

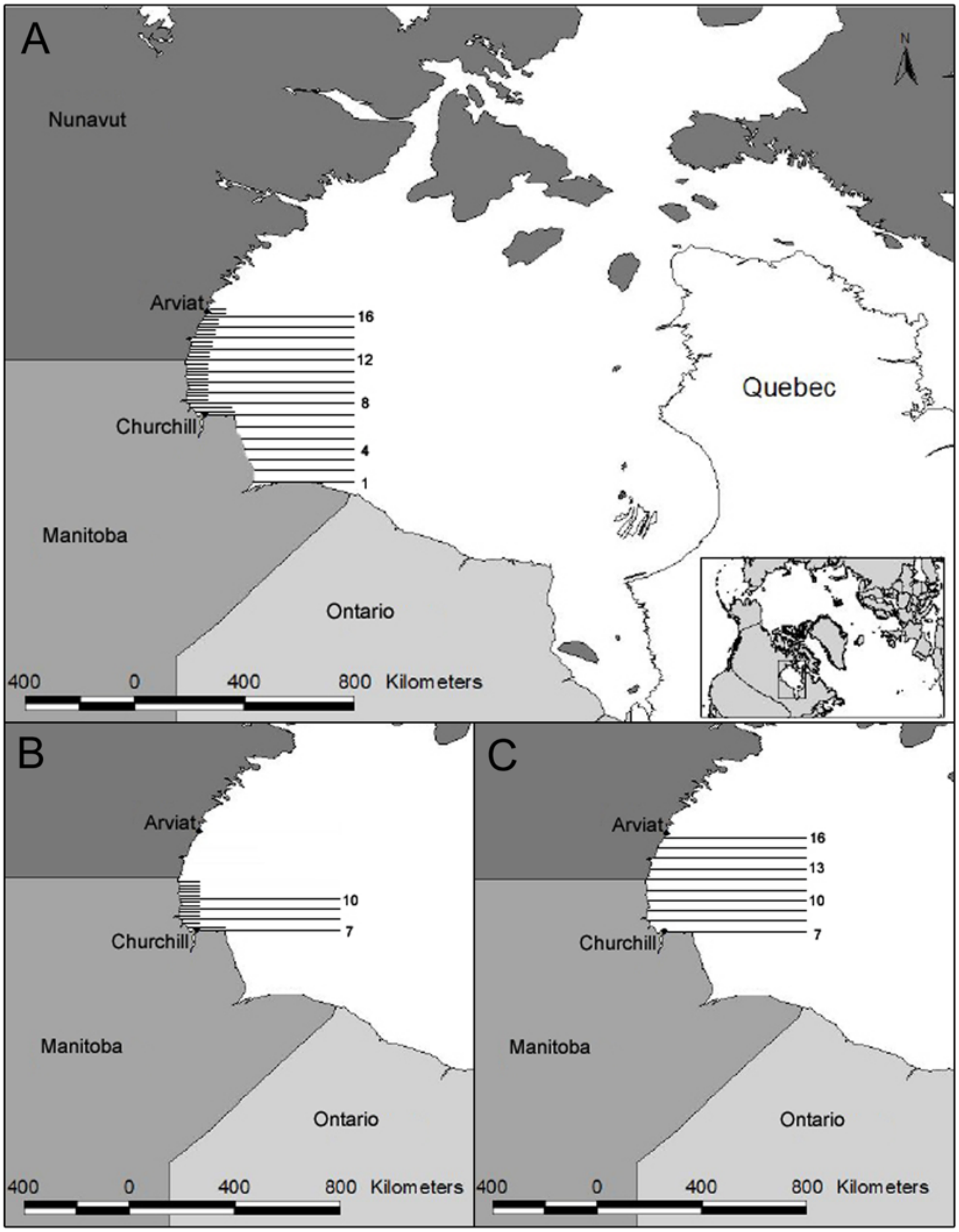

Figure 1. Western Hudson Bay study area illustrating planned (A) and conducted aerial survey transects for June 2009 (B) and 2010 (C).

We used a systematic, strip-transect survey design (Lunn et al. 1997) whereby two observers sat in the rear of the airplane. Each observer was assigned one side of the plane for the whole survey duration. Wing struts and windows were marked for each observer using the $y = Xa/A$ formula, where y is the projected transect width on the ground, X is the desired transect width

(400 m) at 150 m of altitude, *A* is the flying altitude and *a* is the specific height of observer eye level in the plane from the ground.

For the 2007 and 2008 surveys, Magaly Chambellant and Steven Ferguson observed, in 2009 the observers were Natalie Asselin and Darren Saltel, and in 2010 Natalie Asselin and Brent Young were the observers. Observers did not communicate real-time results while on survey. Waypoints and start and end times of each transect were recorded by a co-pilot, Blair Dunn, using a GPS for all four DFO surveys. Observers surveyed the 400 m transect width and recorded sightings by distance intervals marked on the wing struts and windows of the aircraft. Sightings beyond transects (i.e., >400 m) were not included in the estimates of density and abundance. Ringed Seals hauled-out on the ice were the focal species but we also recorded seal holes and snow lairs, bearded seals (*Erignathus barbatus*), polar bears, beluga (*Delphinapterus leucus*), and other marine mammals. Group size of Ringed Seals was recorded. A group consisted of two or more seals within five seal body lengths of each other typically around the same hole or along a crack. We noted sea ice characteristics such as ice cover (%), landfast, floe size, and color, as well as cloud cover and visibility.

Length of each of the ten transects was calculated by the great circle distance method (http://www.movable-type.co.uk/scripts/latlong-vincenty.html) using the starting and ending coordinates. We adjusted transect length to account for missing effort due to technical problems (e.g., recorder failure) or reduced visibility (e.g., fog). Total study area and ice area within the study area were calculated by multiplying total effort (sum of transect lengths) and effort over ice (sum of transect lengths flown over ice), respectively, by the distance between each transect (i.e., 27.795 km corresponding to 15' of latitude).

SEAL DENSITY AND ABUNDANCE ESTIMATES

Density (Ringed Seals•km^{-2}), $\hat{D}$, was estimated by observer, by strip and for observers and strips combined, following the standard ratio estimate (Buckland et al. 2001):

$$\hat{D} = \sum_{i=1}^{k} n_i / \omega \sum_{i=1}^{k} l_i \tag{2}$$

where k is the number of transects, n_i is the number of Ringed Seals counted on the ith transect, ω is the strip width and l_i is the length of the ith transect.

Strip-transect analysis assumes the detection of all animals present on transect and typically results in negatively biased density and abundance estimates compared to line-transect analysis (Burnham and Anderson 1984, Chambellant and Ferguson 2009). Moreover, density and abundance estimates were not corrected for availability bias (i.e., seals not on top of ice at the time of the survey and therefore not available for visual observation) and are expected to be biased low. We therefore consider reported densities as indices.

The variance of $\hat{D}$, ($\sigma^2(\hat{D})$), was obtained following Kingsley and Smith (1981) for systematic survey:

$$\sigma^2(\hat{D}) = k * \frac{\sum_{i=1}^{k-1} (d_i - d_{i+1})^2}{2(k-1) * \left(\omega \sum_{i=1}^{k} l_i \right)^2}$$

with log-based confidence intervals estimated following Buckland et al. (2001). The abundance of Ringed Seals in the study area ($\hat{N}$) was estimated by multiplying the estimated density ($\hat{D}$) by study area (A). The standard error of $\hat{N}$ ($se(\hat{N})$) was computed as described in Stirling et al. (1982): $se(\hat{N}) = \hat{N} * cv(\hat{D})$

RESULTS

2009 AND 2010 SURVEY

Using Churchill, MB, as the focal airport, survey lines were flown on 2-8 June 2009. Due to the delay in the start of the survey, only 4 of the 10 basic survey lines could be flown. North of line 10, a large lead had opened up (Fig. 2) and north of transect 11_2 no landfast ice occurred (Fig. 3).

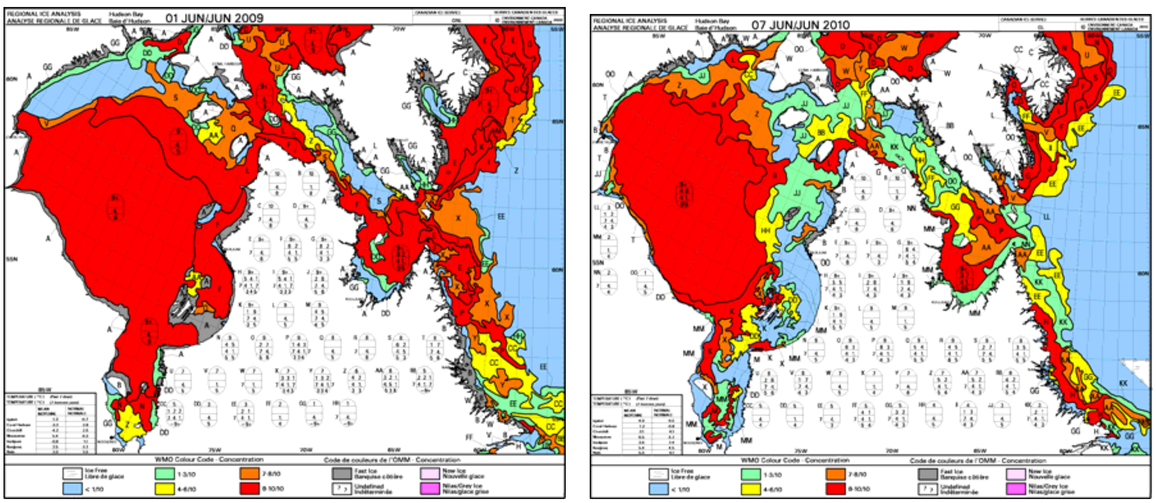

Figure 2. Canadian Ice Service regional ice analysis map for 1 June 2009 (left) and 7 June 2010 (right) for eastern Canadian Arctic (Canadian Ice Service. http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=D32C361E-1)

As in 2009, the start of the survey in 2010 was delayed by weather. Survey lines were flown from Churchill, MB, on 5-9 June 2010 (Fig. 1). Although we planned to incorporate survey lines south of Churchill to the Nelson River and increased stratified lines over landfast ice, only the 10 basic survey lines between Churchill and Arviat could be flown. By the time the survey was able to begin, there was very little landfast ice and a large lead along the shore stretching from Churchill to Arviat and northward (Fig. 3).

Distances to seal groups were recorded. As occurred in 2007 and 2008 (Chambellant and Ferguson 2009), both the 2009 and 2010 surveys recorded few sightings in the 0-100 m interval (results not shown).

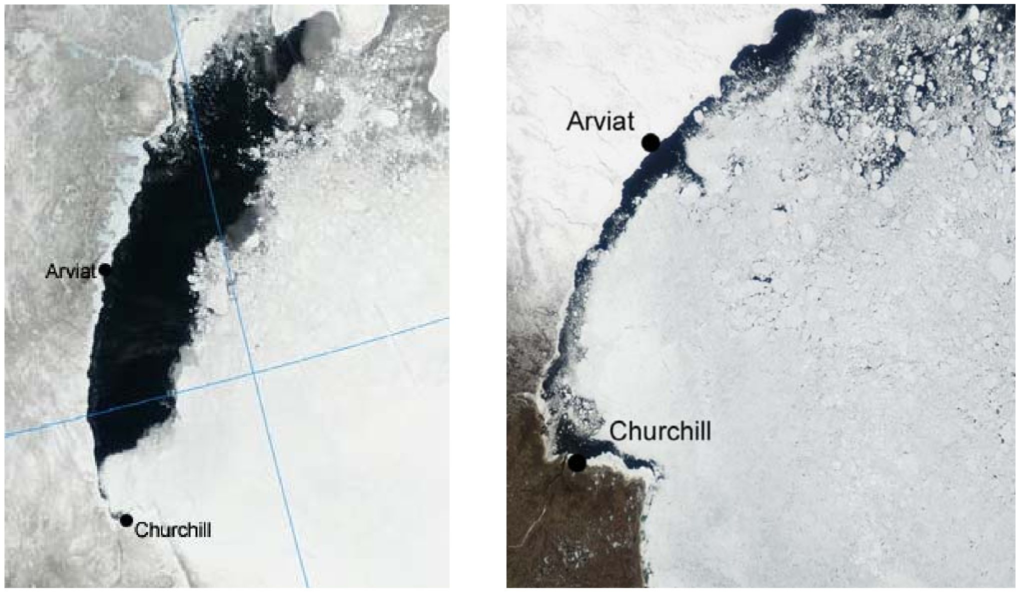

Figure 3. Satellite photo of western Hudson Bay taken on 9 June 2009 (left) and 5 June 2010 (right) showing ice cover at the start of the western Hudson Bay aerial survey. Locations of Churchill and Arviat are approximate. (Photo Credit: NASA/GSFC, MODIS Rapid Response. http://rapidfire.sci.gsfc.nasa.gov/).

DENSITY OF RINGED SEALS

We analyzed the data using the strip survey methodology (versus line transect) with an 800 m strip width for comparison with past results. For the long transect lines (7, 8, 9, 10) flown on 8 June 2009, we estimated Ringed Seal density at 0.27 seals/km^2 (SE=0.05) (Table 1). Short transects (7_1, 7_2, 8_1, 8_2, 9_1, 9_2, 10_1, 10_2, 11_1, 11_2) flown over the high density strata landfast ice estimated 2.10 seals/km^2 (SE=0.21) (Appendix 1). Combining the short and long transects flown on 8 June 2009 estimated 0.52 seals/km^2 (SE=0.07).

For the 2010 survey, we estimated Ringed Seal density at 0.73 seals/km^2 (SE=0.06) (Table 1). In 2010 there was very limited landfast ice at the time of the survey; therefore the short, landfast ice transects were not flown and a separate estimate of seals in this high density strata was not completed. The total study area for the 2010 survey was 85,450 km^2.

1995-2010 TRENDS

Ringed Seal density estimates varied considerably from year-to-year (Table 2). The Canadian Wildlife Service surveys estimated a maximum of 1.22 seals/km^2 of ice in 1995, and a minimum of 0.45 seals/km^2 of ice in 1999 (Table 2). The declining trend in Ringed Seal density estimates indicated by surveys in the 1990s ($r^2 = 0.79$; slope = -0.134; n = 5; $p = 0.045$) was not apparent when the 2007 and 2008 estimates were included ($r^2 = 0.20$; slope = -0.025; n = 7; $p = 0.32$; Chambellant 2010). Including the 2009 and 2010 estimates of 0.28 and 0.73 seals/km^2 calculated here did not result in a significant negative trend ($r^2 = 0.27$; slope = -0.026; n = 9; p = 0.16) (Fig. 4). Ringed Seal density varied from a high of 1.22 seals/km^2 in 1995 to a low of 0.28 seals/km^2 in 2009 (Fig. 4; Table 2). However, estimates made using the limited data set collected during the 2009 survey should be considered with caution.

Table 1. Ringed Seal density ($\hat{D}$; seals/km^2 ice) and abundance ($\hat{N}$) estimates ± standard error from aerial surveys conducted in 2009 and 2010 in western Hudson Bay. See Appendix 1 for details of other lines flown in June 2009.

Observer	Total Length (km)	Ringed Seals	Density (seals/km^2)	95%CI	Abundance	95%CI	%CV
June 2009							
Right	546.41	86	0.3935 ± 0.0894	0.2780-0.5570	33,623 ± 6,009	23,752-47,595	45.4
Left	546.41	34	0.1556 ± 0.0386	0.1337-0.1809	13,293 ± 1,026	11,429-15,461	49.6
Both Observers	546.41	120	0.2745 ± 0.0488	0.2269-0.3322	23,458 ± 2,288	19,385-28,386	35.5
June 2010							
Right	3,074.29	929	0.7555 ± 0.0795	0.6065-0.9410	64,554 ± 7,257	51,825-80,410	14.9
Left	3,074.29	860	0.6993 ± 0.0651	0.5840-0.8374	59,759 ± 5,505	49,906-71,557	13.2
Both Observers	3,074.29	1,789	0.7274 ± 0.0608	0.6148-0.8607	62,157 ± 5,344	52,533-73,543	11.8

Note: %CV: percent coefficient of variation; 95% CI: 95% confidence interval.

Table 2. Ringed Seal density ($\hat{D}$; seals/km^2 ice) and abundance ($\hat{N}$) estimates ± standard error, total effort over ice and ice cover area (LFI=land fast ice) for each year of nine aerial surveys conducted in western Hudson Bay, 1995-2010. Note density estimates reported here are for the entire survey area whereas previous results calculated seal density only over available sea ice within the survey area (Lunn et al. 1997, Chambellant and Ferguson 2009).

Year	Total Effort (km)	% LFI	% 1/8 to 5/8	% 6/8 to 8/8	% open water	Density	95% CI	Abundance	95% CI	% CV
1995	3,074.6	1.6	13.7	61.1	23.6	1.219	1.062-1.400	104,162	90,738-119,572	7.0
1996	22,98.0	2.5	27.1	69.7	0.8	0.992	0.832-1.183	63,338	53,090-75,564	9.0
1997	3,074.5	1.9	20.6	68.0	9.5	0.677	0.594-0.772	57,883	50,812-65,938	6.7
1999	2,951.4	1.5	49.7	46.4	2.4	0.445	0.363-0.545	36,481	29,775-44,697	10.4
2000	2,630.0	2.0	7.4	88.8	1.8	0.606	0.529-0.695	44,298	38,648-50,775	7.0
2007	2,869.5	1.8	8.3	85.6	4.3	0.917	0.784-1.073	73,170	62,574-85,561	8.0
2008	2,764.8	2.6	5.4	84.7	7.3	0.439	0.357-0.539	33,701	27,375-41,488	10.6
2009	546.4	1.7	0.0	77.1	21.2	0.275	0.227-0.332	23,458	19,385-28,386	35.5
2010	3,074.3	1.5	4.8	89.9	3.8	0.727	0.615-0.861	62,157	52,533-73,543	11.8

Note: %CV: percent coefficient of variation; 95% CI: 95% confidence interval.

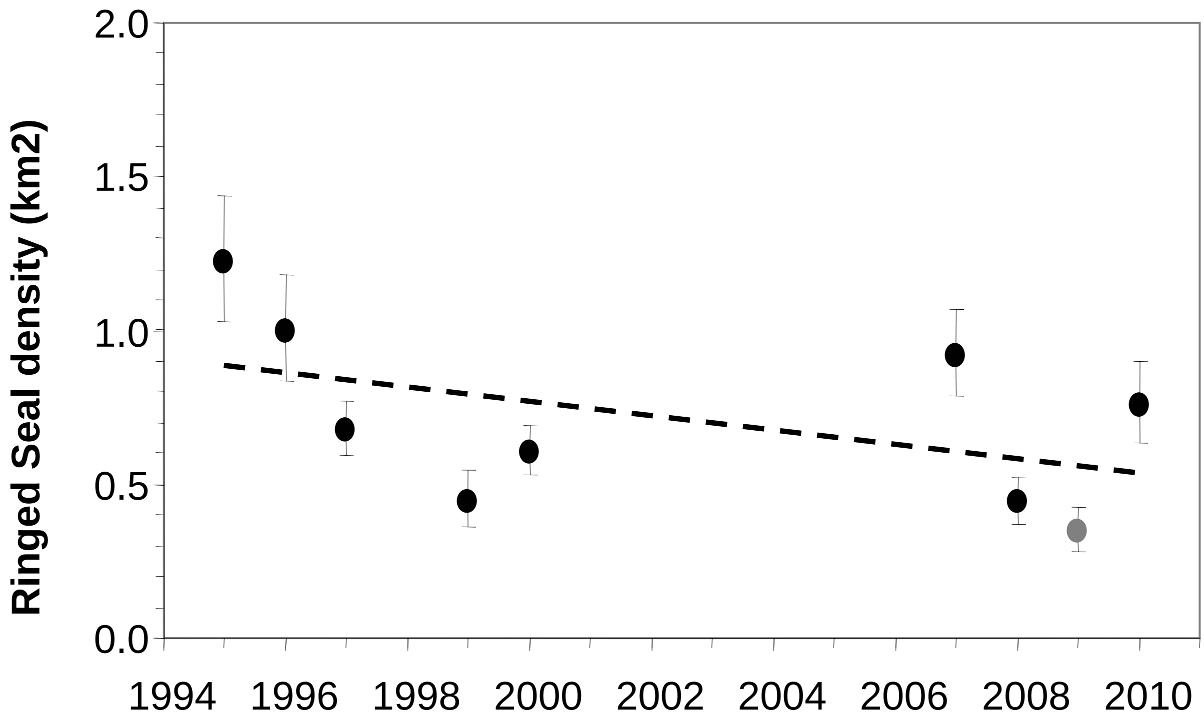

Figure 4. Trend in Ringed Seal density over the past 16 years from nine aerial surveys of western Hudson Bay (95% confidence intervals). Linear regression (---) (r^2 = 0.266 and r^2 = 0.149 with and without 2009 estimate (limited to 40% coverage), respectively).

DISCUSSION

Density estimates of Ringed Seals varied greatly from year to year in western Hudson Bay, a finding that has been commonly reported in the literature using similar aerial survey methods (Stirling et al. 1982, Kingsley et al. 1985, Smith 1987, Hammill and Smith 1990, Frost et al. 2004). Density results for 2009 on landfast ice (2.10) agree with previous studies across the Arctic that document a range of land-fast ice density of 0.21-10.44. Density estimates on moving, offshore sea ice for 2009 (0.28) and 2010 (0.73) compare with previous studies across the Arctic which have found a range of 0.19-1.47 (see Chambellant 2010).

Factors that can cause inter-annual variation include (1) survey conditions (ice type and conditions, water depth, temperature, wind speed and cloud cover, and time of the day and year); (2) seal behaviour such as haul-out activity and detectability; and (3) population changes such as emigration/immigration (Finley 1979, Smith and Hammill 1981, Stirling et al. 1982, Kingsley et al. 1985, Kelly and Quakenbush 1990, Lunn et al. 1997, Frost et al. 2004, Bengtson et al. 2005, Kelly 2005, Carlens et al. 2006).

However, despite the difficulty in interpreting aerial survey data, due to year-to-year variations in the number of Ringed Seals hauled-out on the ice in the study area, patterns are evident. The decline of density estimates observed from 1995 to 1999 is supported by results found by Holst et al. (1999) and Stirling (2005) of low pregnancy rates and percent of pups in the harvest in the 1990s for seals from the same area. Ferguson et al. (2005) confirmed low pup survival in the

1990s and suggested a decadal pattern in Ringed Seal recruitment reflecting environmental cycles. Pups represented about 5% of all seals in the harvest in the 1990s, 22% in 2000 (Stirling 2005), and 14-23% from 2003 to 2006 (Vincent-Chambellant 2010), suggesting better recruitment in the 2000s and supporting a decadal cycle in seal demography. Environmental data presented by Vincent-Chambellant (2010) suggested a regime transition in 1999 that corresponded with a shift in the composition of fish brought back by Thick-billed Murres to their chicks at Coats Island in northern Hudson Bay from Arctic species (Arctic Cod, *Boreogadus saida*) to subarctic species (Capelin, *Mallotus villosus* and Sand Lance, *Ammodytes sp.*) (Gaston et al. 2003).

Results for Ringed Seal pregnancy rate, pup physical condition, percent pups in the fall harvest, indicate poor reproductive years in the 1990s in contrast to the 2001 to 2006 period in western Hudson Bay (Vincent-Chambellant 2010). However, no Ringed Seal density estimates are available from 2001 to 2006. Demographic data in combination with environmental data suggested that the number of Ringed Seals in western Hudson Bay may follow a decadal cycle that mirrored an environmental change at the end of the 1990s (Vincent-Chambellant 2010). Decadal fluctuations in the Arctic environment, especially in the ice regime through atmospheric forcing (i.e., North Atlantic Oscillation, Arctic Oscillation), have been previously described (Mysak and Manak 1989, Wang et al. 1994, Hurrell 1995, Johannessen et al. 1999, Gagnon and Gough 2005) and linked to fluctuations in life-history parameters of several Arctic species (Stirling et al. 1982, Smith 1987, Skinner et al. 1998, Post and Forchhammer 2002, Derocher 2005, Ferguson et al. 2005, Regehr et al. 2007).

Here, we have presented 2009 and 2010 aerial survey results for western Hudson Bay that, although limited by flying few lines during deteriorating sea ice conditions in 2009 (40% survey coverage), does add to a long time-series of Ringed Seal density and abundance in the Arctic. A declining, albeit not significant, trend in Ringed Seal density estimates in western Hudson Bay is evident over the past sixteen years based on results obtained from nine aerial surveys. The population ecology of polar bears (Stirling et al. 1999), time of sea ice break-up (Gagnon and Gough 2005), sea ice extent in Hudson Bay (Parkinson and Cavalieri 2008) describe a concurrent pattern. A major source of uncertainty in the Ringed Seal density estimates is associated with annual variation in movements of sea ice and pattern of ice melt during the spring survey period when seals are hauled out moulting. Ringed Seals are a good indicator species of long-term changes occurring in the Arctic marine ecosystem because of their dependence on sea-ice for reproduction and survival. Due to the accelerated changes in timing of spring sea ice break-up, we recommend an additional survey of this area in 3 years (2013) to assess changes in seal density. In the meantime, in the context of global warming and continued ice loss in the Arctic, we propose sustained monitoring of the western Hudson Bay seal condition to assess temporal changes in demography.

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Appendix 1. Ringed Seal density ($\hat{D}$; seals/km^2 ice) and abundance ($\hat{N}$) estimates ± standard error from incomplete aerial surveys conducted in 2009 in western Hudson Bay.

Observer	Total Length (km)	Ringed Seals	Density (seals/km^2)	95%CI	Abundance	95%CI	%CV
June 8, 2009 Transects 7,8, 9, 10							
Right	546.41	86	0.3935±0.0894	0.2780-0.5570	33623±6009	23752-47595	45.4
Left	546.41	34	0.1556±0.0386	0.1337-0.1809	13293±1026	11429-15461	49.6
Both Observers	546.41	120	0.2745±0.0488	0.2269-0.3322	23458±2288	19385-28386	35.5
June 8, 2009 Short Transects Only							
Right	85.83	73	2.1263±0.2337	0.5542-8.1577	-	-	36.5
Left	85.83	71	2.0680±0.2574	0.4850-8.8181	-	-	41.3
Both Observers	85.83	144	2.0972±0.2138	0.6002-7.3280	-	-	33.8
June 8, 2009 All Transects							
Right	632.24	159	0.6287±0.0772	0.3544-1.1155	-	-	47.6
Left	632.24	105	0.4152±0.0826	0.2251-0.7657	-	-	77.1
Both Observers	632.24	264	0.5220±0.0723	0.3047-0.8942	-	-	53.6

Note: %CV: percent coefficient of variation; 95% CI: 95% confidence interval.