ARCTIC
VOL. 68, NO. 3 (SEPTEMBER 2015) P. 301–309
http://dx.doi.org/10.14430/arctic4503

Variation in Ringed Seal Density and Abundance in Western Hudson Bay Estimated from Aerial Surveys, 1995 to 2013

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(*Received 12 May 2014; accepted in revised form 20 November 2014*)

ABSTRACT. We conducted systematic aerial surveys of ringed seals along strip transects in western Hudson Bay (WHB), Canada, in late May to early June of 1995–97, 1999, 2000, 2007–10, and 2013. The density of ringed seals hauled out on ice over the entire study area ranged from 1.22 seals/km^2 in 1995, to 0.20 seals/km^2 in 2013. Density estimates varied significantly over the study period and, with the exception of 2013, appeared to follow a cyclical pattern. Although density estimates also appear to follow a downward trend over time, results of multiple linear regression, weighted by survey effort, indicated no significant trend in ringed seal density as a function of year, survey date, or proportion of open water. In addition, no significant correlation was observed among any of the environmental variables and density estimates. As the proportion of seals hauled out at the time of the survey is unknown, the density estimates of WHB ringed seals presented in this study should be considered indices that might be useful to explore trends in abundance. Although our results do not indicate that a significant decline has occurred, the low density estimate in 2013 may indicate that population changes unrelated to a natural cycle are taking place. We were unable to test for direct effects of changes in food supply or predation, but polar bears, Arctic foxes, and Inuit communities in the Hudson Bay region all would be negatively affected should ringed seal populations undergo significant declines. Further monitoring and directed research are necessary to understand what mechanism may be responsible for the observed changes in ringed seal density.

Key words: ringed seal; *Pusa hispida*; density; abundance; aerial survey; sea ice; Hudson Bay; decline

RÉSUMÉ. Nous avons fait les levés aériens systématiques de phoques annelés sur de longs transects en bandes dans l'ouest de la baie d'Hudson (OBH), au Canada, de la fin de mai au début de juin des années 1995 à 1997, 1999, 2000, 2007 à 2010 et 2013. Pendant toute la durée de l'étude, la densité de phoques annelés hissés sur la glace a varié de 1,22 phoque/km^2 en 1995 à 0,20 phoque/km^2 en 2013. Les estimations de densité ont varié considérablement au cours de la période visée par l'étude et, à l'exception de 2013, elles semblaient suivre un profil cyclique. Bien que les estimations de densité semblent également suivre une tendance à la baisse au fil du temps, les résultats de la régression linéaire multiple, pondérée par les levés, n'ont indiqué aucune tendance importante sur le plan de la densité de phoques annelés en fonction de l'année, de la date des levés ou de la proportion d'eaux libres. Par ailleurs, aucune corrélation importante n'a été observée pour n'importe quelle variable environnementale et n'importe quelle estimation de densité. Puisque la proportion de phoques hissés au moment des levés est inconnue, les estimations de densité de phoques annelés dans l'OBH présentées dans cette étude devraient être considérées comme des indices susceptibles d'aider à explorer les tendances en matière d'abondance. Bien que nos résultats ne laissent pas entrevoir la présence d'un déclin important, la faible estimation de densité enregistrée en 2013 pourrait indiquer qu'il se produit des changements de population et que ceux-ci ne sont pas attribuables à un cycle naturel. Nous n'avons pu examiner les effets directs des changements en matière d'approvisionnement alimentaire ou de prédation, mais les ours polaires, les renards arctiques et les communautés inuites de la région de la baie d'Hudson subiraient tous des effets négatifs si les populations de phoques annelés diminuaient considérablement. Il y a lieu de faire de la surveillance et des recherches dirigées pour comprendre à quel mécanisme les changements observés sur le plan de la densité de phoques annelés pourrait être attribuable.

Mots clés : phoque annelé; *Pusa hispida*; densité; abondance; levé aérien; glace de mer; baie d'Hudson; diminution

Traduit pour la revue *Arctic* par Nicole Giguère.

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INTRODUCTION

Concerns about the impact of climate change on Arctic marine mammals have increased the need to monitor populations and predict population responses to future change (Simpkins et al., 2009). A main concern in recent years has been the future of polar bear (*Ursus maritimus*) populations, which are closely linked to that of their primary prey, the ringed seal (*Pusa hispida*) (Stirling and Øritsland, 1995). As weather and sea ice patterns change, both ringed seals and polar bears are being exposed to significant challenges (Derocher et al., 2004; Kovacs et al., 2011; Stirling and Derocher, 2012). With life history events that are closely linked to seasonal sea ice patterns, ringed seals are particularly vulnerable to changing environmental conditions. Single pups are born in subnivean lairs in late March or early April (McLaren, 1958; Smith, 1973; Smith and Stirling, 1975) and weaned before the spring sea ice breakup, after a lactation period of approximately six weeks (Hammill et al., 1991). Although subnivean lairs offer some protection from predators (Smith and Stirling, 1975), spring is also the most important feeding time for polar bears (Stirling and Archibald, 1977; Stirling et al., 1999; Derocher et al., 2004).

Ringed seal parturition, lactation, mating, and weaning take place over a period of approximately three months, from about mid-February to mid-May in Hudson Bay (Chambellant et al., 2012a). These events are followed by the molting season, when ringed seals haul out and bask on the sea ice, where they are available to be counted through aerial surveys. Kelly et al. (2010) found that ringed seals spend approximately 55% of their time out of water during the molt, while Smith and Hammill (1981) observed individual seals that were hauled out for more than 40 consecutive hours. Although the molting season is highly variable among geographic locations and among individuals, it generally lasts from approximately mid-May to mid-July, with its peak period in June (McLaren, 1958; Finley, 1979; Smith and Hammill, 1981; Kelly et al., 2010). Given the lower latitude and relatively earlier timing of ice breakup in Hudson Bay, the peak haul-out period there likely occurs earlier, roughly in late May to early June.

Aerial surveys of ringed seals in western Hudson Bay (WHB) began in 1994 and 1995. The objectives were to analyze ringed seal abundance and distribution in relation to polar bear population parameters and establish a survey design that could be replicated in future years in order to assess long-term changes in the marine ecosystem (Lunn et al., 1997). Subsequent surveys of the same area, following the same survey design, were conducted in 1996, 1997, 1999, 2000, 2007 to 2010, and 2013. The objectives of this paper are (1) to summarize the results of ringed seal aerial surveys flown in WHB between 1995 and 2013, making the full data set available to be used in ecosystem modeling and predator-prey interaction studies, and (2) to test for significant trends in ringed seal density over the 19-year study period. We include the results from surveys flown in 1995–97, 1999, 2000, 2007, and 2008 (Lunn et al., 1997; Chambellant et al., 2012b), as well as previously unpublished results from surveys flown in 2009, 2010, and 2013.

METHODS

Each survey consisted of an attempt to fly 10 transects from the Hudson Bay shoreline in the west to the 89˚ W longitude line in the east (Fig. 1). The communities of Churchill, Manitoba, and Arviat, Nunavut, represented the southern and northern boundaries of the study area, respectively. The study area was defined by Lunn et al. (1997) to coincide with the winter and spring hunting habitat of the WHB polar bear population, determined from satellite telemetry data (Stirling and Derocher, 1993). The original survey plan involved a much larger study area extending south of Churchill and north of Arviat (Lunn et al., 1997); however, poor survey conditions prevented the northern and southern lines from being consistently flown, so they were removed from the survey design. The initial survey in 1994, flown between 7 and 14 June, was characterized by low seal densities and rotten ice, and it was concluded that peak haul-out likely occurs earlier in western Hudson Bay; as early as late May to early June, as suggested by local knowledge (Lunn et al., 1997). In the following year, 1995, the survey was flown between 1 and 4 June, and all subsequent surveys were flown between late May and early June (Table 1) to better coincide with the peak of the ringed seal molting season. Surveys were flown between the hours of 8:30 a.m. and 8:00 p.m. local time, in all weather conditions suitable for flying in which visibility of seals was not affected. The presence of fog, low cloud cover, and heavy precipitation were the main factors that prevented surveys from being flown.

The survey was designed as a systematic strip-transect survey following the protocol described by Lunn et al. (1997). The 10 transects, spaced at intervals of 15′ latitude, were flown in a Cessna 337 Skymaster at a target altitude of 152 m and speed of 260 km/h. The width of each transect strip was 800 m (400 m on each side of the aircraft, excluding the area directly below the aircraft that was not available to the two observers). The inner edge of each 400 m strip was offset from the center line in order to begin where the blind area underneath the aircraft ended. One observer was assigned to each side of the aircraft and remained there throughout the survey. To ensure observations were being made within the 800 m strip width, distance markings for each observer were made on the windows and wing struts, using the formula:

$$y = Xa / A$$

where y is the projected transect width while the aircraft is on the ground, X is the designated strip width (400 m) at flying altitude A (152 m), and a is the distance between the ground and the observer's eyes when the aircraft is on the ground.

TABLE 1. Survey dates, transects flown, survey effort, temperature, wind speeds, and ice cover characteristics for aerial surveys of ringed seals in western Hudson Bay. Temperature and wind speed data were obtained from Environment Canada weather stations (www.climate.weather.gc.ca) and are calculated as means between Churchill and Arviat for the specific time periods during which surveys were flown each day.

Year	Survey dates	Transect numbers flown	Total effort (km)	Temperature (˚C)	Wind speed (km/h)	Ice cover (%)			
						Landfast	1/8 to 5/8	6/8 to 8/8	Open water
1995	1–3 June	7 to 16	3074.6	3.6	18.2	1.6	13.7	61.1	23.6
1996	5–6 June	7 to 14	2298.0	6.1	13.6	2.5	27.1	69.7	0.8
1997	30 May–1 June	7 to 16	3074.5	2.8	21.8	1.9	20.6	68.0	9.5
1999	30–31 May	7 to 16	2951.4	4.7	15.4	1.5	49.7	46.4	2.4
2000	1–2 June	7 to 16	2630.0	-3.3	30.2	2.0	7.4	88.8	1.8
2007	26–29 May	7 to 16	2869.5	6.7	19.5	1.8	8.3	85.6	4.3
2008	28–31 May	7 to 16	2764.8	5.1	26.0	2.6	5.4	84.7	7.3
2009	2–8 June	7 to 10	546.4	3.2	9.3	1.7	0.0	77.1	21.2
2010	5–9 June	7 to 16	3074.3	4.7	19.5	1.5	4.8	89.9	3.8
2013	28 May–5 June	7 to 16	3074.3	8.4	19.3	2.8	24.6	67.8	4.8

For surveys conducted from 2007 to 2013, observations were recorded continuously using handheld audio recorders. For surveys flown between 1995 and 2000, all sightings on each transect were recorded in two-minute bins. Global Positioning Systems (GPS) were used to navigate along transects and, from 2007 to 2013, to record the locations where seals were sighted. The priority of the surveys was to record observations of ringed seals hauled out on the ice; however, observations of bearded seals (*Erignathus barbatus*), beluga whales (*Delphinapterus leucas*), and polar bears were also recorded. The start and end points of transects, as well as ice and weather conditions, including ice concentration, cloud cover, and visibility, were recorded by a co-pilot seated in the front of the aircraft. Temperature and wind speed data for Churchill and Arviat were obtained from Environment Canada weather stations (www.climate.weather.gc.ca).

The density of ringed seals per km^2, $\hat{D}$, was determined for each year of the survey using the standard ratio estimate (Buckland et al., 2001):

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

where k is the number of transects flown, n_i is the number of ringed seals counted on the ith transect, ω is the width of the strip, and l_i is the length of the ith transect. Given what we know about ringed seal natural history, it seems reasonable to assume that in a year with a significant proportion of open water, ringed seals would seek out ice-covered areas for hauling out during the molting season. Operating under this assumption, if data were analyzed as density of seals per km^2 of ice, a year with a lot of open water would result in a large number of seals hauled out on a relatively small area of ice, and thus a high density estimate. However, analyzing those same data as density of seals over the entire study area would give a more accurate estimate of their true density. We therefore analyzed data as density of ringed seals per km^2 over the entire study area, rather than density of ringed seals per km^2 of ice, as in Chambellant et al. (2012b).

Following Kingsley and Smith (1981), the variance of density, $\sigma^2(\hat{D})$, was determined by:

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

where

$$d_i = n_i - \hat{D} \times \omega l_i$$

Following Buckland et al. (2001), log-based 95% confidence intervals were estimated by:

$$\hat{D}_L = \hat{D} / C \text{ and } \hat{D}_U = \hat{D} \times C$$

with

$$C = exp\left\{1.96 \times \sqrt{\log_e\left(1+\left[cv\left(\hat{D}\right)\right]^2\right)}\right\}$$

where $cv(\hat{D})$ is the coefficient of variation of the estimated density:

$$v\left(\hat{D}\right) = se\left(\hat{D}\right) / \hat{D}$$

Abundance estimates $(\hat{N})$ were calculated by multiplying the estimated density $(\hat{D})$ by the total study area. Following Stirling et al. (1982), the standard error of $\hat{N}$ $(se(\hat{N}))$ was estimated by:

$$se\left(\hat{N}\right) = N \times cv\left(\hat{D}\right)$$

The total study area was calculated by multiplying total effort (sum of transect lengths) by the distance between adjacent transects (15′ of latitude, or 27.795 km). The transect lengths were determined using the start and end coordinates and were adjusted to account for missing effort resulting from technical issues or poor visibility due to fog.

Multiple linear regression, weighted by the proportional survey effort, was used to test the effect of year, survey date, and proportion of open water on ringed seal density

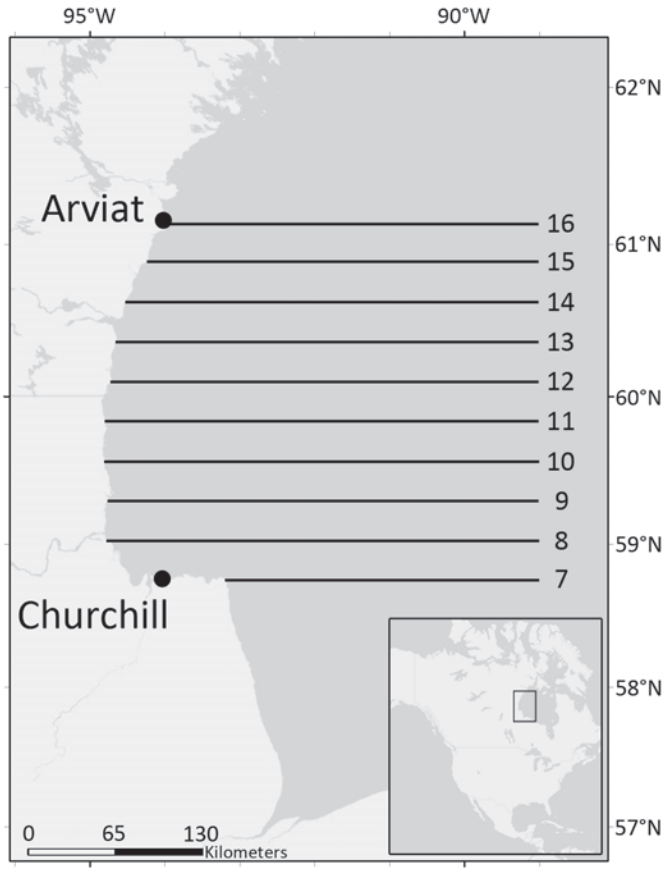

FIG. 1. The 10 transects flown during aerial surveys of ringed seals in western Hudson Bay, 1995–2013. The transect numbering (from 7 to 16) reflects the original study design, which included additional transects south of Churchill and north of Arviat, and is retained to match previous publications.

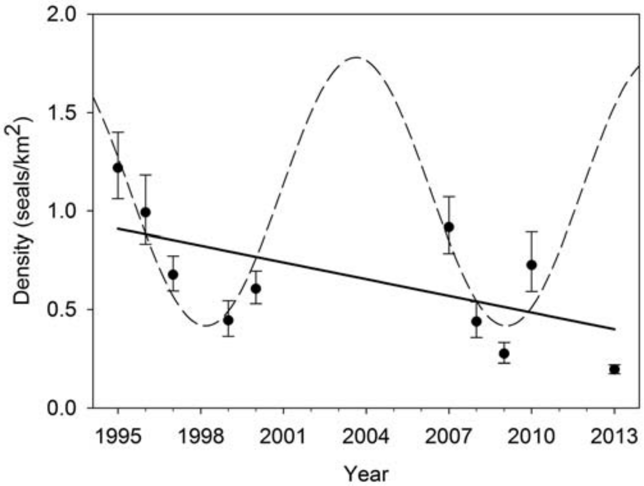

FIG. 2. Density estimates of ringed seals in western Hudson Bay, estimated from aerial surveys flown between 1995 and 2013. Error bars represent 95% confidence intervals. The solid line represents linear regression of ringed seal density as a function of year, weighted by proportional survey effort ($y = -0.0283x + 57.41$). The dashed line represents a sine function with an 11-year period ($y = 0.7*\sin((2\pi/11)*(x - 1990)) + 1.10$).

estimates. Proportional survey effort was defined as the proportion of the total length of transects surveyed in a given year. For example, in 1995 all transects were flown in their entirety (proportional survey effort of 1.0) whereas in 1996 only 2298 km out of 3074 km were completed (proportional survey effort of 0.75). Survey date was defined as the day of the year that represents the midpoint of the survey. Year, survey date, and proportion of open water were included in the regression analysis because they were the variables we considered most likely to influence ringed seal density. Regression analysis was performed using the lm function in R (R Core Team, 2014). To further explore the relationships among variables, we used a Pearson correlation matrix weighted by proportional survey effort, which included the variables year, survey date, temperature, wind speed, proportion of landfast ice, proportion of open water, and ringed seal density. Correlation analysis was performed using the wtd.cor function from the weights package in R (R Core Team, 2014). Data from the 1994 survey, which was believed to have been conducted outside of the peak haul-out period, were not included in these analyses.

Variations in weather and ice conditions have a significant influence on ringed seal behaviour and may alter the timing of peak haul-out from year to year. In the absence of observational or telemetry data collected throughout the molting season, it is difficult to determine the precise timing of peak haul-out in any given year. If surveys do not coincide with peak haul-out, results may not represent a true estimate or index of ringed seal density. To try to account for variation in peak haul-out in relation to the timing of the survey, the survey date and the proportion of open water were included as covariates in the regression analysis, and relationships among variables were explored using a correlation matrix. The proportion of open water and survey date were used as covariates in the regression analysis to account for the possibility that peak haul-out was influenced by a certain proportion of ice coverage and by photoperiod.

RESULTS

As aerial surveys can be flown only under specific weather conditions, weather determined the exact survey dates, the number of transects flown, and the length of transects each year (Table 1). In 1996, the survey covered eight of the ten transects, while in 2009 only four partial transects could be flown. To account for variation in survey effort, regression and correlation analyses have been weighted by survey effort; however, density and abundance estimates from these years, particularly from 2009, should be considered with caution.

Density and abundance estimates varied by year (Table 2) with the highest estimated density (1.22 ringed seals/km^2) occurring in 1995 and the lowest (0.20 ringed seals/km^2) in 2013. Density and abundance estimates appear to follow a cyclical pattern, with highs observed in 1995, 2007, and 2010 and lows observed in 1999 and 2009

TABLE 2. Density (seals/km²) and abundance estimates of ringed seals in western Hudson Bay, determined from spring aerial surveys conducted between 1995 and 2013. 95% CI: 95 percent confidence intervals; % CV: percent coefficient of variation.

Year	Density	95% CI	Abundance	95% CI	% CV
1995	1.219	1.062 – 1.400	104 162	90 738 – 119 572	7.0
1996	0.992	0.832 – 1.183	63 338	53 090 – 75 564	9.0
1997	0.677	0.594 – 0.772	5 883	50 812 – 65 938	6.7
1999	0.445	0.363 – 0.545	36 481	29 775 – 44 697	10.4
2000	0.606	0.529 – 0.695	44 298	38 648 – 50 775	7.0
2007	0.917	0.784 – 1.073	73 170	62 574 – 85 561	8.0
2008	0.439	0.357 – 0.539	33 701	27 375 – 41 488	10.6
2009	0.275	0.143 – 0.527	23 458	12 214 – 45 052	34.2
2010	0.727	0.592 – 0.893	62 157	50 625 – 76 315	10.5
2013	0.196	0.175 – 0.220	16 746	14 945 – 18 765	5.8

TABLE 3. Pearson correlation matrix, weighted by proportional survey effort, indicating relationships among variables for western Hudson Bay ringed seal surveys conducted between 1995 and 2013.

		Year	Survey date	Temperature	Wind speed	Landfast ice	Open water	Seal density
Year	Pearson's r	1.00						
	p-value	0.000						
Survey date	Pearson's r	−0.04	1.00					
	p-value	0.918	0.000					
Temperature	Pearson's r	0.47	−0.14	1.00				
	p-value	0.168	0.690	0.000				
Wind speed	Pearson's r	0.12	−0.21	−0.61	1.00			
	p-value	0.744	0.557	0.061	0.000			
Landfast ice	Pearson's r	0.36	−0.06	0.33	0.20	1.00		
	p-value	0.307	0.878	0.345	0.572	0.000		
Open water	Pearson's r	−0.32	−0.05	−0.06	−0.15	−0.26	1.00	
	p-value	0.368	0.885	0.873	0.685	0.464	0.000	
Seal density	Pearson's r	−0.60	0.17	−0.14	−0.19	−0.45	0.45	1.00
	p-value	0.068	0.635	0.703	0.599	0.190	0.195	0.000

(Fig. 2). Note that the 2013 estimate appears to be anomalous with respect to a possible cycle. Results of multiple linear regression, weighted by survey effort, indicate no significant trend in ringed seal density as a function of year, survey date, or proportion of open water ($R^2 = 0.459$, $p = 0.267$). The Pearson correlation analysis indicates no significant correlation between any of the variables (Table 3).

DISCUSSION

Estimates of ringed seal density and abundance through aerial surveys are subject to error from many sources. While surveys are flown to coincide with timing of peak haul-out, not all seals are hauled out at any one time. An unknown proportion of seals are under the ice, where observers cannot count them, and the result is a negative bias in abundance estimation. The proportion of seals hauled out has been found to vary according to weather conditions, ice conditions, time of day, and location (Smith and Hammill, 1981; Moulton et al., 2002; Frost et al., 2004; Carlens et al., 2006; Krafft et al., 2006). In addition, a small proportion of hauled-out seals will dive in response to aircraft noise before observers have a chance to see them (Born et al., 1999), and this proportion may vary with environmental factors such as wind. As in nearly all wildlife surveys, observers will miss some animals because of factors such as aircraft speed, poor sighting conditions, and observer fatigue (Caughley, 1974). Therefore the density and abundance estimates of WHB ringed seals presented in this study should be considered indices, rather than absolute estimates.

To account for the proportion of seals not hauled out and not visible to be counted during surveys, several authors have investigated ringed seal haul-out behaviour in order to develop a correction factor for use in abundance estimates (Smith, 1975; Finley, 1979; Smith and Hammill, 1981; Hammill and Smith, 1990; Kelly and Quakenbush, 1990; Born et al., 2002). Suggested correction factors have varied from 1.3 to 2.0 and most are considered to be conservative estimates, as they were developed from data on adult seals in prime breeding habitat (Stirling and Øritsland, 1995). Ringed seal haul-out behaviour varies by location, age class, time of day, and weather and ice conditions. Therefore, further investigation into haul-out behaviour in Hudson Bay should be conducted before deciding on a correction factor to use with our survey data.

Despite our inability to obtain true density and abundance estimates, the long-time series of indices presented here provides important information regarding variation in ringed seal abundance. Ferguson et al. (2005) and Chambellant et al. (2012b) found evidence for decadal patterns in both ringed seal recruitment and density in WHB. Except in 2013, recent aerial survey results have continued to follow an 11-year period sine function similar to the one presented by Chambellant et al. (2012b). The reasons for the low density estimate in 2013, whether related to environmental conditions and survey timing or to a true decline in ringed seal abundance, require further discussion.

The low density of WHB ringed seals observed in 2013 could be linked to a variety of environmental and ecological factors. For example, Iacozza and Ferguson (2014) have found a relationship between ringed seal pup survival and snow cover characteristics in WHB. Greater variability in snow depth and decreased duration of snow cover resulted in greater pup mortality (Iacozza and Ferguson, 2014). Similarly, Chambellant et al. (2012a) suggested that nutritional stress and increased predation pressure, as a result of unusually cold winters and heavy ice conditions, were responsible for the decreased reproductive success and increased pup mortality in WHB in the 1990s. In each of the above scenarios, increased predation pressure (e.g., from polar bears and Arctic foxes, *Vulpes lagopus*) is believed to have an impact on ringed seal survival. In the case of inadequate snow conditions, the likelihood that adult ringed seals can build effective birth lairs is reduced, and pups are more likely to be exposed to the elements and to predators (Smith and Stirling, 1975; Furgal et al., 1996). In the case of unusually cold winters, ice breakup occurs later than normal; thus, predation pressure may be increased because predators can remain on the ice, hunting seals, longer into the spring (Stirling and Derocher, 1993; Stirling et al., 1999). However, early ice breakup can also have negative effects on ringed seals: it may interrupt the lactation period and force pups into the water at an earlier age, resulting in increased energy expenditure, slow growth, and decreased overall fitness (Hammill et al., 1991; Smith et al., 1991; Smith and Harwood, 2001). In addition, warmer spring temperatures and early season rains can melt and degrade birth lairs, increasing exposure of pups to predators (Derocher et al., 2004; Stirling and Smith, 2004).

Bottom-up processes also appear to be influencing ecosystem dynamics in the Hudson Bay marine environment and changing the feeding ecology of ringed seals and marine birds (Gaston et al., 2012; Chambellant et al., 2013; Young and Ferguson, 2014). Changes in pelagic fish species include a shift from an abundance of Arctic cod (*Boreogadus saida*) to an increase in sub-Arctic species such as capelin (*Mallotus villosus*) and sandlance (*Ammodytes* sp.) (Gaston et al., 2012; Chambellant et al., 2013). Rainbow smelt (*Osmerus mordax*), a temperate species that is expected to thrive in Hudson Bay (Franzin et al., 1994), has also begun to appear in the diet of ringed seals harvested from Arviat (Chambellant et al., 2013). Although the effects that such changes could have on ringed seals are unclear, it has been suggested that climate-related shifts in marine mammal prey communities could lead to nutritional stress caused by limited access to high-quality prey (Bluhm and Gradinger, 2008).

Environmental and ecosystem change can also have significant effects on marine mammal health by increasing levels of stress, decreasing body condition, and altering lines of pathogen transmission (Burek et al., 2008). In late 2010 and early 2011, there were numerous reports of sick and stranded ringed seals in Hudson Bay. Affected seals generally exhibited skin abnormalities and laboured breathing and were easily approached by hunters (Nielsen, 2012). Along the coast of western Hudson Bay, polar bears were observed taking large numbers of presumably sick seals (J. Gunter, pers. comm. 2011) and may have been a significant cause of seal mortality during the outbreak period. Though the ultimate cause of this unusual mortality event remains unknown, it is suspected to be linked to similar events that have occurred in ringed seals and other pinniped species in Baffin Island, the Northwest Territories, Alaska, and Russia (Nolen, 2011). It is unclear how much of an impact this event would have had on the ringed seal population in WHB, but die-offs of seals as a result of outbreaks of disease have been reported elsewhere (Härkönen et al., 2006). It seems probable that a large die-off is at least partially responsible for the low seal density observed in 2013, though it is unlikely that such a causal link will ever be established.

The effect of survey timing and environmental conditions on ringed seal haul-out behaviour must also be considered as a possible explanation for the low density observed in 2013. The 2013 survey was conducted between 28 May and 5 June, dates which are directly comparable to those of all previous surveys, and slightly earlier than the 2009 and 2010 surveys. In comparison to the mean from all survey years, weather and ice conditions in 2013 were characterized by higher-than-average temperatures, landfast ice, and loose pack ice; average wind speeds; and less than average consolidated pack ice and open water. The warmer-than-average temperatures during the 2013 survey could have increased the likelihood of seals' hauling out; however, the warm temperatures would also have contributed to the higher-than-average proportion of loose pack ice, as well as the melt ponds on top of the ice—conditions that may have reduced the number of seals hauled out, decreased the observers' ability to sight seals, or both.

Results presented here indicate a high degree of variation in ringed seal density and, except for the density observed in 2013, continue to support the decadal cycle proposed by Chambellant et al. (2012b). Without additional data to assess ringed seal haul-out behaviour over the survey period, it is difficult to determine whether the observed variation in seal densities is related to timing of the peak haul-out period or represents true changes in ringed seal abundance. The warming temperatures, reduced snow cover, changes in sea ice cover, and earlier ice breakup projected in various studies (Joly et al., 2010; Castro de la Guardia et al., 2013; Iacozza and Ferguson, 2014) are all likely to have significant negative impacts on ringed seals. The low density observed in 2013 suggests that ringed seal abundance has declined in recent years, or that survey design does not adequately account for the possibility of year-to-year variation in the timing of peak haul-out. In either case, we need to continue monitoring WHB ringed seals because population decline, in response to environmental and ecological change, is a real possibility. Further research is also needed to better understand the mechanisms driving the observed variation and the anomalous decline between 2010 and 2013, as well as to assess variation in ringed seal haul-out behaviour throughout the spring season when surveys are conducted.

ACKNOWLEDGEMENTS

Funding for this research was provided by Environment Canada, Fisheries and Oceans Canada, the University of Manitoba, ArcticNet, the Nunavut Wildlife Management Board, Federal Program Office of International Polar Year, NSERC, and Manitoba Hydro. We would like to thank Lloyd Lowry, Ole Nielsen, and Lori Quakenbush for their valuable comments on earlier drafts of the manuscript. We would like to thank the following past members of our survey team: Sasha Nowicki, Meike Holst, Chad Nordstrom, Corey Davis, Darren Saltel, Magaly Chambellant, Natalie Asselin, and Blair Dunn. We would also like to thank the pilots: John Kuipers, Brian Goldie, and Joe Van Horne of Hicks & Lawrence Ltd.; Sean Briesboek and Jason Harvey of Wildlife Observation Services; and Justin Simle of Landa Aviation. We also thank the Churchill Northern Studies Centre, as well as the communities of Churchill, Manitoba, and Arviat, Nunavut, for supporting this research.

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