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Demographic, ecological and physiological responses of ringed seals to an abrupt decline in sea ice availability

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To assess whether demographic declines of Arctic species at the southern limit of their range will be gradual or punctuated, we compared large-scale environmental patterns including sea ice dynamics to ringed seal (*Pusa hispida*) reproduction, body condition, recruitment, and stress in Hudson Bay from 2003-2013. Aerial surveys suggested a gradual decline in seal density from 1995-2013, with the lowest density occurring in 2013. Body condition decreased and stress (cortisol) increased over time in relation to longer open waterperiods. The 2010 open water period in Hudson Bay coincided with extremes in large-scale atmospheric patterns (NAO, AO, ENSO) resulting in the earliest spring breakup and the latest ice formation on record. The warming event was coincident with the highest stress levels and the lowest recorded ovulation rate and low pregnancy rate, few pups in the Inuit harvest, and observations of sick seals. We conclude that although negative demographic responses of Hudson Bay seals are occurring gradually with diminishing sea ice, a recent episodic environmental event played a significant role in a punctuated population decline.

1	Demographic, ecological and physiological responses of ringed seals to an abrupt
2	decline in sea ice availability
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14 ABSTRACT

To assess whether demographic declines of Arctic species at the southern limit of their 15 range will be gradual or punctuated, we compared large-scale environmental patterns 16 including sea ice dynamics to ringed seal (*Pusa hispida*) reproduction, body condition, 17 recruitment, and stress in Hudson Bay from 2003-2013. Aerial surveys suggested a gradual 18 19 decline in seal density from 1995-2013, with the lowest density occurring in 2013. Body condition decreased and stress (cortisol) increased over time in relation to longer open 20 water periods. The 2010 open water period in Hudson Bay coincided with extremes in 21 large-scale atmospheric patterns (NAO, AO, ENSO) resulting in the earliest spring breakup 22 and the latest ice formation on record. The warming event was coincident with the highest 23 stress levels and the lowest recorded ovulation rate and low pregnancy rate, few pups in 24 the Inuit harvest, and observations of sick seals. We conclude that although negative 25 demographic responses of Hudson Bay seals are occurring gradually with diminishing sea 26 ice, a recent episodic environmental event played a significant role in a punctuated 27 population decline. 28

- 29 Subjects: Animal population, Climate change
- 30 Keywords: abundance, body condition, disease, Hudson Bay, Pusa hispida, sea ice

31

32 BACKGROUND

Organisms evolve specific adaptations to their habitats through natural selection (Mayr 33 1963) and when their habitats change gradually, organisms can adjust phenotypically 34 within an evolved range of flexibility (Levins 1968). However, this evolved adaptation has 35 limitations and in extreme situations, organisms may not be able to adapt to particular 36 37 habitats and environmental conditions above an evolved threshold (Southwood 1977). Under these circumstances, populations suffer demographic mortality of individuals 38 and/or immigrate to new habitats that may allow increased demographic success 39 (MacArthur and Wilson 1966). The result is a shift in species distribution (Guisan and 40 Thuiller 2005) and understanding this process by identifying thresholds to adaptability 41 and the demographic mechanism of population decline are both critical to species 42 conservation. 43

Predicting how climate warming will result in retraction of an Arctic species range 44 northward requires knowledge of demographic changes and their ecological plasticity in 45 response to environmental change. Few studies have linked marine mammal demographic 46 47 responses to climate change (Poloczanaska et al. 2007) with the notable exception of ringed seals (Meier et al. 2004, Post et al. 2009), where the majority of research results 48 49 reflect changes in foraging behaviour (Young and Ferguson 2014, Hamilton et al. 2015). Ringed seals (*Pusa hispida*) have a circumpolar distribution and show high variability in the 50 51 relative importance of predation from polar bears (Ursus maritimus) (Thiemann et al. 2008) and to varying food habits (Yurkowski et al. 2016a). However, key habitat attributes 52 53 are linked to survival and successful reproduction. In particular, ringed seals require sea

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ice during the critical spring period when reproduction and molting occurs (Smith &
Stirling 1975) and a seasonal pulse in food availability in the summer ice-free season
(Young & Ferguson 2013). Evolved life history characteristics that match these highlatitude environmental features include relative small body size for a pinniped and a life
history characterized by early age of maturation, annual birthing, short lactation duration,
widely varying but high pup mortality, relatively low adult mortality, and greater fitness
investment in long life (Ferguson & Higdon 2006).

High latitude species are characterized by a strong seasonal cycle of feast and fast 61 with both periods critical to reproduction and survival. Ringed seals are adapted to cycle 62 annually from intensive foraging during the open water season to accumulate fat reserves 63 to sustain them over winter and during the birthing, nursing, and mating periods when 64 adults are restricted to small home ranges with depleted food resources. In spring, pups 65 are independent and adults undergo molting with little feeding opportunities and 66 increased risk of predation (Young and Ferguson 2015). During periods of deteriorating 67 68 environmental conditions, the phenology of ringed seals can be interrupted leading to inadequate energy reserves prior to the next year's reproduction. Ringed seal populations 69 can also be negatively affected by infrequent, annual, extreme climatic conditions that exert 70 pressure on their demographics. 71

Endemic Arctic species are challenged by the rapid pace of sea ice declines and
resulting changes in ecological dynamics of the marine ecosystem (Post et al. 2013).
Southern Hudson Bay represents one of the most southerly distributions of ringed seals
and therefore, as an ice-obligate marine mammal, the prediction is for a retraction

northward in range from the southern edges of their distribution (Kovacs & Lydersen
2008). The initial characteristics of population and demographic changes may already be
occurring with a decrease in ringed seal density observed in western Hudson Bay between
the two recent aerial surveys in spring 2010 and 2013 (0.78 to 0.20/km²) (Young et al.
2015).

81 Here, we assess whether a 2010 extreme climatic event was another year in a longterm declining trend for Hudson Bay or an infrequent episodic event that impacted ringed 82 seal demography, body condition, and reproduction. Our objective was to compare annual 83 trends in sea ice breakup and formation and the influence of major climatic indices to 84 biological data from seal collections, 2003-13 that include (1) body fat from seals harvested 85 by Inuit, (2) reproduction from examination of reproductive tracts, (3) recruitment from 86 hunter harvest statistics, and (4) stress from blubber cortisol levels. We hypothesize that 87 gradual deteriorating change in sea ice characteristics will correlate with a gradual 88 decrease in ringed seal body condition, ovulation rate and pup recruitment, whereas an 89 90 abrupt decline in sea ice availability in 2010 will result in dramatic negative demographic, ecological and physiological responses by ringed seals. 91

92 METHODS

Sea ice breakup and freeze-up dates were determined from weekly data obtained from the
Canadian Ice Service using Icegraph 2.0 (http://iceweb1.cis.ec.gc.ca/IceGraph/), for
eastern Hudson Bay, 1979-2014. For a given region, ice breakup date was defined as the
date on which the sea ice concentration decreased and remained below 50% (Stirling et al.
1999). Conversely, freeze-up date was defined as the date on which sea ice concentration

increased and remained above 50%. Major climatic indices were obtained from the Climate 98 Prediction Center (http://www.cpc.ncep.noaa.gov/), including the Arctic Oscillation (AO), 99 the North Atlantic Oscillation (NAO), and El Nino-Southern Oscillation (ENSO) for the 100 101 December to February monthly mean estimates from 1971-2014. We included ENSO due to its significant climatic influence in North America and due to its effect on ecological 102 relationships in several ecosystems across the globe (Wang et al. 2010; Nye et al. 2014; 103 Rustic et al. 2015). The longer time frame available for environmental data provided a 104 background to the 2003-2013 period with available ringed seal biological data. 105 Morphological measurements and tissue samples were collected from 926 Hudson Bay 106 ringed seals harvested during the Inuit subsistence hunt from Sanikiluag, NU, Canada 107 (56°32′34″ N, 79° 13′ 30″ W) and Arviat, NU (61° 6′ 29″ N, 94° 3′ 25″ W) from 2003-2013 108 in autumn when age/sex composition is considered representative of the population (Holst 109 et al. 1999). Permits to collect samples as part of the Inuit subsistence hunts were acquired 110 from Fisheries and Oceans Canada. Canine teeth were extracted from the lower jaw for age 111 112 determination using annual growth layer groups in the cementum (Chambellant and Ferguson 2009). Reproductive tracts were stored frozen before being examined. After 113 gross examination of reproductive tracts, ovaries were excised, formalin-fixed and 114 sectioned at 2-mm intervals, and examined macroscopically for the presence of a corpus 115 luteum (ovulation in the year of collection) and corpora albicantia (previous pregnancies) 116 (Laws 1956). Pup survival was defined as the percentage of pups (i.e., <1 year) in the 117 118 autumn subsistence hunt and is considered a good measure of 0-6 month survival (Chambellant et al. 2012). An extraction method for ringed seal blubber samples was used 119

122

in conjunction with radioimmunoassay to measure cortisol levels representing stress(Trana et al. 2014).

Four separate general linear models were used to investigate relationships between

environmental (i.e. duration of the open water period, ENSO, NAO and AO indices) and 123 biological variables (i.e. percentage of ovulating females, percentage of pups in the harvest, 124 125 body condition and cortisol levels) over time using R v 3.2.3 (R Core Team 2015). Continuous predictor variables were screened for collinearity and removed when a 126 Pearson's correlation coefficient was ≥ 0.6 and a variance inflation factor (VIF) was > 3.0. 127 NAO was highly correlated with AO (0.8), thus was removed from all analyses. Prior to 128 analysis, percentage of ovulating females, percentage of pups in harvest, and body 129 condition were normally distributed upon visual examination of histograms and quantile-130 quantile plots. Cortisol levels were log-transformed before analysis to improve normality. 131 RESULTS 132 Results support a gradual pattern of earlier spring ice breakup and later autumn freeze-up 133 in Hudson Bay; where from 2003-2013, sea ice breakup has varied more widely than 134 freeze-up. No relationship occurred with any climate variability index over 1979-2014, but 135 the NAO and AO have been more positive from 1999-2015 (Fig. 1). The longest ice-free 136 season on record for eastern Hudson Bay occurred in 2010, with the earliest spring 137 breakup (May) and latest freeze-up (January 2011) and an anomalous negative NAO and 138

139 AO, and a high ENSO index (Fig. 1).

Body condition significantly decreased over time (t = -8.2, p < 0.001), from about
55% blubber mass in 2004 to approximately 45% in 2011 (Fig. 2). In addition, body

condition significantly decreased with increasing open water period (t = -2.0, p < 0.05), 142 ENSO index (t = -2.3, p = 0.02) and NAO index (t = -2.0, p < 0.05; Table 1; Fig. 3). Ovulation 143 rate varied considerably among years from 100% in 2008 to 56% in 2011, albeit with no 144 145 relationship with year, open water duration, or climatic indices. Percentage of pups in the harvest, as an estimate of pup survival, exhibited a marginal decline from 2003-2013 (t = -146 2.09, p = 0.08) from about 40% of the harvest to about 20% (Table 1; Fig 2). Stress, as 147 measured by cortisol concentration (ng/g), significantly increased over time (t = 8.0, p < 148 0.001) from about 0.1 to 0.6ng/g over the 2003-12 period (Table 1; Fig. 2). A significant 149 decrease in cortisol level occurred with NAO index (t = -2.6, p = 0.01), whereas a marginally 150 significant increase occurred with ENSO index (t = 1.93, p =0.05; Fig. 3). In 2010, cortisol 151 levels in ringed seals had the highest amount of variability (standard deviation = 1.84) 152 compared to other years (Fig. 2). The highest stress levels occurred in 2010, and the lowest 153 recorded ovulation rates occurred in 2011 which supports the pattern of a decrease in 154 ovulation rate after the record high stress levels. 155

156 DISCUSSION

We predicted demographic change occurring at the southern limit of the ringed seal
distribution with both gradual changes in environmental variables and episodic events
associated with extreme lows in sea ice concentration. Our results suggest both patterns
have occurred in southern Hudson Bay over the past decade. Previous research has
indicated that Hudson Bay ringed seals (Chambellant et al. 2012) and polar bears
(Derocher et al. 2004) have shown gradual reductions in body condition and survival over
the past decades which are concurrent with negative consequences of continued

environmental change (Holst et al. 1999; Ferguson et al. 2005). We provide additional 164 evidence for a continuation of these progressive patterns for ringed seals with decreasing 165 body condition and increasing stress over 2003-2013. However, no research results have 166 suggested short-temporal pulses in condition and abundance for either seals or polar bears 167 in the Hudson Bay ecosystem, although a regime shift likely occurred in late 1990s (Gaston 168 et al. 2012). Here, we document for the first time, a relationship with ringed seal 169 demographics and the 2010 climatic event that resulted in a punctuated decrease in 170 ovulation, reduced body condition, reduced seal pups in the following autumn harvest, and 171 increased cortisol levels. 172

Gradual reduction in body condition could be associated with the recent changes in 173 Hudson Bay prey resource abundance and availability. The prevalence of capelin (*Mallotus* 174 villosus) and sand lance (Ammodytes spp.) and decrease in Arctic cod (Boreogadus saida) 175 176 abundance in Hudson Bay since 2000 has caused dietary shifts from endemic Arctic cod to sub-Arctic capelin and sand lance in Arctic marine megafauna including sea birds (Gaston 177 et al. 2003) and ringed seals (Chambellant et al. 2012). In addition, the isotopic niche size 178 of Hudson Bay ringed seals is significantly larger than individuals from higher latitudes 179 which principally consume Arctic cod, indicating a more diverse and omnivorous diet 180 (Young and Ferguson 2013; Yurkowski et al. 2016a, b). Among ringed seal prey items, 181 Arctic cod represent the highest energy content compared to other fish and invertebrate 182 species (Weslawski et al. 1994; Hedeholm et al. 2011) where its decreased consumption in 183 Hudson Bay ringed seal diet and temporal shifts in forage fish availability and abundance 184 may negatively impact ringed seal energetic demands and body condition. 185

Assessing the causes of an episodic event is more difficult. The extremely low extent 186 and duration of the 2010 ice-covered period in Hudson Bay may have adversely affected 187 the abundance, availability and distribution of prey resources but it is unlikely to have, 188 189 triggered a punctuated decrease in their physiological and energetic demands. We summarized anecdotal evidence for an episodic event affecting the abundance and body 190 condition of ringed seals in Hudson Bay related in 2010-11 (see supplementary material). 191 Anecdotal observations in 2010 are suggestive of a hitherto never before seen event 192 causing impaired biological responses in ringed seal behaviour including unusual 193 approachability, lethargy, and increased tendency for hauling out on land, possibly due to 194 associated respiratory problems that were first seen during that autumn season. Polar 195 bears are thought to have benefited from this behavior since affected seals were easily 196 captured but no estimate of predation over and above normal could be calculated. Evidence 197 198 for a biological response to an episodic environmental event comes from the low ringed seal density observed between spring 2010 and 2013 surveys and the unusual 199 environmental patterns that suggest a possible shift in seal condition after 2010 (Table 1). 200 An Unusual Mortality Event was declared in 2011 by the US government due to a 201 'new' ulcerative-dermatitis-disease-syndrome of unknown etiology observed in Alaskan ice 202 seals and Pacific walrus (Atwood et al. 2015). A large scale, trans-boundary, 203 interdisciplinary, disease-investigative team from Alaska, Chukotka, Northwest Territories 204 (NWT) and scientists (USA and internationally) found significant pathology of the lung, 205 206 liver, immune system, and skin of the seals (Barbosa et al. 2015, Bowen et al. 2015). Hundreds of ice seals of all ages had been reported in Alaska (ringed, bearded (*Erignathus* 207 *barbatus*), spotted (*Phoca largha*), ribbon (*Histriophoca fasciata*) and Pacific walrus 208

(Odobenus rosmarus)), Chukotka (RU) (ice seals and walrus) and NWT (CA) (ice seals) 209 displaying a variety of skin associated lesions distributed around the eyes, snout, hind 210 flippers, tail, and trunk. As observed in Hudson Bay, the affected ice seals displayed 211 212 uncommon behaviours such as unusual approachability, lethargy, and increased tendency for hauling out on land, as well as respiratory problems. There was some mortality 213 associated with the disease syndrome; however reliable baseline abundance estimates 214 were not available to assess its significance. Alaskans also reported seeing polar bears 215 preving upon affected seals, suggesting that this additional predation is widespread and 216 represent a significant cause of seal mortality. As of the summer of 2016 no cause of the 217 syndrome has yet been identified. 218

Potential repercussions of a gradual sea ice decline and punctuated decreases in 219 some years include a continual reduction in ringed seal body condition and greater stress 220 221 leading to implications on their demographics. The years marked by extremes in climatic indices (Fig. 1) are associated at higher latitudes with excessive sea ice extremes; whereas 222 our results at the southern range of ringed seals indicate a lack of sea ice may have 223 attributed to decreased body condition, increased stress, and low ovulation rates and pup 224 recruitment. Spring 2010 recorded an unusually early ice breakup that may have 225 predisposed seals to a delayed molt. In the fall of 2010, numerous (100's) moribund seals 226 were found in distress along the shore of western Hudson Bay. Rising temperatures, 227 reduction of sea ice, reduction in body condition and the resulting stress are known to 228 229 increase the likelihood of disease outbreaks (Burek et al. 2008). Severity of enzootic diseases can increase and new disease presentations are also likely (Burge et al. 2014) as 230 was seen in Hudson Bay ringed seals in 2010. 231

Numerous examples of episodic events causing major ecological shifts include 232 regime shifts (Hughes et al. 2013), continental growth (Santosh 2013), drought (Ireland et 233 al. 2012), disease (Pickles et al. 2013), and range shifts due to climate (Baker et al. 2008, 234 235 Seppä et al. 2009, Chen et al. 2011). For ringed seals, the literature suggests periods of ringed seal crashes in abundance associated with poor reproduction during significant 236 heavy ice years. Variation in ringed seal density associated with ENSO events include 1973 237 (Smith and Stirling 1978), 1992 (Ferguson et al. 2005), 1998 (Smith and Harwood 2001). 238 and in 2010 (Fig. 1). Evidence of high latitude regime shifts include 1977 and 1989 (Hare 239 and Mantua 2000), 1998-99 (Litzow 2006, Benson and Trites 2002). Synchronous 240 fluctuations of seabird species across the entire Arctic and sub-Arctic regions were 241 associated with changes in sea surface temperatures that were linked to two climate shifts, 242 in 1977 and again in 1989 (Irons et al. 2008), and 1998 (Flint 2013), including Hudson Bay 243 244 in 1998 (Gaston et al. 2012). Major atmospheric patterns suggest that we can expect episodic events occurring once every 10-15 years and that they are largely unpredictable in 245 timing but have major consequences on ecosystem structure and function (Ottersen et al. 246 2004). 247

248 CONCLUSIONS

Considerable uncertainties exist with deciphering past patterns to determine possible
cause and effect relationships among environmental variation, body condition, and their
demographic responses. However, mounting evidence indicates endemic Arctic species,
such as ringed seals, are under immense pressure from climate change and complex spatiotemporal shifts in ecology have subsequently resulted in decreased abundance as a
harbinger of range shift. Managers need to be wary of climate change culminating in both a

- 255 gradual decline in condition and unpredictable episodic events that when combined can
- 256 have major abundance and distribution consequences.
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- 269 The author's declare there are no competing interests.
- 270 Author Contributions
- 271 Steven H. Ferguson conceived and secured the funding for the project and wrote the first
- 272 draft. All authors contributed to the writing process. David J. Yurkowski and Brent G. Young
- 273 ran the statistical analysis and developed the figures. Randi Anderson ran the cortisol

- 274 experiment. Cornelia Willing conducted the reproductive assessments. Ole Nielsen worked
- 275 on the disease studies.
- 276 Animal Ethics
- 277 Permits to collect samples as part of the Inuit subsistence hunts were acquired from
- 278 Fisheries and Oceans Canada.
- 279 Data availability
- 280 Raw environmental data and a summary of observations associated with unusual seal
- behaviour in 2010-11 is available as electronic supplementary material.
- 282 Supplemental Information
- 283 Supplemental information for this article can be found online at:
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440

- 441 Table 1. Relationships between Hudson Bay ringed seal biological parameters and
- environmental correlates assessed using general linear models, 2003-2013.

Covariates	Ovulation rate (%)	Pup recruitment (%)	Seal condition (blubber %)	Cortisol (ng/g)
Intercept	-48.00 ± 69.51	60.03 ± 28.56^{a}	23.82 ± 2.85***	-34.90 ± 43.48***
Year	0.02 ± 0.03	-0.03 ± 0.01^{a}	-0.01 ± 0.001***	$0.002 \pm 0.0002^{***}$
Ice-free period (days)	0.0003 ± 0.006	0.0008 ± 0.002	-0.0004 ± 0.0002*	0.00003 ± 0.0005
El-Niño Southern Oscillation	0.004 ± 0.01	-0.02 ± 0.05	$-0.009 \pm 0.004^*$	0.001 ± 0.006^{b}
North Atlantic Oscillation	0.011 ± 0.012	-0.0008 ± 0.05	-0.009 ± 0.005*	-0.02 ± 0.007 *

^a = 0.08; ^b = 0.055; * P < 0.05; ** P < 0.01; *** P < 0.001

 R^2 was 0.40 for ovulation rate model, 0.46 for pup recruitment model, 0.09 for body condition model, and 0.21 for cortisol level model.

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- Figure 1. Top: Annual winter (December to February) North Atlantic Oscillation index
- 446 (NAO), Arctic Oscillation (AO), and El Nino-Southern Oscillation (ENSO), 1971-2014. Note
- red arrows indicate possible regime shifts (1977, 1989, 1989/99, 2010) and black arrows
- 448 possible years with poor ringed seal condition: 1973/74, 1983, 1992, 1998, 2010. Bottom:
- 449 Sea ice patterns over the day of the year showing inter-annual variation in timing of spring
- 450 breakup, duration of open water season, and time of freeze-up, 2003-2013. Note that
- 451 autumn 2010 freeze-up did not occur until January 2011.
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Figure 2. Barplots (A and B) of annual ovulation rates (%) from adult females and annual
percentage of pups in the harvest. Linear regressions between ringed seal body condition
and harvest year (C; slope = -0.01, t = -8.2, p <0.001), and cortisol level and harvest year (D;
slope = 0.02, t = 8.0, p < 0.001). Sample sizes (n) by year: 2003 (115), 2004 (56), 2005 (88),
2006 (82), 2007 (126), 2008 (105), 2009 (51), 2010 (96), 2011 (97), 2012 (65) and 2013
(45).



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Figure 3. Linear regressions between ringed seal body condition and ice-free duration (A; slope = -0.0004, t = -2.0, p < 0.05), body condition and El-Nino Southern Oscillation (ENSO) index (B; slope = -0.009, t = -2.32, p = 0.02), body condition and North Atlantic Oscillation (NAO) index (C; slope = -0.009, t = 2.0, p < 0.05), and cortisol and NAO index (D; slope = -0.02, t = 2.6, p = 0.01).



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470 Supplementary Table1. 1971-2014 NAO, AO, ENSO, and eastern Hudson Bay breakup and

471 freeze-up from 1979 to 2014.

Year	AO	ENSO	NAO	E	Breakup	Freeze-up	
	1971	-0.49459	-1.3	-0.69667			
	1972	0.264983	-0.7	0.396667			
	1973	1.08517	1.7	0.36			
	1974	-0.1462	-1.7	0.506667			
	1975	0.781803	-0.5	0.486667			
	1976	0.993478	-1.5	0.226667			
	1977	-2.6173	0.7	-1.04333			
	1978	-1.20007	0.7	-0.84667			
	1979	-1.30322	0	-1.20667	1	.66	340
	1980	-0.56821	0.6	0.1	1	.63	335
	1981	-0.16841	-0.2	0.69	1	.91	337
	1982	-0.37507	0	0.08	1	.64	334
	1983	0.17346	2.1	0.946667	1	.71	339
	1984	0.262857	-0.5	0.89	1	.56	328
	1985	-1.2665	-0.9	-0.7	1	.51	333
	1986	-1.80645	-0.4	0.11	1	.85	326
	1987	-0.85368	1.1	-0.29667	1	.80	345
	1988	-0.44515	0.8	0.7	1	.54	342
	1989	2.688033	-1.6	1.26	1	.80	334
	1990	1.252883	0.1	0.433333	1	.80	335
	1991	0.374647	0.4	0.706667	1	.74	336
	1992	1.094977	1.6	0.466667	1	.81	329

1993	1.768833	0.2	0.856667	169	328
1994	-0.41784	0.1	1.02	180	348
1995	0.722987	0.9	1.363333	173	334
1996	-1.05476	-0.9	-0.62	184	357
1997	-0.09629	-0.5	-0.06667	164	330
1998	-0.7783	2.1	-0.22667	159	352
1999	0.648627	-1.4	0.643333	146	350
2000	1.1297	-1.6	1.303333	157	351
2001	-1.31188	-0.7	0.04	150	361
2002	0.454133	-0.2	0.236667	171	338
2003	-0.64532	0.9	-0.05333	185	362
2004	-0.98303	0.3	0.07	177	338
2005	0.105223	0.6	0.89	158	350
2006	-0.81005	-0.7	0.104837	145	355
2007	1.002867	0.7	0.36307	173	345
2008	0.859387	-1.4	0.6561	150	348
2009	0.25841	-0.8	-0.07584	184	347
2010	-3.42177	1.3	-1.67293	141	369
2011	-0.9129	-1.3	-0.67427	163	349
2012	0.654935	-0.7	1.371767	159	348
2013	-1.12184	-0.4	0.02096	159	346
2014	0.183305	-0.5	0.85704	168	341

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473	Supplementary Table2. Chronology of unusual ringed seal and polar bear observations						
474	gathered fro	2010.					
	Date	Comment	Reporter				
	4 Nov. 2010	Marc Hebert,					
		you guys and now 7 in a month?	Manitoba				
			Conservation Officer				
	14 Nov.	Mike Macri (Sea North					
	2010	Tours, Churchill)					
	seal kills that hadn't been consumed.						
	16 Nov.	He states that seals are venturing inland than normal.	Amanda Currie (DFO)				
	2010	Bears are eating seals. The only physical problems or	conversation with				
		abnormalities he notes he has seen is one seal that	Donnie (Great White				
		appeared to be bleeding from the anus. Sick seals	Bear tours).				
	16 Nov.	Recently found a seal that was still alive but crawling over	LeeAnn Fishback				
	2010	land near the Rx road just out of the Town of Churchill.	(CNSC) with Manitoba				
			Conservation				

- 17 Nov. First Vince had heard of dead seals. But noted Darryl Ole Nielson (DFO
- 2010 Hedman flew coast and saw over 300 bears saw 18 dead Science) with Vince seals that had been killed so he says by bears - when I Crichton (Manitoba

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asked him how the bears were catching seals he said they Conservation are likely getting caught on the flats when tide goes out Manager, Game Fur & and bears just taking advantage of easy meal - maybe Problem Wildlife) something wrong with seals that they are getting caught like this.

- 18 Nov. They both confirm they're have been no reports of any Tara Bortoluzzi (DFO
- 2010 killer whale sightings in the area, as its too late in the Science) spoke with seasons for Killer Whales. Also the local polar bears are Mike Macri and Bob also very fat, and several appear to be 'stock piling' the Windsor seals they catch (i.e. some people have witness and (Conservation Officer photographed the bears stock piling or buried seals in Churchill) inland instead of eating them). Mike was on a flight a week ago and saw a fat polar bear kill a seal, walk away and kill another seal on the shore, drag it back to the first, and then walk away without eating either. And another sow with cubs had a dead seal and was not eating it. Another seal was seen moving along RX road about 1-2 km from shore. Received two pictures of this from Mike Macri.
- 24 Nov. I met two hunters from Chesterfield Inlet and Whale Cove Ole Nielsen (DFO)
 2010 in the Iqaluit airport on Monday that were also very
 concerned with the 'behavior' of ringed seals near their

communities this fall. I'm following up with them and several other HTOs. They reported that they are catching more adult seals this year which are really large, and very few pups. The seals are also very easy to catch, in many cases they said 'too easy'. One hunter caught 30 seals in one day trip. The seals are also coming inland and hanging around the shoreline for extended periods of time. Of course, it's great for hunting, but they were really concerned as this is very unusual.

- 26 Nov. Some of the Hunters and Trappers Organizations in the Tara Bortoluzzi (DFO)
- 2010 Kivalliq region have recently reported concerns with 'odd summarizing behaviour' of ringed seals near the communities (i.e. seals response from Kivalliq coming close to shore and hanging around, and hauling Region communities out on shore), as well as some seals that appears to be sick (i.e. molting and loss of hair, seal pocks, low fat content, etc.).
- 26 Nov. She has heard the same concerns from hunters: "After Leah Muckpah (Arviat
 2010 discussion with my board of directors, they have reported HTO Manager)
 some hunters catching seals on shore, and far away from
 shore with loss of hair (like bald patches) but nobody
 took pictures and the seals were used as dog food."

- 27 Nov. He hasn't seen any more seals on shore, neither have the email from Mike Macri
- 2010 helicopters or tundra buggy camps. Also notes another (Sea North Tours) odd thing, the zodiacs, for the first time ever, are covered with scratches from bearded seals who were hauling up into them in September.
- 17 Dec. "A couple weeks ago while he was out of town, Lucassie Lucassie Arragutainaq
- 2010Takatak, found 6 dead seals on the beach, their heads(Secretary Managerseem to be craving for air like their heads up back."Sanikiluaq HTO)
- 06 Jan. 2011 They observed a very few number of seals were shedding reports from local and that even a few number of them were sinking after hunters of Arviat being shot. The seal harvest in Arviat is usually done when the first ice forms in the salt water, usually late
 October to Late November. During that time, it is unheard of that seals would be shedding fur and that they would sink after being shot.
- 26 Jan. 2011 Ringed seals usually molt in the spring but locals noted Ferguson phone seals molting in the fall. The local Conservation Officer conversation with sent seal parts to DFO showing the unusual molt. During Noah Nakoolak of fall large numbers (100s) of seals were observed along Coral Harbour HTO shorelines. Other communities including Repulse Bay also noted the same unusual conditions. Coral Harbour

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seldom sees seals near town but this past fall large numbers were in the Harbour and some went on land in the harbour (very unusual).

His own personal experience - he was traveling along shoreline in August and found a seal on the beach. The ringed seal kept traveling up the shore – unusual behaviour. Three weeks later he was in a different area and saw a harp seal on land – about ¼ mile inland. It was a late freeze up this autumn and a very warm fall. The ice formed along the shoreline twice in mid-November but drifted off with winds both times before it finally formed fast in December. In December rain fell.

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