Testing the hypothesis that routine sea ice coverage of 3-5 mkm^2 results in a greater than 30% decline in population size of polar bear (*Ursus maritimus*).

Version 2

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Abstract

The polar bear (*Ursus maritimus*) was the first species to be classified as threatened with extinction based on predictions of future conditions rather than current status. These predictions were made using expert-opinion forecasts of population declines linked to modeled habitat loss – first by the International Union for the Conservation of Nature (IUCN)'s Red List in 2006, and then by the United States Fish and Wildlife Service (USFWS) in 2008 under the Endangered Species Act (ESA), based on data collected to 2005 and 2006, respectively. Both assessments predicted significant population declines of polar bears would result by mid-century as a consequence of summer sea ice extent rapidly reaching 3-5 mkm^2 on a regular basis: the IUCN predicted a >30% decline in total population, while the USFWS predicted the global population would decline by 67% (including total extirpation of ten subpopulations within two vulnerable ecoregions). Biologists involved in these conservation assessments had to make several critical assumptions about how polar bears might be affected by future habitat loss, since sea ice conditions predicted to occur by 2050 had not occurred prior to 2006. However, summer sea ice declines have been much faster than expected: low ice levels not expected until mid-century (about 3-5 mkm^2) have occurred regularly since 2007. Realization of predicted sea ice levels allows the 'rapid sea ice decline = population decline' assumption for polar bears to be treated as a testable hypothesis. Data collected between 2007 and 2015 reveal that polar bear numbers have not declined as predicted and no subpopulation has been extirpated. Several subpopulations expected to be at high risk of decline remained stable and five showed increases in population size. Another at-risk subpopulation was not counted but showed marked improvement in reproductive parameters and body condition with less summer ice. As a consequence, the hypothesis that repeated summer sea ice levels of below 5 mkm^2 will cause significant population declines in polar bears is rejected, a result that indicates the ESA and IUCN judgments to list polar bears as threatened based on future risks of habitat loss were scientifically unfounded and that similar predictions for Arctic seals and walrus may be likewise flawed. The lack of a demonstrable 'rapid sea ice decline = population decline' relationship for polar bears also potentially invalidates updated survival model outputs that predict catastrophic population declines should the Arctic become ice-free in summer.

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Introduction

The polar bear (*Ursus maritimus*) is the top predator of the Arctic ecosystem and is found in five nations with appropriate sea ice habitat (Fig.1). This icon of the Arctic was the first species to be listed as threatened with extinction based on population declines anticipated to occur as a result of forecasted habitat loss, rather than on current circumstances (Adler 2008). The International Union for the Conservation of Nature (IUCN), via its Red List of Threatened Species, made this unique conservation decision in 2006 (Schliebe *et al.* 2006a): it assigned polar bears the status of 'Vulnerable' after the IUCN Polar Bear Specialist Group (PBSG) in 2005 reported that the global population was likely to decline by "more than 30% within the next 35-50 years" (Aars, Lunn & Derocher 2006:61)(note the IUCN Red List status term 'Vulnerable' is equivalent to the ESA term 'Threatened' (indicating a species likely to become endangered) while both use the term 'Endangered' to indicate a higher-risk status). This Red List decision reversed the 'Lower Risk/Conservation Dependent' status (now called 'Least Concern') that polar bears were assigned in 1996 to reflect their recovery from previous decades of over-hunting (Wiig *et al.* 2015).

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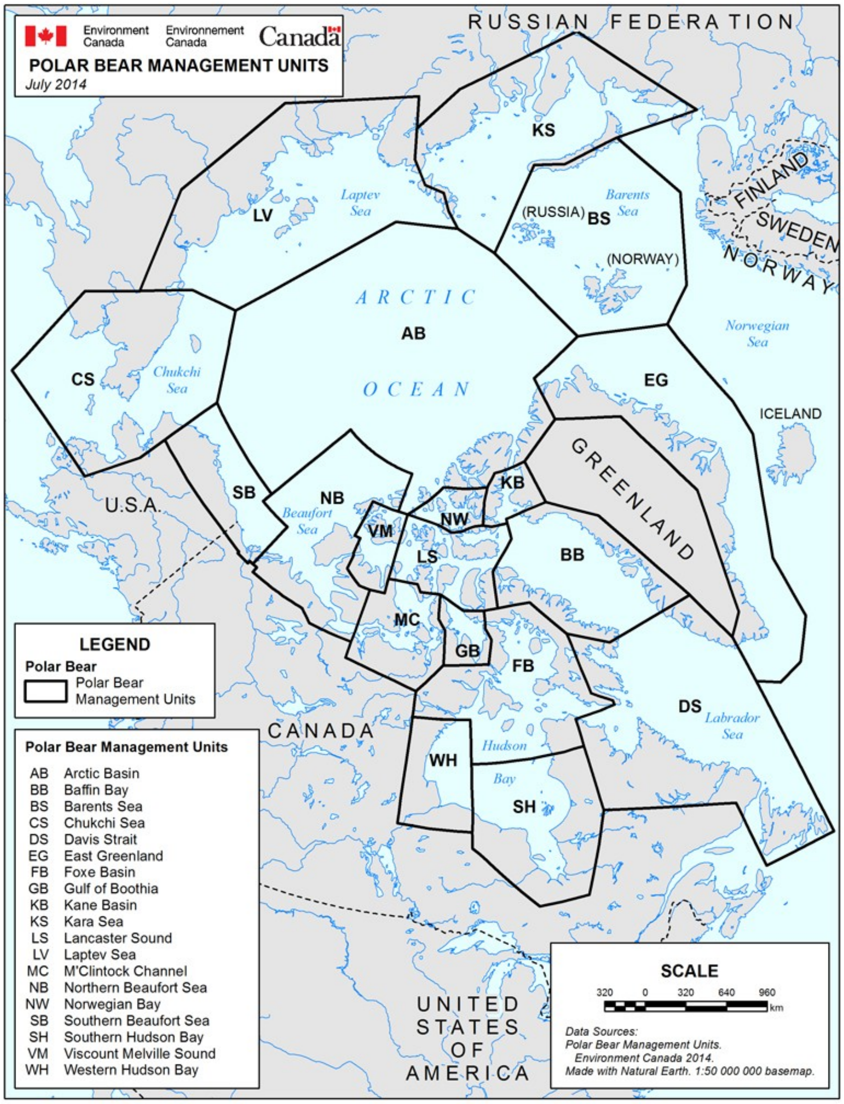

Figure 1. Global polar bear subpopulations, as defined by the IUCN Polar Bear Specialist Group, managed by five nations (Canada, Russia, Norway, United States of America, and Denmark (for Greenland). Image credit: Environment Canada.

The Fish and Wildlife Service (USFWS) of the United States of America (US), in 2008, similarly declared polar bears 'Threatened' in response to a petition filed in 2005 by the Center for Biological Diversity and two other not-for-profit conservation organizations (Schliebe *et al.*

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2006b). Said the US Fish & Wildlife Service as it invoked the Endangered Species Act (ESA) to protect polar bears (USFWS 2008: 28213):

> "We find, based upon the best available scientific and commercial information, that polar bear habitat—principally sea ice—is declining throughout the species' range, that this decline is expected to continue for the foreseeable future, and that this loss threatens the species throughout all of its range. Therefore, we find that the polar bear is likely to become an endangered species within the foreseeable future throughout all of its range."

ESA protection for polar bears (referred to henceforth as the "ESA decision") came on top of existing regulations mandated by the 1972 US Marine Mammal Protection Act (which gave broad-scale safeguards to polar bears and other marine mammals), as well as a specific international treaty signed in 1973 by all Arctic nations to protect polar bear populations against over-hunting and poaching (Larsen & Stirling 2009; Marine Mammal Commission 2007).

The 1973 international treaty spawned the formation of the IUCN Polar Bear Specialist Group (PBSG), tasked with coordinating the research necessary for assessing polar bear health and population size worldwide (Anonymous 1968). For management purposes, the PBSG divided polar bears into more than a dozen more or less discrete subpopulations. At present, the 19 designated subpopulations are continuously distributed across available sea ice habitat (Fig. 1 – note the abbreviations for subpopulations used throughout this analysis). Polar bears have experienced no recent range contractions due to habitat loss, no continuous declines within any subpopulation, and currently have a large population size estimated at more than 22,000-31,000 bears (Norwegian Polar Institute 2015; SWG 2016; Wiig *et al.* 2015)(see "Global population size observations" below). Thus, by all measures used to assess contemporary conservation status (Akçakaya *et al.* 2006), the global polar bear population is currently healthy and would qualify for the IUCN Red List status of 'Least Concern' and would not qualify as a threatened species under the ESA based on these parameters – a fact which was also true in 2006 and 2008.

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Therefore, the ’Vulnerable’ to extinction and ‘Threatened’ with extinction status granted polar bears in 2006 and 2008, respectively, referred exclusively to what might occur in the future, should sea ice continue to decline in response to rising carbon dioxide levels in the atmosphere generated by human fossil fuel use, variously called anthropogenic global warming, climate warming, or climate change (Derocher, Lunn & Stirling 2004, Derocher *et al.* 2013; Furevik, Drange & Sorteberg 2002; Stirling & Derocher 2012). The Red List assessment and the ESA decision, based on comparable sets of assumptions and modeled forecasts of habitat loss, predicted potentially catastrophic declines in the global population of polar bears by 2050 as a direct effect of crossing a particular threshold of sea ice loss based on a number of research reports produced by the US Geological Survey (USGS)(e.g., Amstrup, Marcot & Douglas 2007; Durner *et al.* 2007; Hunter *et al.* 2007; Regehr, Amstrup & Stirling 2006; Regehr *et al.* 2007a; Rode, Amstrup & Regehr 2007). Based on similar models and assumptions, the US Fish & Wildlife Service subsequently declared Arctic ringed seals (*Phoca hispida,* aka *Pusa hispida*) and Pacific bearded seals (*Erignathus barbatus nauticus*) to be ‘Threatened’ (USFWS 2012a, 2012b) – with the same proposed for Pacific walrus (*Odobenus rosmarus divergens*) (USFWS 2011, 2014) – but the IUCN did not (Kovacs 2016; Lowry 2015; Lowry 2016).

As Amstrup, Marcot & Douglas (2007:1) stated: “Our modeling suggests that realization of the sea ice future which is currently projected would mean loss of ≈ 2/3 of the world’s current polar bear population by mid-century.” Although other potential future risks were considered (such as contamination with pollutants, oil spills, and poaching), IUCN and USGS/USFWS biologists determined that future declines in sea ice constituted the overwhelmingly largest threat to future health and survival of polar bears. Therefore, given the simple cause and effect relationship assumed to exist between sea ice loss and polar bear population size, if forecasted

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ice conditions occurred sooner than expected, the resulting changes in population size would be expected sooner than expected as well. Since sea ice declines have progressed much faster than expected since 2007, this 'rapid sea ice decline = population decline' assumption can now be treated as the following hypothesis to be tested against recently collected polar bear data: *Polar bear population numbers will decline by >30% in response to rapid and sustained sea ice coverage of 3-5 mkm*^{2} *and all ten subpopulations in Seasonal and Divergent ecoregions will be extirpated.*

Methods

Sea ice and population decline predictions

Loss of future summer sea ice coverage (July to September) was the primary risk assessed for the Red List and ESA decisions in 2006 and 2008, sea ice coverage in winter and spring were not predicted to change appreciably (ACIA 2005; Amstrup, Marcot & Douglas 2007; Durner *et al.* 2007; Hassol 2004).

The report supporting the 2006 Red List decision (Schliebe *et al.* 2006a), as well as the updates that followed (Wiig *et al.* 2007; Schliebe *et al.* 2008), were based on assumptions about how polar bears would respond over the next 45-100 years (e.g., Derocher, Lunn & Stirling 2004) to modeled declines in sea ice coverage published in the synthesis report of the Arctic Climate Impact Assessment (Hassol 2004), which are shown in Fig. 2. In contrast, the studies supporting the ESA decision undertaken by the U.S. Geological Survey for the US Fish & Wildlife Service modeled declines of preferred polar bear habitat (ice of >50% concentration over continental shelves) forecasted over a maximum of 95 years (2005-2100) (Durner *et al.* 2007).

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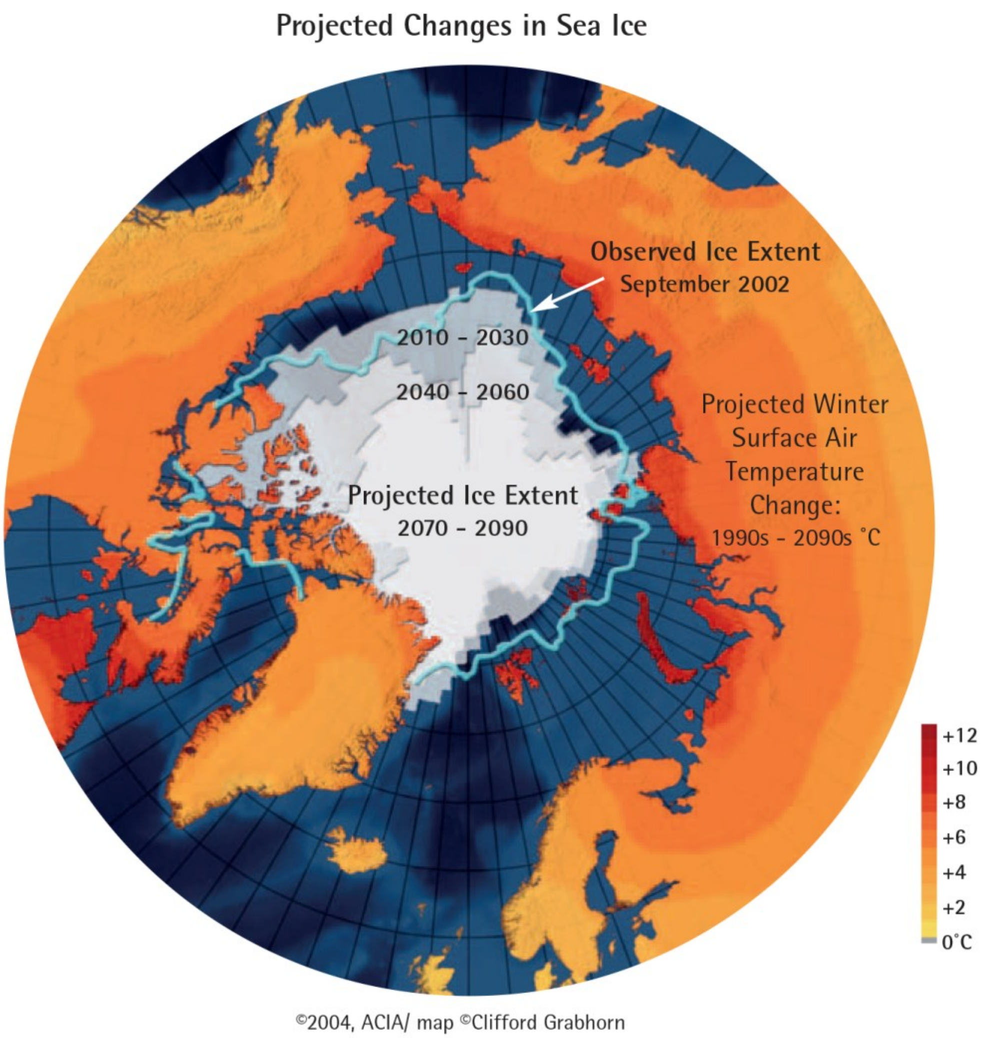

Figure 2. Projected September sea ice extent for 2010-2030, 2040-2060, and 2070-2090 (centered on 2020, 2050 and 2080, respectively) compared to the observed extent at 2002. Image credit: 2005 Arctic Climate Impact Assessment, map by Clifford Grabhorn. See also Hassol (2004:192-194).

These habitat predictions utilized ten of the "business as usual" sea ice models (SRES A1B) included in the IPCC AR4 report (Durner *et al.* 2007; IPCC 2007; Zhang & Walsh 2006) with the ensemble mean at 2050 falling somewhat below Fig. 2 levels (Durner *et al.* 2009).

The critical limit of sea ice extent used to predict catastrophic declines in polar bear population size was not defined numerically in the original assessments but the threshold of 3-5

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mkm^2 used in this analysis is taken from figures included in those documents. For example, a forecast graph published in the Arctic Climate Impact Assessment scientific report (ACIA 2005:193) shows two out of five models consistently predicted September ice below 5.0 mkm^2 (but above 3.0 mkm^2) after 2045 while three out of five models consistently predicted 3-5 mkm^2 after 2060. Amstrup, Marcot & Douglas (2008:238) illustrated a specific example of their sea ice prediction, reproduced here as Figure 3, that shows their ten IPCC AR4 SRES A1B model results for September 2045-2054: five of the models predicted coverage of approximately 3.7-5.3 mkm^2 (± 1 sd), three predicted 1-3 mkm^2 and two predicted less than 1 mkm^2 (see also Stroeve *et al.* 2007).

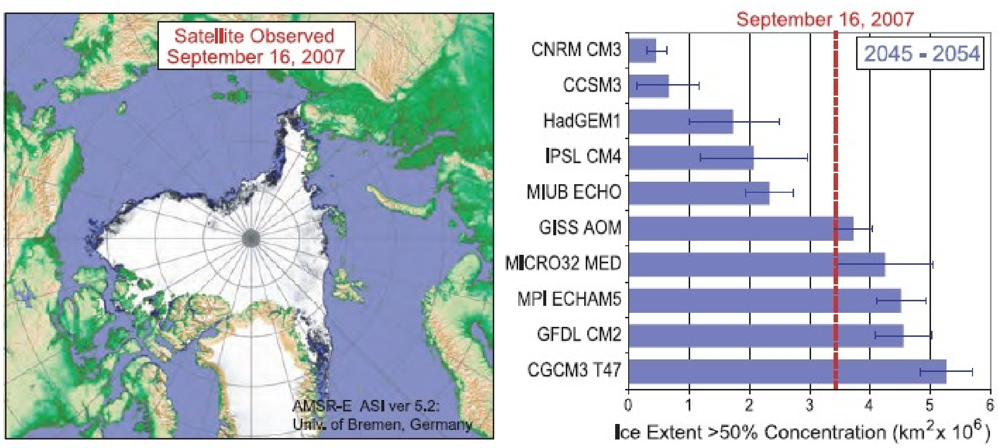

Figure 3. From Amstrup, Marcot & Douglas 2008, caption from original (as per American Geophysical Union): Area of sea ice extent (>50% ice concentration) on 16 September 2007, compared to 10 Intergovernmental Panel of Climate Change Fourth Assessment Report GCM mid century projections of ice extent for September 2045–2054 (mean ±1 standard deviation, n = 10 years). Ice extent for 16 September 2007 was calculated using near-real-time ice concentration estimates derived with the NASA Team algorithm and distributed by the National Snow and Ice Data Center (http://nsidc.org). Note that five of the models we used in our analyses project more perennial sea ice at mid century than was observed in 2007. This suggests our projections for the future status of polar bears may be conservative. Image credit: American Geophysical Union.

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Also, the "resource selection function" (RSF) polar bear habitat maps for September generated by Durner *et al.* (2007:44) for various decades from 2046-2099 conform to this interpretation that a critical threshold of about 3-5 mkm^2 (give or take some measure of error) was expected at mid-century. Durner *et al.*'s (2007:16, 49) description of this threshold is explicit: "By the mid-21st century, most peripheral seas [of the Arctic Ocean, e.g. Barents, Kara, Beaufort, etc.] have very little remaining optimal polar bear habitat during summer."

For the population decline portion of the predictions, the ESA decision depended upon the outputs of Bayesian forecasting, a method that in this case relied on the expert judgment of one USGS biologist (Steven Amstrup) regarding how polar bears would respond to the presumed stresses of forecasted sea ice declines (Amstrup, Marcot & Douglas 2007). Rather than population size estimates for all 19 subpopulations, the predictive models used estimated carrying capacity figures for each of four newly-defined sea ice 'ecoregions.' Sea ice ecoregions were a new concept developed for this analysis that were based on "current and projected sea ice conditions" (Amstrup, Marcot & Douglas 2007:1, 6-8), shown in Fig 4.

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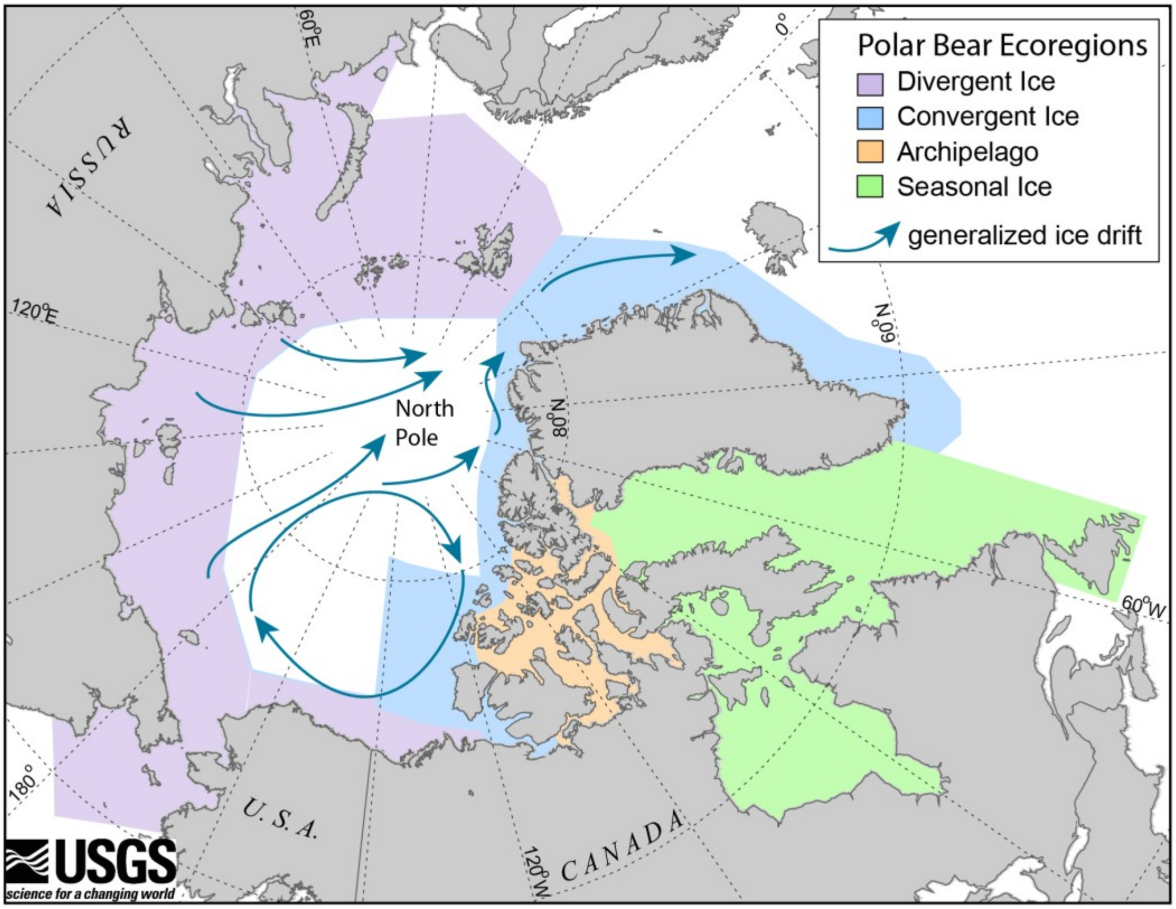

Figure 4. Boundaries of polar bear ecoregions and predominant direction of sea ice drift. All polar bears in green and purple areas (Seasonal and Divergent sea ice) were predicted by computer models based on one biologist's expert opinion to be extirpated by 2050 (USFWS 2008; Amstrup et al. 2007). Image credit: US Geological Survey.

For example, the 'Seasonal' ice ecoregion comprised all subpopulation regions where sea ice melts completely during the summer, stranding polar bears onshore (Western Hudson Bay, WH; Southern Hudson Bay, SH; Foxe Basin, FB; Davis Strait, DS; Baffin Bay, BB), while the 'Divergent' ecoregion comprised all subpopulation regions where sea ice recedes from the coast into the Arctic Basin during the summer, leaving bears the option of staying onshore or remaining with the sea ice (Southern Beaufort Sea, SB; Chukchi Sea, CS; Laptev Sea, LS; Kara

Sea, KS; Barents Sea, BS). Forty-five years from 2005 (i.e., 2050) was considered the "foreseeable future" according to the ESA decision, derived from the length of time to produce three generations of polar bears (USFWS 2008:28229). Within this foreseeable future, the models upon which the decision was made predicted that extirpation of polar bears from all subpopulations within the 'Seasonal' ice and 'Divergent' ice ecoregions was "most likely" – Hunter *et al.* (2007, 2010) put the probability of extirpation at >80%. Bears in the Archipelago ecoregion were predicted to persist at 2050 but to possibly decline in population size by 2100, while bears in the Polar Basin Convergent ecoregion were predicted to persist through 2050 but would "most probably" be extirpated by 2080. In other words, ten subpopulations (a total of 17,300 polar bears) were forecasted with a high degree of confidence to be wiped out completely by 2050 – in association with the global population (estimated at 24,500) declining by 67% – in response to September sea ice conditions routinely (e.g. 8/10 years or 4/5 years, see Hunter *et al.* 2007, 2010) declining to about 3-5 mkm^2.

In contrast, the Red List assessors took a more generalized approach (Schliebe *et al.* 2006a; Wiig *et al.* 2007). They predicted a decline in the global polar bear population of >30% by 2050 in conjunction with predicted sea ice declines to about 3-5mkm^2, also based on three generations of 15 years each (Aars, Lunn & Derocher 2006).

Sea ice decline observations

Archived sea ice charts for 2007-2015 provided by the US National Snow and Ice Data Center (NSIDC), see Fig. 5, as well as published sea ice studies, show that sea ice coverage for September was well below 6 mkm2 since 2007, and fell to 3-5 mkm2 in seven of those nine years. Published ice analyses for the Beaufort Sea, for example (Frey *et al.* 2015:35, for 2003-

2010; Meier *et al.* 2014:4, for 2004-2012; Parkinson 2014:4321, for 2013; Perovich *et al.* 2015:39, for 2006-2015), showed that during the period 2007-2015, the length of the ice-free season over the continental shelf area was >127 days (the critical threshold suggested for BS polar bears) (Hunter *et al.* 2007, 2010). Recently, Stern & Laidre (2016) devised a method for describing sea ice habitat similarly across all 19 polar bear subpopulations. Their method, which tracks the calendar date when the area of 15% ice concentration rises above (or falls below) a mid-point threshold in winter or summer, respectively, shows a marked decline in sea summer ice since 2007 within all USGS-defined polar bear ecoregions. Even allowing for the uncertainties in the sea ice computer models used by USGS analysts (discussed in DeWeaver *et al.* 2007), and the fact that most agencies track ice concentrations of >15% (rather than the >50% concentration used by USGS biologists), conditions not anticipated until mid-century had become reality by 2007. After 2006, sea ice declined much faster than expected (Douglas 2010; Overland & Wang 2013; Serreze *et al.* 2016; Stirling & Derocher 2012; Stroeve *et al.* 2014; Wang & Overland 2015), a phenomenon that was apparent even at the time the USGS documents for the ESA decision were prepared (e.g., Amstrup, Marcot & Douglas 2007; Durner *et al*. 2007; Stroeve *et al.* 2007).

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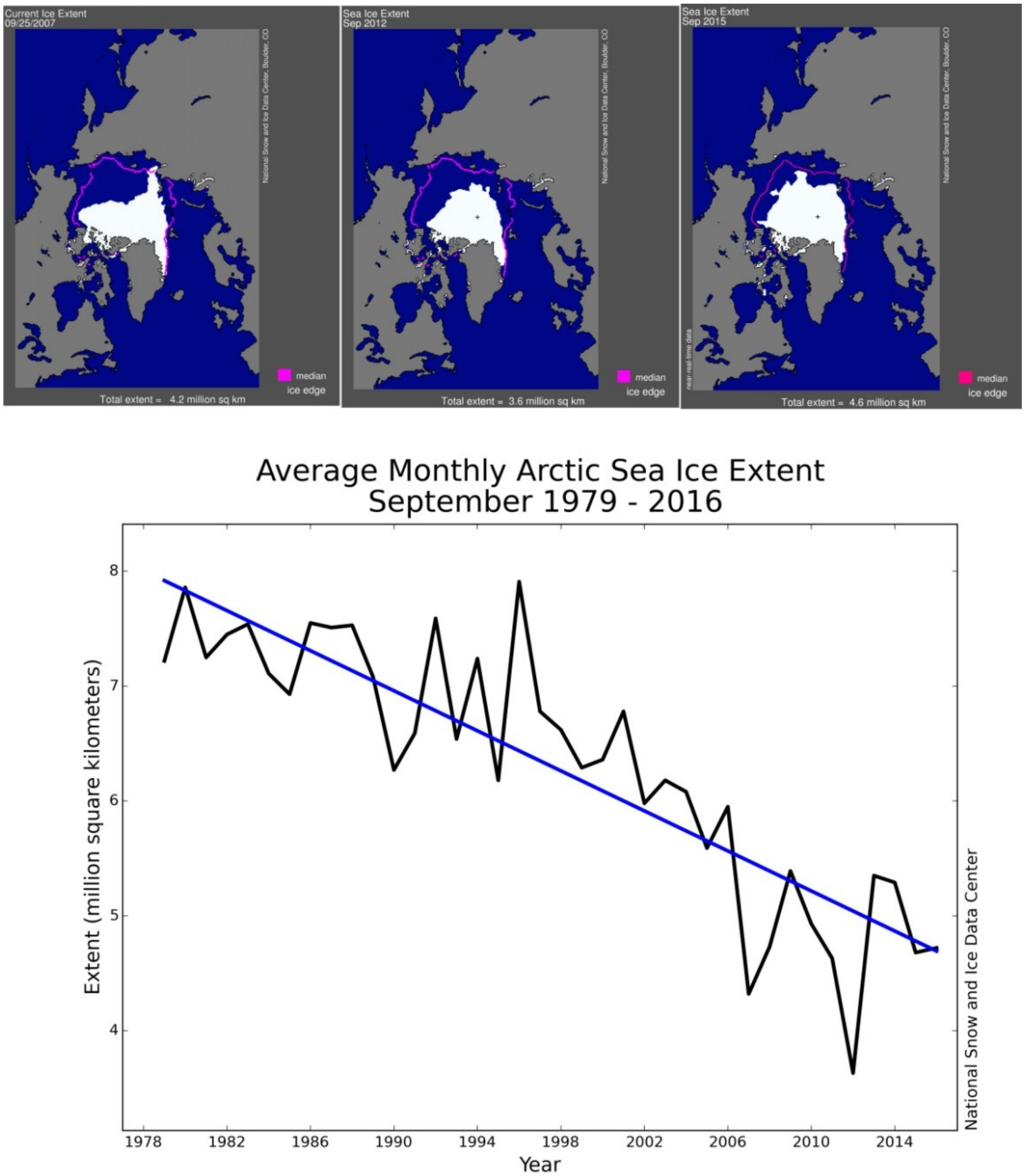

Figure 5. Average monthly Arctic sea ice extent for September, the month of the yearly minimum. Upper panel, left to right: 2007, 2012, 2015 (image for 2007 is for 25 September, 0.09 mkm^2 below the monthly average for that year). Orange lines for 2007 and 2012 show the median ice edge for 1979-2000, while the median for 2015 is based on 1981-2010 data. Lower panel: Average ice extent for September, 1979-2016. Image credit: NASA's NSIDC Sea Ice Index.

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Unfortunately, the persistent use of a 15% concentration threshold to describe sea ice conditions among both sea ice experts and polar bear researchers makes it a bit challenging to assess the sea ice component of the hypothesis considered here. However, Amstrup, Marcot & Douglas (2008:238-239), as shown in Fig. 3, showed that in 2007, sea ice of 50% concentration at the September minimum dropped to approximately 3.5 mkm^2 (18% lower than the 4.13 mkm^2 figure – now officially 4.29 mkm2, according to NSIDC – derived using a 15% concentration threshold, i.e., just outside the 1 standard deviation error bars for the model estimates). Both of these figures (3.5 mkm^2 and 4.13 mkm^2) were lower than five out of the ten projections for September 2045–2054 used in the original ESA decision documents (see also Amstrup, Marcot & Douglas 2007). Parkinson (2014:4320) compared 15% and 50% ice concentration thresholds in the Arctic for 2013. She demonstrated that in most local regions, the observed differences due to ice concentration thresholds were minimal (see also Durner *et al*. 2006:47). In addition, while the 50% threshold shown by Parkinson always gave a shorter ice season than the 15% threshold (and thus, a longer ice-free season), the trends for both were very similar.

Therefore, since the lowest minimum September extent recorded since 1979 (using a 15% concentration threshold) occurred in 2012 (3.4 mkm^2), if the 18% difference shown by Amstrup, Marcot & Douglas (2008) for 2007 was also true for 2012 (or close to it), the 50% concentration threshold for 2012 would have been approximately 2.9 mkm^2 – close to one standard deviation from 3.0 mkm^2. This suggests that published sea ice data based on 15% ice concentration can be used to broadly delimit the critical threshold of ice expected at mid-century as between 3.0 and 5.0 mkm^2 for both the 2006 Red List assessment and the 2008 ESA decision.

Although the polar bear habitat predictive model used to support the ESA decision utilized only data from the 'Pelagic Ecoregion' subset (i.e., Divergent and Convergent

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ecoregions, aka the Polar Basin)(Amstrup, Marcot & Douglas 2007; Durner *et al.* 2007), summer sea ice coverage in the Seasonal ecoregion was also forecasted to decline but was not unspecified (e.g. Regehr *et al.* 2007b). However, similar to the situation for the Divergent ecoregion, observations for FB (a subpopulation with seasonal ice in the northern portion of Hudson Bay), for example, show the length of the season with least preferred habitat in summer for polar bears (≤ 30% concentration) increased from three months to five (Galicia *et al.* 2016), while in the rest of Hudson Bay the ice-free season has increased by approximately three weeks – leaving SH and WH bears onshore for almost five months compared to about four months previously (Cherry, Derocher & Lunn 2016; Obbard *et al.* 2007, 2016). In Baffin Bay and Davis Strait (west of Greenland), there has been a significant decrease in sea ice concentrations preferred by polar bears from 15 May – 15 October (Peacock *et al.* 2013; Rode *et al.* 2012; SWG 2016).

Testing the hypothesis

Polar bear population numbers will decline by >30% in response to rapid and sustained sea ice coverage of 3-5 mkm^2 and all ten subpopulations in Seasonal and Divergent ecoregions will be extirpated

Since the 2006 Red List assessment and the ESA decision of 2008 both predicted that a significant decline in the global population of polar bears would occur by 2050 as a direct effect of predicted sea ice losses, either the 2050 deadline or realization of the predicted sea ice loss can be used to test the validity of the hypothesis. Due to the fact that summer sea ice extent for 2007-2015 rapidly dropped to levels not predicted until mid-century or later (in 7/9 years for the period 2007-2015 and 5/6 years for 2007-2012, see Fig.5), data are now available with which to assess

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whether polar bear populations in the Seasonal and Divergent ecoregions have been extirpated as predicted and if the global population has declined by >30% to as much as 67%. Although new data are not available for all subpopulations, several critical ones have data that were not available in 2005, and one subpopulation that was assessed in 2005 as unknown (Kara Sea) has now been surveyed (Matishov *et al.* 2014) and it is unclear if this reflects a real increase.

Unfortunately, for a few subpopulations estimates are decades-old figures based on limited studies rather than comprehensive survey counts and most of these have not been updated. For example, the estimate for the LS (800-1200), accepted since 1993 by the PBSG (Belikov 1995; Wiig *et al.* 1995), has not changed since then. The estimate for the CS (3,000-5,000), also assessed by Belikov in 1993, became "2000-5000" in the 1993 PBSG report (Wiig *et al.* 1995:24), and "2000" in 2005 (Aars, Lunn & Derocher 2006:34). While less than ideal, these estimates are the best data available.

Seasonal and Divergent ecoregion population size observations

Table 1 shows that the ten subpopulations predicted to be extirpated by 2050 have not experienced any overall decline since 2005, nor has any single subpopulation been extirpated. Polar bear population size for the Seasonal ecoregion went from 7778 in 2005 to 9537 in 2015 (a 22.6% increase), while population size for the Divergent ecoregion rose from 9497 to 10861 (a 14.4% increase). It may be that due to inherent error ranges in individual estimates such increases are not statistically significant and indicate stable rather than increasing populations. Overall, as of 2015, an estimated 20,398 bears lived in Seasonal and Divergent ecoregions, up 18% from the 2005 estimate. While could be argued that this is not necessarily a statistically significant increase, it is apparent that a catastrophic decline has not occurred.

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Table 1. Polar bear subpopulation size estimate changes between 2005 and 2015 for Seasonal and Divergent ecoregions. Except where noted in comments, numbers and trends are from Aars, Lunn & Derocher (2006) and Wiig et al. (2015). Seasonal ecoregions are shaded. See text regarding estimate for Kara Sea. * Figures not included in Wiig et al. (2015).

Subpopulation	Estimate 2005	Estimate 2015	Year of last estimate	Ref. for Estimates	Comments
W. Hudson Bay WH	935	1030	2011	Aars et al. 2006; Wiig et al. 2015	2011 survey methods (Lunn et al. 2016) differed markedly from 2004 survey (Regehr et al. 2007b)
S. Hudson Bay, SH	1000	943	2012	Aars et al. 2006; Wiig et al. 2015	
Foxe Basin, FB	2119	2580	2010	Aars et al. 2006; Wiig et al. 2015	
Davis Strait, DS	1650	2158	2007	Aars et al. 2006; Wiig et al. 2015	
Baffin Bay, BB	2074	2826*	2013	Aars et al. 2006; Wiig et al. 2016	2013 estimate from SWG 2016
'Seasonal' total	7778	9537			
S. Beaufort Sea, SB	1500	907	2010	Aars et al. 2006; Wiig et al. 2015	Survey & assessment methods differed markedly (Regehr et al. 2006; Bromaghin et al. 2015)
Chukchi Sea, CS	2000	2000	2005	Aars et al. 2006; Wiig et al. 2015	2005 estimate is a PBGS-adjusted guess, based on Belikov 1995
Laptev Sea, LS	1000	1000	1993	Aars et al. 2006; Wiig et al. 2015	2005 estimate unchanged since 1993 (Belikov 1995)
Kara Sea, KS	~2000	3200	2013	Amstrup et al. 2007; Wiig et al. 2015	2005 estimate was a USGS guess (Amstrup et al. 2007) ; 2015 estimate is from a survey done in 2013 that was the first ever
Barents Sea, BS	2997	3749*	2015	Aars et al. 2006; Wiig et al. 2015 Norweg. Polar Institute 2015	2005 estimate of 2997 was preliminary; adjusted to 2650 (Aars et al. 2009); Wiig et al. 2015 used 2644; NPI 2015 documented a 42% increase in the Svalbard half since 2004, here applied to the entire region using 2640
'Divergent' total	9497	10861			
Total of Seasonal plus Divergent	**17,275**	**20,398**			

Note that Amstrup, Marcot & Douglas (2007) used an estimate of 17,300 as the population size starting-point for the ten subpopulations residing in Seasonal and Divergent ecoregions together (7,800 in Seasonal plus 9,500 in Divergent) and a global total of 24,500 bears (Aars, Lunn & Derocher 2006). However, since they did not state what figure they used for KS (which had no

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estimate in Aars, Lunn & Derocher 2006), 2000 was assumed for Table 1 because only this figure generated the correct ecoregion total. A preliminary estimate for 2004 BS survey ("2997") appeared in Aars, Lunn & Derocher (2006) that was later amended twice (Aars *et al.* 2009; Wiig *et al.* 2015), to "2650" and "2644" but it is clear the preliminary estimate of "2997" was the one used by Amstrup, Marcot & Douglas and was used for the 2005 value in Table 1. For the 2015 value, a recent update to the Wiig *et al.* (2015) data for BS is now available: according to a press release issued by the government entity that conducted the survey, in 2015 the Svalbard portion of the BS increased by 42% (from 685 to 975, an increase of 290) since a similar count in 2004 (Norwegian Polar Institute 2015), and apparently anticipated despite poor sea ice conditions since 2004 (Fauchald *et al.* 2014). Applied to the entire region (using the estimate derived by Aars *et al.* (2009) of 2650) gives a 2015 estimate of about 3749, an increase of 1109. This estimate fits well with the comment by Aars *et al.* (2009) that in 2004 there were about three times (actually 2.87) as many bears in the Russian sector than in Svalbard: using the Svalbard figure of 975 would give an estimate of 3773 for the entire region. Svalbard has been monitored separately for decades (e.g., Andersen & Aars 2016; Larson 1971; Derocher 2005; Derocher *et al.* 2010), providing ample context for the 2015 survey data as a known and usual subset of Barents Sea. This result is significant since Svalbard is the only region for which survey data span the entire period considered for the hypothesis (although that for SH, KS, and BB are almost as long).

As of 2015, only one of the ten subpopulations predicted to be extirpated (SB) experienced a statistically significant decline (which may have been a natural and temporary fluctuation, given its similarity to a decline that occurred in 1974-1976 (discussed in detail below) and the evidence that the drop in bear numbers documented by Bromaghin *et al.* (2015)

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for 2005-2006 followed an even more dramatic *increase* in numbers from 2002-2004 not discussed by Regehr *et al.* (2006) for the ESA decision. In contrast, five subpopulations increased by a substantial amount (BB, BS, DS, FB, KS). While there has been no recent count of CS bears, research on body condition and reproductive parameters (see discussion below) indicate a stable or increasing population. Note that neither the BB survey report citing a population estimate of 2,826 (95% CI = 2,059-3,593) at 2013 (and a KB estimate of 357 (95% CI: 221 – 493) at 2013) (SWG 2016), nor the preliminary results of the BS survey (Norwegian Polar Institute 2015), were completed in time to be included in the Wiig *et al.* (2015) global population estimate.

In summary, the population estimates for polar bears residing within Seasonal and Divergent ecoregions have increased despite the realization of summer sea ice declines predicted to precipitate population declines to zero. For these two polar bear ecoregions, "sea ice decline ≠ population decline."

Global population size observations

In 2005, the average global population of polar bears according to the PBSG was approximately 22,500, based on an estimate of 20,000-25,000 (Aars, Lunn & Derocher 2006), although as noted above Amstrup, Marcot & Douglas (2007) used a figure of 24,500 for their USGS analysis. By 2015, that had officially increased to about 26,500 on average or 22,000-31,000 (Wiig *et al.* 2015). Recently released survey data for BS and BB (completed in 2015 and 2013, respectively) means this number is actually higher (by about 3316 on average). Of all the PBSG estimates for subpopulations in Convergent and Archipelago ecoregions, none changed in time for the 2015 Red List assessment (Wiig *et al.* 2015) except for Kane Basin (KB). The

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results of a 2013 survey of the KB subpopulation in eastern Canada (SWG 2016) stated it increased from 164 (95% CI: 94 – 234) to 357 (95% CI: 221 – 493), or 118%. In other words, other than the KB increase for the Convergent ecoregion, all of the changes recorded are in Seasonal and Divergent ecoregions.

Therefore, the growth of the global population comes primarily from documented increases in the BS, BB, DS, FB, and KS subpopulations, which more than offsets the (possibly temporary) decline in SB numbers. Therefore, while the 2015 Red List assessment declared the global population trend for polar bears 'Unknown' based in part on unevaluated subpopulations and out-of-date surveys (Wiig *et al.* 2015), recent data collected between 2013 and 2015 but made public after July 2015 shows there was a potential net increase of ~3316 between 2005 and 2015 in studied portions of the population worldwide, with little rational for supposing unstudied subpopulation have fared differently.

In summary, despite the fact that sea ice coverage has repeatedly reached levels not predicted until 2050 or later, not only has the estimated global population size of polar bears not declined by >30% (or as much as 67% - i.e., to 6660-8325), it has in fact increased approximately 13.5% above the estimate used by USGS analysts (Amstrup, Marcot & Douglas 2007). Even without a statistical analysis of the estimate data that includes error estimates, the lack of any documented decline in population size worldwide, and the failure of any subpopulation to be extirpated despite realized of summer sea ice loss predicted by mid-century, means the hypothesis that global polar bear population numbers would decline by >30% in response to rapid and sustained sea ice coverage of 3-5mkm^2 in summer must be rejected.

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Discussion

The evidence that polar bear populations did not decline as expected in response to virtually constant summer sea ice levels of 3-5 mkm^2 since 2007 poses an obvious question. Why were the predictions made by the Red List assessors and USGS biologists in 2006 and 2008 so far off the mark? Results of recent studies suggest that these researchers vastly over-estimated the importance of summer feeding for polar bears but also neglected to consider negative effects on survival for any season except summer.

It is now apparent that well-fed bears are able to survive a summer fast of five months or so, no matter whether they spend that time on land or on the sea ice (e.g., Whiteman *et al.* 2015). The known concentration of feeding on ringed, bearded, and harp seal pups between March/April and May/June (Obbard *et al*. 2016; Stirling & Øritsland 1995; Stirling *et al.* 1975, Stirling, Archibald & DeMaster 1975), when two-thirds of the yearly total of calories are consumed (with the remaining one-third consumed summer through winter but primarily late fall), means that virtually all polar bears in Seasonal and Divergent ecoregions effectively live off their accumulated fat from June/July to November wherever they spend this time. One or two successful seal hunts – or foods scavenged onshore – may decrease slightly the amount of weight lost during the summer fasting period but are unlikely to make a significant difference for most bears (Obbard *et al.* 2016; Rode *et al.* 2015a). While a few persistent individuals may garner an advantage from such abundant local resources as eggs of ground-nesting geese and marine birds (Gormezano & Rockwell 2013a, 2013b) or the refuse left after aboriginal whaling (Atwood *et al.* 2016b; Rogers *et al.* 2015), they appear to be the exception rather than the rule.

For example, even though the Chukchi and Beaufort Seas have experienced some of the most dramatic declines of summer and early fall sea ice of all subpopulations worldwide (e.g.

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Serreze *et al.* 2016), studies found polar bears that spent longer time ashore in recent years suffered no negative effects. Rode *et al*. 2015b) report that for 2008-2013, the average time on land increased by 30 days (compared to 1986-1995) but there was no concomitant change in body condition or reproductive parameters. Similarly, while USGS researchers working in the Beaufort Sea (Atwood *et al.* 2015b) found that between 2010 and 2013, three times as many SB bears came ashore than did before 2000 – and bears spent an average of 31 more days onshore than they did in the late 1990s – the authors found no significant negative effects.

In addition, contrary to predictions, recent reductions of summer ice in the Chukchi Sea have been shown to be a huge benefit to ringed seals (*Phoca hispida*), the principal prey of polar bears (Crawford & Quakenbush 2013; Crawford, Quakenbush & Citta 2015; Rode *et al.* 2014). Since ringed seals feed primarily during the ice-free season (Kelly *et al.* 2010; Harwood & Stirling 1992; Smith 1987), the increase in productivity that came with less summer ice (Arrigo & Van Dijken 2015; George *et al.* 2015) resulted in more healthy seal pups the following spring. The benefits to polar bears of improved ringed seal reproduction with longer open water conditions were pronounced. Rode *et al.* (2014) found that compared to other subpopulations, the body condition of southern CS polar bears in 2008-2011 was second only to bears in FB (which had the best condition of all subpopulations studied): the weight of three adult CS males exceeded 544 kg (Rode & Regehr 2010). Rode *et al* (2014) also found that reproductive measures (reproductive rate, litter size, and percentage of females with cubs) in 2008-2011 had all improved compared to the 1986-1994 period, despite the greater duration of open water. Consequently, while a CS population count was not undertaken in 2008-2011, indicators used for other regions (e.g. FB, Stapleton, Peacock & Garshelis 2016) suggest the population had possibly increased or was at least stable. Similarly, on the other side of the Divergent ecoregion,

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the Svalbard portion of the BS subpopulation saw a documented population size increase between 2004 and 2015 (discussed above) over the period of pronounced low sea ice cover.

Therefore, in contrast to the limited data collected for SB bears (2001-2006) that the USGS predictive models depended upon to predict extirpation of all Divergent ecosystem polar bears, more recent data show that populations in two other Divergent ecoregion (CS, BS) − and possibly three (KS) − improved with realization of sea ice levels not expected until mid-century. The fact that SB appears to be an outlier compared to other Divergent ecoregion subpopulations is likely due to season sea ice phenomena unique to the Southern Beaufort that are not addressed in the ESA listing documents.

USGS polar bear assessors assumed that the only habitat changes capable of causing negative effects on polar bears were human-caused increases in the length of the ice-free period in summer (e.g. Amstrup, Marcot & Douglas 2007, 2008). Only one variable was considered (summer ice extent): all others were assumed to be constant. However, there is strong evidence that this implied causation is incorrect, at least for the SB: known natural fluctuations in winter and spring sea ice thickness in this region of the Arctic are known to periodically affect polar bear survival.

The first well-documented occurrences of thick spring ice in the SB occurred in 1974 and 1975, when multiyear ice from the north was driven onshore, compressing first year and fast ice near shore into an unbroken swath of thick buckled ice (Ramseier *et al.* 1975; Stirling, Archibald & DeMaster 1975; Stirling, Cleator & Smith 1981**).** Ringed seals and bearded seals suffered from the lack of open leads and from ice that was too deep in most places to maintain breathing holes – and because the seals suffered during their critical birthing season, so did polar bears (DeMaster, Kingsley & Stirling 1980; Harwood & Stirling 1992; Harwood, Smith & Melling

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2000; Martinez-Bakker *et al.* 2013; Smith 1987; Smith & Stirling 1975; Stirling 1997, 2002; Stirling & Lunn 1997; Stirling, Cleator & Smith 1981; Stirling, Kingsley & Calvert 1982). While calculations were crude compared to modern methods, according to Stirling *et al.* (1975), the estimated size of the polar bear population in the eastern portion of the Southern Beaufort Sea (then considered a discrete Canadian subpopulation) decreased by 45.6% between 1974 and 1975 (from 1522 bears in 1974 to 828 in 1975), but subsequently rebounded (Stirling *et al.* 1985).

Unfortunately, the USGS-led population size survey of the SB in 2001-2006 used to support the ESA decision coincided with a severe thick spring ice episode from 2004-2006 that was as devastating to seals and polar bears as the well-documented 1974-1976 event (Harwood *et al.* 2012; Stirling *et al.* 2008; Pilfold *et al.* 2014, 2015). Although a statistically non-significant population decline was reported at the time for the 2001-2006 period (Regehr, Amstrup & Stirling 2006), a more recent estimate for the period 2001-2010 (Bromighan *et al.* 2015) reported that numbers dropped between 25% and 50% in 2004-2006. However, none of the USGS reports (e.g. Amstrup *et al*. 2007; Hunter *et al.* 2007; Regehr, Amstrup & Stirling 2006; Regehr *et al.* 2007a; Rode, Amstrup & Regehr 2007) mention the thick spring ice conditions of 2004-2006 in the Canadian portion of the SB, which were described by Stirling *et al.* (2008:15) as so severe that "only once, in 1974, did we observe similarly extensive areas of rubble, pressure ridges, and rafted floes."

While reports on the 2006 status of the SB population (Regehr, Amstrup & Stirling 2006; Regehr *et al.* 2007a) did note incidents of winter/spring starvation and poor survival in the eastern SB, they implied these were effects of reduced summer ice (a 'correlation implies causation' fallacy). These USGS reports did not mention the pronounced lack of ringed seal pups

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and the thick ice conditions of 2004-2006 in the eastern half of the SB that their Canadian colleagues found during the 2004 and 2005 spring field seasons (e.g., Harwood *et al*. 2012; Stirling *et al.* 2008), even though Canadian Ian Stirling was a co-author. Official accounts of those devastating years for seals and polar bears (Harwood *et al.* 2012; Stirling *et al*. 2008) were not published until after the ESA listing process was complete. In contrast, in their follow-up population count report for 2001-2010, USGS researchers Bromaghin *et al.* (2015:646-647) reiterated the comment by Stirling *et al.* (2008) that the thick spring ice phenomena that occurred in the mid-2000s was similar in scope and magnitude to the 1974-1976 event, but still presented the population decline they calculated as a likely result of summer sea ice loss. Overall, the failure of USGS models to take into account the well-documented negative effects of these periodic spring ice phenomena on SB polar bear health and survival means that neither the statistically insignificant population decline recorded by Regehr, Amstrup & Stirling (2006), nor the 25-50% decline calculated by Bromaghin *et al.* (2015), can be reliably attributed to effects of reduced summer sea ice.

Given that management of SB polar bears is shared by the USA and Canada, it is pertinent to note the Canadian position on the status of this subpopulation, as well as others within their jurisdiction. In 2008, Canada listed the polar bear as a species of ‘special concern’ (COSEWIC 2008) but did not assess subpopulations residing outside, or not shared with, Canada. Based on the same sea ice data as used in the 2006 IUCN Red List assessment (ACIA 2005; Hassol 2004), Canadian scientists determined that only two of Canada’s thirteen polar bear subpopulations – SB and WH – had a “high risk of declining by 30% or more over the next three polar bear generations (36 years)” due to reduced sea ice. Although the models used by USGS researchers to support the ESA decision were available to them, the Canadian committee did not

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use them for their appraisal. While the COSEWIC decision was certainly not as extreme a prediction as the ESA's assumption of extirpation, it is apparent that like USGS biologists and the US Fish & Wildlife Service, the COSEWIC committee accepted the fallacy that declining body condition and cub survival of SB polar bears was an exclusive effect of summer sea ice loss, and the same is true of the latest (2015) IUCN Red List assessment (Wiig *et al.* 2015).

In summary, recent research has shown that most bears are capable of surviving a summer fast of five months or so as long as they have fed sufficiently from late winter through spring, which appears to have taken place since 2007 despite marked declines in summer sea ice extent. The assumption that summer sea ice is critical feeding habitat for polar bears is not supported. Recent research shows that changes in summer ice extent generally matter much less than assumed in predictive polar bear survival models of the early 2000s as well as in recent models devised to replace them (Amstrup *et al.* 2010; Atwood *et al.* 2016a; Regehr *et al.* 2015; Regeher *et al.* 2016; Wiig *et al.* 2015), while variations in spring ice conditions matter more. As a consequence, the evidence to date suggests that even if an 'ice-free' summer occurs sometime in the future — defined as sea ice extent of 1 million km2 or less (Jahn *et al.* 2016) — it is unlikely to have a devastating impact on polar bears or their prey.

Conclusion

It is appropriate to enact rigorous conservation measures for a species or population that is currently threatened with extinction due to low population numbers, such as the Amur tiger *Panthera tigris altaica*, which was listed as 'Endangered' on the IUCN Red List when it numbered only about 360 animals (Miquelle, Darman & Seryodkin 2011), but inappropriate to predict the future extinction of a species comprised of tens of thousands of individuals using assumptions that may or may not be true. Because very low summer sea ice levels had not been observed by 2005 and 2006, when conservation assessments were made by the IUCN PBSG and the US Geological Survey (for the US Fish & Wildlife Service), polar bear biologists made excessively confident assumptions and hasty generalizations about how polar bears would respond to the profound sea ice losses predicted to occur by 2050. Since those extreme ice conditions were realized much faster and earlier than expected, the most critical assumption of all (that rapid summer sea ice decline = polar bear population decline) became a testable hypothesis.

Contrary to predictions, polar bear numbers in so-called Seasonal and Divergent ecoregions have increased: these ten subpopulations show no sign of being on their way to extirpation (either singly or as a unit) despite the realization of sea ice levels not predicted to occur until mid-century or later. Similarly, there is no evidence that the total global population has declined as predicted. Therefore, the hypothesis that polar bear population numbers will decline by >30% in response to rapid and sustained sea ice coverage of 3-5 mkm^2 and that all ten subpopulations in Seasonal and Divergent ecoregions will be extirpated is rejected.

While polar bears may be negatively affected by declines in sea ice sometime in the future – particularly if early spring ice loss is significant – so far there has been no convincing evidence of significant population declines, consistent reductions in cub production, or widespread poor body condition in the most vulnerable of polar bear subpopulations, even though summer sea ice coverage since 2007 has routinely reached levels not expected until mid century. It is evident from data collected since 2006 that summer sea ice conditions are much less important to polar bear health and survival than previously assumed. Not only does this outcome make the basis of the conservation assessments for polar bears made by the US Fish &

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Wildlife Service in 2008 (and the IUCN Red List in 2006 and 2015), scientifically unfounded, it suggests that similar assumptions made with respect to future conservation status of Arctic ringed seals, bearded seals, and walrus may also be incorrect. The lack of a demonstrable ‘sea ice decline = population decline’ relationship for polar bears also invalidates more recent survival model outputs that predict catastrophic population declines should the Arctic become ice-free in summer.

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