DECLARATION OF STEVEN AMSTRUP

FOR THE CENTER FOR BIOLOGICAL DIVERSITY

I, Steven Amstrup, state and declare as follows:

1. The facts set forth in this declaration are based upon my personal knowledge. If called as a witness, I could and would testify to these facts. As to those matters which reflect an opinion, they reflect my personal opinion and judgment on the matter.

2. I am submitting this declaration on behalf of myself and the member declarants of the Center for Biological Diversity.

3. I live in Kettle Falls, Washington. I hold a Bachelor of Science in Forestry from the University of Washington (1972), a Master of Science in Wildlife Management from the University of Idaho (1975), and a Ph.D. in Wildlife Management from the University of Alaska, Fairbanks (1995).

4. I am one of the world's foremost experts on polar bear ecology and conservation.

5. Since 2010, I have served as the chief scientist for Polar Bears International (PBI). PBI is a non-profit organization dedicated solely to the research and conservation of wild polar bears. At PBI, I engage in outreach activities with other conservation organizations, the public, media, and

policymakers, including communicating about the threats that global warming poses to polar bears and the sea ice and coastal habitats they depend on. I also identify key research gaps and participate in studies related to polar bear survival and conservation.

6. Since 2006, I have also served as an Adjunct Full Professor at the University of Wyoming in Laramie.

7. Prior to working with PBI, I was a research wildlife biologist with the United States Geological Survey (USGS) at the Alaska Science Center in Anchorage for 30 years, where I led polar bear research in Alaska as Leader of the Ursid and Arctic Marine Research Team. As part of my duties in that position, I led research on all aspects of polar bear ecology in the Beaufort Sea from 1980 to 2010.

8. While at USGS, in 2007, I led a research team in the production of nine reports that provided the scientific basis for the U.S. Secretary of Interior's determination in 2008 that polar bears should be declared "threatened" under the U.S. Endangered Species Act due to threats from human-caused global warming.

9. In 2012, I received both the Indianapolis Prize and the Bambi Award for my work on behalf of polar bear conservation. I am a past chairman of the International Union for Conservation of Nature (IUCN) Polar Bear Specialist Group and have been an active member of the group since 1980.

10. I have authored or coauthored over 150 peer-reviewed articles on the movements, distribution, and population dynamics of large mammals. Approximately 140 of those research articles are related to polar bears.

11. My research on polar bears has investigated polar bear movement, distribution, maternity denning, demography (including recruitment and survival rates), and population dynamics (including estimating changes in polar bear population size), with a focus on polar bears in the Beaufort Sea of Alaska and Canada. My 1995 Ph.D. dissertation was titled "Movements, Distribution, and Population Dynamics of Polar Bears in the Beaufort Sea," and my subsequent scientific articles have expanded on the findings of that original research. I have coauthored research papers focused on polar bear populations in the Chukchi Sea of Alaska and Canada's Northern Beaufort Sea and Western Hudson Bay populations, and I have coauthored two major papers projecting the future global status of polar bears.

12. I plan to continue my research and public advocacy work and will return to Churchill, Canada, for the 2021 season, if the COVID pandemic has abated and it is safe to travel.

13. During my 40-year research career with polar bears from 1980 to the present, increasing greenhouse gas emissions and resulting human-caused global warming have become the primary threat to polar bear populations worldwide. The

harms have become so severe that in 2008, polar bears were listed as “threatened” with extinction under the Endangered Species Act.

14. As a result of global warming, the Arctic sea ice that polar bears depend on for survival has decreased markedly in extent, duration, and thickness. My research has detected significant, widespread, and worsening impacts to polar bears from increasing sea ice loss driven by greenhouse gas emissions—both at present and in the future. One of my most important research contributions has been showing that rapid and immediate reductions in greenhouse gas emissions are essential for protecting polar bears from extinction.

15. I am aware that the Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) have issued a rule that weakens the standards for greenhouse gas emissions and criteria pollutants from passenger cars and light trucks (SAFE II Rule). I have learned that EPA and NHTSA estimate that the SAFE II Rule will increase carbon dioxide (CO_2) emissions by nearly one billion metric tons through model year 2029, and by 7.8 billion metric tons between 2021 and 2100, worsening human-caused global warming. In addition, I understand that the SAFE II Rule will increase the emissions of two other potent greenhouse gases, methane and nitrous oxide, which will further worsen the impacts of global warming. The greenhouse gas emissions resulting from this rule may be higher than the agencies’ estimates. But even the

immense emissions projected by the agencies pose serious risks to polar bears.

16. I have ongoing personal and professional interests in protecting polar bears, which will be harmed by the SAFE II Rule. I have loved polar bears since I was young, and my research and public education work depend on being able to observe and study polar bears. Global warming is indeed global, and its effects on polar bears are only an early and easy-to-discern sign of global impacts. Therefore, the SAFE II Rule will harm livelihoods and economies around the world.

17. My personal interest in studying bears began when I was a child. I have been enamored with these animals for as long as I can remember. As a kid, bears were synonymous with "wild country." If there were bears, I thought, there would be everything else wild too, and I loved bears from my earliest sentient days. I read everything about bears I could get my hands on, from *Field and Stream* magazine to library books. I must have said something in a group of relatives about my career ambitions very early on, as I recall on a later trip to visit distant family, my aunt patted me on top of the head and asked if I still wanted to "go into the woods and study bears?" My answer to my aunt's question was a simple "yes."

18. My deep interest in polar bears, with roots in my youth, has grown into a 40-year career studying and protecting these animals. During my decades of research, I documented the comeback of polar bear populations from excessive

trophy hunting, only to see and document them declining anew due to another human-caused threat: global warming. The increase in greenhouse gas emissions resulting from the SAFE II Rule stands to worsen all of the climate change responses to a warming world, including sea ice loss and its related harms to polar bears.

Greenhouse Gas Emissions Pose an Existential Threat to Polar Bears

19. My research on polar bears over 40 years, along with numerous studies and analyses by other scientists and research groups, has established that rising greenhouse gas emissions and the resulting loss of Arctic sea ice jeopardize the polar bear's continued existence. The projected range-wide decline of polar bear populations resulting from global warming and associated sea ice loss was the principal reason that the U.S. Fish and Wildlife Service declared the polar bear a threatened species across its range in 2008.

20. Global warming—and the greenhouse gas emissions that drive it—threaten the polar bear's very existence because these bears depend entirely on sea ice for survival. First and foremost, polar bears need sea ice to catch their prey. They derive most of their nutrition from two species of seals that they can only predictably catch from the sea ice surface. Polar bears also rely on sea ice to travel, find mates, teach their cubs how to live, and in some populations, for maternity

dens, where polar bear mothers give birth and rear young cubs.

21. The Arctic is on the front lines of climate change as one of the fastest-warming regions on Earth. As temperatures rise due to increasing greenhouse gas emissions, the Arctic sea ice on which polar bears rely has plummeted in extent, duration, and thickness. Sea ice is declining in every region of the Arctic and in all seasons, with especially rapid losses of summer sea ice. Despite year-to-year variation, satellite data shows that September sea ice extent has declined by more than 13 percent per decade since the satellite record began in 1979. Without a reduction in greenhouse gas emissions, state-of-the-art climate models continue to project the first “ice-free” Arctic summer by or before mid-century.

22. As sea ice extent is diminishing in all seasons, it also is forming later in the fall and breaking up earlier in the summer, resulting in fewer days during which polar bears are able to feed and more days during which they are food deprived. The harms to polar bears from declining sea ice are well-studied and well-documented. Research across the Arctic has shown that sea ice loss results in declining polar bear physical stature and weight, declining body condition, poorer survival of adults and cubs, and declining population size.

Loss of Sea Ice Deprives Polar Bears of Food, Leading to Numerous Harms Including Reduced Weight, Poorer Survival and Reproduction, and Shrinking

Populations

23. My research on polar bears in the Beaufort Sea of Alaska and Canada, and that of my colleagues, has documented the widespread and adverse impacts of sea ice loss, resulting in a recent ~40 percent decline in the Southern Beaufort Sea polar bear population (Bromaghin et al. 2015) (Please see Exhibit A for a full list of citations).

24. One of the earliest harms documented for the Southern Beaufort Sea population was the increasing frequency of long-distance swims by polar bears as the summer and fall sea ice retreats earlier from the coast (Pagano et al. 2012). Research shows that swimming is much more energetically costly for polar bears than walking. Long swims also increase the risks of drowning (Monnett and Gleason 2006) and are dangerous for young cubs, who will die if they are too cold for too long (Blix and Lentfer 1979). The most extreme record was an adult female that swam for 427 miles (687 kilometers) over 9 days to reach the distant sea-ice edge in the Beaufort Sea, followed by another 54 days of walking and swimming an additional 1,118 miles (1,800 kilometers). During this time, this mother bear lost her cub and 22 percent of her body mass, illustrating the heavy costs of long-distance swimming (Durner et al. 2011).

25. We also made unprecedented observations of cannibalism by male polar bears, which we hypothesize was driven by nutritional stress due to the

decline of sea ice (Amstrup et al. 2006, Regher and Amstrup 2006). In one case, we recorded a male that stalked and killed a mother polar bear in her den. This kind of behavior had not been observed during decades of previous research, and likely occurred because of food stress. As polar bears cannot hunt seals without sea ice, they are facing longer and longer stretches during which hunting is not possible.

26. Our research has documented other ways that sea ice loss increases energetic stress on polar bears. For example, we found that polar bears in the Beaufort and Chukchi Seas are covering greater daily distances to compensate for the higher drift rates of Arctic sea ice, as sea ice declines. This increases energetic costs for polar bears (Durner et al. 2017), forcing them to expend more energy without a corresponding increase in nutritional intake.

27. Other researchers have also demonstrated increasing nutritional deprivation in polar bears. Research by colleagues documented an increased proportion of food-deprived polar bears in the Southern Beaufort Sea during late winter, corresponding with the loss of sea ice (Cherry et al. 2008). Our research showed that Southern Beaufort Sea bears do not have the ability to undergo any special energy-saving or “adaptive” fasting during the summer, when sea ice is not available. Instead, polar bears show familiar signs of food deprivation such as declines in activity and body temperature that are “typical” for animals that are

food deprived. This research confirms that polar bears do not have any special adaptations that could make them less vulnerable to deleterious declines in body condition during ever more prolonged periods of summer food deprivation due to sea ice loss (Whiteman et al. 2015, 2018).

28. As food deprivation has increased, our research has documented the declining body size of polar bears in the Southern Beaufort Sea linked to nutritional stress from sea ice loss. Between 1982 and 2006, we found decreases in skull size and body length of polar bears three years and older (Rode et al. 2010).

29. Our research has also found that more polar bear mothers are denning on land, rather than sea ice, as stable sea ice habitat declines and autumn ice freeze-up is delayed (Fischbach et al. 2007). Meanwhile, denning habitat along the Alaska coast is being threatened by increasing coastal erosion due to sea ice loss and the thawing of permafrost due to global warming (Durner et al. 2006).

30. In terms of population-level impacts, we have documented that polar bear survival and reproductive success in the Southern Beaufort Sea are declining with the loss of sea ice. Female survival, breeding rates, and cub litter survival declined as the ice-free period increased during the period of 2001 to 2006 in the Southern Beaufort Sea (Regehr et al. 2010). In a subsequent study in the Southern Beaufort Sea, extending from 2001 to 2010, only 2 of 80 cubs tagged during the years 2003 to 2007 were ever seen again. This exceptionally poor survival rate was

linked to unfavorable ice conditions that limited access to prey during multiple seasons (Bromaghin et al. 2015).

31. In this 2015 study, we documented a 25 to 50 percent decline in population size for Southern Beaufort Sea polar bears—linked mainly to a significant reduction in ice availability between 2004 and 2007 (Bromaghin et al. 2015). Our population estimate of 900 bears in 2010, from this same study, was significantly lower than our estimate of 1,800 animals in 1986 (Amstrup et al. 1986), and this decline appeared to be driven by the increase in ice-free days during this period. A more recent study suggested relative stability at this lower population size through 2016 (Atwood et al. 2020); yet the fact that cub survival in most years after 2001 was well below historic levels (Amstrup and Durner 1995) suggests the apparent stability may reflect the inability of estimation procedures to capture true trends rather than real population stability.

32. Polar bear research has shown that adverse impacts from sea ice loss are affecting other polar bear populations, as well as the one in the Southern Beaufort Sea. In the Northern Beaufort Sea, for example, research indicates that the survival of polar bears of all age classes decreased with declines in the sea-ice concentration over shallow continental shelf waters (Stirling et al. 2011).

33. In Canada's Western Hudson Bay, another area with rapid sea ice loss, we documented that the survival of juvenile, subadult, and older bears

declined between 1984 and 2004, and that the Western Hudson Bay polar bear population suffered a 22 percent or greater decline after the early 1980s (Regehr et al. 2007). This was linked to the annual sea-ice breakup occurring earlier in the year (Regehr et al. 2007).

34. An unavoidable consequence of frequent and/or long term reductions in survival is declining population size. Prolonged periods of food deprivation resulting from growing ice-free seasons during the same time frame are the only plausible explanation for these trends.

Without Significant Reductions in Greenhouse Gas Emissions, Most of the World's Polar Bears May Be Lost by 2050

35. Multiple publications based on the large body of my research and that of my colleagues provide unequivocal evidence of the dire threat of global warming to future polar bear persistence. The evidence is unequivocal that aggressive reductions in greenhouse gas emissions are critical for saving polar bears from extinction.

36. As noted above, in 2007 I led a USGS research team in the production of nine reports to inform the U.S. Fish and Wildlife Service decision on whether to list polar bears as a threatened species under the U.S. Endangered Species Act. The USGS team included scientists from within USGS, polar bear scientists from

Canada, and scientists from academia, the private sector, and other federal agencies.

37. I was the lead author on the synthesis report titled "Forecasting the Range-wide Status of Polar Bears at Selected Times in the 21st Century" that forecast the status of the world's polar bear populations 45, 75, and 100 years into the future. We applied the best available information about predicted changes in sea ice in the 21st century to current knowledge of polar bear populations and their ecological relationships to the sea ice to understand how the range-wide population of polar bears might change. I developed the concept, now universally adopted, that the world's 19 polar bear subpopulations can be grouped into 4 ecological regions based on current sea ice conditions and how the bears respond to them. These "ecoregions" are the (1) Seasonal Ice Ecoregion, which includes Hudson Bay, and occurs mainly at the southern extreme of the polar bear range, (2) the Archipelago Ecoregion of the Canadian Arctic, (3) the Polar Basin Divergent Ecoregion, which includes the two Alaska polar bear populations, and (4) the Polar Basin Convergent Ecoregion. We incorporated projections of future sea ice in each ecoregion, based on 10 general circulation models, into two models of polar bear habitat and potential population response.

38. Our modeling indicated that, if global warming is allowed to continue, future sea ice declines will result in the loss of approximately two-thirds of the

world's current polar bear population by the mid-21st century, including all of Alaska's polar bears. Because the observed trajectory of Arctic sea ice decline appears to be underestimated by currently available models, we warned that this assessment of future polar bear status may be conservative. Our projected declines in polar bear populations across the Arctic provided the scientific basis for the U.S. Secretary of Interior's determination in 2008 that polar bears should be declared threatened under the U.S. Endangered Species Act due to threats from sea ice loss driven by greenhouse gas emissions.

39. Building on this research, in the December 2010 issue of the journal *Nature*, six coauthors and I published a study titled "Greenhouse gas mitigation can reduce sea-ice loss and increase polar bear persistence," where we quantified the range-wide costs to polar bears of continued greenhouse gas emissions and assessed the value of greenhouse gas mitigation. Our study (Amstrup et al. 2010) concluded that preserving polar bears depends on reducing greenhouse gas emissions.

40. Specifically, our research showed that substantially more sea-ice habitat would be retained in scenarios where greenhouse gas emissions are reduced below a business-as-usual scenario. We showed that implementing aggressive reductions in greenhouse gas emissions means that polar bears could persist throughout the century in greater numbers and more areas than in the business-as-

usual emissions case.

41. Furthermore, we detected a linear relationship between increasing global mean surface air temperature and decreases in sea ice habitat and found no evidence for a “tipping point” threshold beyond which sea ice loss would be irreversible. Because sea-ice habitat decreases are driven by increases in mean global temperature in a largely linear fashion, the loss of sea-ice habitat and corresponding declines in polar bear distribution and numbers are not unavoidable—if immediate and rapid greenhouse gas reductions are implemented.

42. Similar to our 2007 study, this study projected that by mid-century we could lose two-thirds of the world’s polar bears—including all the bears in Alaska—under a business-as-usual emissions scenario.

43. Most recently, in a paper released in July 2020 (Molnár et al. 2020, attached as Exhibit B), my colleagues and I refined our 2010 findings and projected, for the first time, when sea ice loss would begin to impact polar bears in different subpopulations around the Arctic. Our paper titled “Fasting season length sets temporal limits for global polar bear persistence,” which I conceived and coauthored, appeared in the journal *Nature Climate Change*, and corroborated the global trends we projected in 2010. These “population by population” projections for the future collapse of polar bears are dire, and once again demonstrate that aggressively reducing greenhouse gas emissions is the key to the polar bear’s

future survival.

44. In our 2020 study, we determined how many days polar bears can fast, depending on body condition, before cub recruitment and/or adult survival are impacted and decline rapidly. We then used anticipated increases in ice-free days in different regions, under different greenhouse gas emissions scenarios, to project when these reproduction and survival thresholds will be exceeded in different polar bear populations across the Arctic.

45. Therefore, in this study, we explained that polar bears across their range ultimately will decline due to reaching their energetic fasting limit if we don’t rapidly halt warming. We answered questions pertinent to particular locales such as: “When will each population cross these critical fasting thresholds and begin to disappear?” We also projected that declines may be reduced if greenhouse gas emissions are mitigated.

46. Our projections for the future collapse of polar bear populations are dire and disturbing, yet, like our 2010 projections, are probably optimistic (see discussion below). Our model captures demographic trends observed during the years 1979 to 2016, showing that reproduction and survival impact thresholds are “likely” to have been crossed already in the Western Hudson Bay, Southern Hudson Bay, and Davis Strait populations.

47. Our model projections suggest that under a business-as-usual

greenhouse gas emissions scenario, many polar bear populations, including the Southern Beaufort Sea and Chukchi Sea populations in Alaska, will cross reproduction and survival thresholds by mid-century, and could indeed be extirpated in just a few decades. Following the current trajectory of atmospheric greenhouse gas concentrations, steeply declining reproduction and survival will jeopardize the persistence of all but a few high-Arctic subpopulations by 2100. That means that without aggressive efforts to reduce greenhouse gas emissions, polar bears will be extirpated throughout the vast majority of their range by or before the end of the century. Some polar bears will potentially persist in a few areas of far northern Canada where the last remaining summer sea ice will be found—before it also disappears. Without aggressive greenhouse gas mitigation, however, polar bears will be largely eliminated from most of their current range, including Alaska.

48. The Beaufort Sea of Alaska illustrates that the dire projections of our 2020 paper should, in fact, be considered optimistic. We projected declines in the reproduction in the Southern Beaufort Sea are currently "possible." However, lower cub survival and an approximately 40 percent population size reduction during the first decade of the 2000s indicates those "possible" impacts are already occurring.

49. Optimistic projections result for three reasons. First, our "Timelines of

Risk" are based on the broadest range of possible body conditions at which bears could enter future fasting periods. Yet, we know that the frequency of "bad" ice years, with shorter on-ice foraging periods and longer periods of food deprivation, can only increase as global warming continues. Becoming very fat in advance of increasingly more prolonged annual fasting seasons will be ever more difficult. Therefore, thresholds are most likely to be crossed in the early part of our projected time frames.

50. Second, we applied conservative estimates of energetic costs for basic body maintenance, yet energetic costs may be much higher in a declining ice environment, when less ice will be stable enough for easy walking, and more swimming, which is energetically more demanding than walking, will be required.

51. Third, our estimates didn't explicitly take into account local differences in environmental productivity or historic differences in acclimation to seasonal ice cycles. For example, nearly the entire Seasonal Ice Ecoregion lies over productive shallow waters. The length of the summer fast is increasing, but the environment is still very productive, and these bears are facing a relatively gradual decline in their on-ice foraging. In contrast, productivity in the Alaskan Beaufort Sea, within the Divergent Ice Ecoregion, is limited to a narrow band of shallow continental shelf waters near the arctic Alaska shoreline. Despite having access to a smaller area of productive habitat, polar bears used to flourish in the Beaufort Sea

because they could forage through the summer on ice that historically covered that narrow but productive continental shelf. Unlike polar bears in western Hudson Bay, these Alaskan bears reached peak body weights by autumn (Durner and Amstrup, 1996), after spending most of the summer hunting on the productive ice near shore. However, the sea ice over the Alaskan continental shelf is now gone by mid-summer. The impact of this summer ice loss from the most productive portion of the Beaufort Sea, when the bears there are still thin, is likely greater than that currently felt by bears in the Seasonal Ice Ecoregion, where historically bears are closing in on maximum body weight as the summer fast approaches.

52. The greater impact of early ice loss may make polar bears of the Alaskan Beaufort Sea the most imperiled of all polar bears, and explains their recent catastrophic decline. The degree of peril these Alaskan bears face is emphasized by the fact that the population has declined to only half of its former size, and cub survival appears to be far below historic levels (Bromaghin et al. 2015). Yet, because our 2020 projections were based on estimated body weights from Hudson Bay, where bears facing more prolonged fasts are closer to their normal seasonal maximums, we described bears of the Alaskan Beaufort Sea as only “possibly” experiencing reproductive failure at this time, rather than reproductive failure currently being “highly likely” or “inevitable,” which current observations suggest.

53. In our 2020 paper, we determined that “moderate” emissions mitigation would slow progressive extirpation, prolonging the persistence of some, but not all, polar bear populations through this century. But with modest mitigation, global warming continues beyond this century, continuing to threaten long-term polar bear persistence.

54. The need to halt the rise of atmospheric concentrations of CO_2 and other greenhouse gases is more urgent than our results may suggest, because it will take approximately 30 years for sea ice to stabilize after atmospheric CO_2 concentrations are stabilized (Amstrup et al. 2010). This means that regardless of which emissions scenario society follows in the near term, fasting periods for polar bears will continue to lengthen for decades. In sum, our study concluded that aggressive greenhouse gas mitigation will be required to save polar bears from extinction, and the sooner we halt CO_2 rise, the more likely polar bears will survive in greater portions of their current range.

The SAFE II Rule Directly Threatens Polar Bears by Increasing Greenhouse Gas Emissions.

55. Our 2007 reports to the Secretary of Interior provided ample evidence that the global warming resulting from increasing greenhouse emissions threatens polar bears. The relationship between warming and polar bear habitat loss

underpinned the polar bear's Endangered Species Act listing. However, I'm aware that in 2008, when polar bears were listed as a threatened species, the then-Solicitor of the Department of Interior, David Bernhardt, issued a memo concluding that it was impossible to connect the dots between greenhouse gas emissions from a specific project and harm to polar bears. While the connection was not in doubt a decade ago, our latest research identifies quantifiable, direct links between emissions and harm. The research findings in our 2020 paper establish that the number of ice-free days polar bears face each year determines their reproductive and survival potential. Follow-up research allows us to draw a direct link between individual greenhouse gas emissions increases and the ice-free days that threaten polar bear persistence. This link between emissions and increases in the number of ice-free days shows unequivocally that the SAFE II Rule will harm the already-threatened polar bear.

56. Our analysis shows that polar bears in Alaska face an additional ice-free day—during which they are food deprived—for each 9.0 billion metric tons of CO_2 emitted from fossil fuel combustion and industrial processes (Cecilia Bitz, in Preparation) (See Exhibit C). This is crucial because our 2020 paper established that risks of recruitment and survival failure are determined by the number of days that are sea-ice free within the range of each polar bear population.

57. As noted above, rates of recruitment and survival ultimately determine

the persistence probabilities of each polar bear population. And now we know the causal connection between CO_2 emissions and the vital rates of recruitment and survival (with each additional ice-free day pushing polar bears closer to extirpation). Compared with the prior rule, the SAFE II Rule alone, among all the other actions being taken around the world, will add nearly a full ice-free day, by 2100, to the period of food deprivation season faced by polar bears in Alaska, and in many other areas. Thus, because the SAFE II rule will nearly add another ice-free day on top of the already growing number polar bears are facing, it is clear that the emissions that result from the SAFE II rule will negatively impact polar bears.

58. Because of the direct negative impact the SAFE II Rule will have on polar bears in Alaska and around the world, it must not be upheld. The SAFE II Rule will significantly increase greenhouse gas emissions, which in turn will increase their period of food deprivation causing direct harms to polar bear populations and increasing the likelihood that the vast majority of the world's polar bear populations will be extirpated before the end of the century.

59. The agencies' failure to consult with the wildlife services under the Endangered Species Act prior to finalizing the SAFE II Rule virtually ensures the harms from the SAFE II Rule will occur, while consultation could have helped the agencies identify and mitigate these threats. I am deeply saddened at the damage,

including possible extinction of these magnificent creatures, to which the SAFE II Rule will contribute. Vacating the SAFE II Rule is an important step needed to protect the polar bear and the Arctic ecosystem.

Pursuant to 28 U.S.C. § 1746, I declare, under penalty of perjury, that the foregoing is true and correct.

Executed on January 6th, 2021, at Kettle Falls, Washington.

Steve E Amstrup

STEVEN AMSTRUP

Exhibit A: List of References

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EXHIBIT B

LETTERS
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Fasting season length sets temporal limits for global polar bear persistence

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Polar bears (*Ursus maritimus*) require sea ice for capturing seals and are expected to decline range-wide as global warming and sea-ice loss continue[1,2]. Estimating when different subpopulations will likely begin to decline has not been possible to date because data linking ice availability to demographic performance are unavailable for most subpopulations[2] and unobtainable a priori for the projected but yet-to-be-observed low ice extremes[3]. Here, we establish the likely nature, timing and order of future demographic impacts by estimating the threshold numbers of days that polar bears can fast before cub recruitment and/or adult survival are impacted and decline rapidly. Intersecting these fasting impact thresholds with projected numbers of ice-free days, estimated from a large ensemble of an Earth system model[4], reveals when demographic impacts will likely occur in different subpopulations across the Arctic. Our model captures demographic trends observed during 1979–2016, showing that recruitment and survival impact thresholds may already have been exceeded in some subpopulations. It also suggests that, with high greenhouse gas emissions, steeply declining reproduction and survival will jeopardize the persistence of all but a few high-Arctic subpopulations by 2100. Moderate emissions mitigation prolongs persistence but is unlikely to prevent some subpopulation extirpations within this century.

Polar bears occur in 19 subpopulations across four arctic ecoregions[1,2] (Fig. 1). In the southernmost ecoregion (that is, the Seasonal Ice Ecoregion (SIE)), complete sea-ice melt forces bears ashore each summer[1,2], where they rely on body energy reserves for survival and lactation due to the absence of energetically adequate food[5]. Prolonged ice absence from productive continental shelf waters now also forces increasingly long fasts in parts of the other ecoregions (that is, the Divergent Ice Ecoregion (DIE), Convergent Ice Ecoregion (CIE) and Archipelago Ecoregion (AE))[6]—areas where bears historically continued foraging on perennial ice through summer[1]. Although polar bears can fast for months, limits are imposed by the amount of energy bears can store in body reserves before periods of food deprivation[3,5,7]. Lengthening fasts have already lowered body condition, reproduction, survival and abundance in some SIE and DIE subpopulations[8–13], and similar trends are expected throughout the Arctic as ice loss continues[1,2]. However, it remains unclear how long bears can fast before substantial declines in lactation (and therefore cub recruitment) and/or adult survival occur. Information on when such fasting thresholds might be exceeded in different subpopulations, or how rapidly demographic rates would decline following threshold exceedance, is also lacking.

Estimating timelines for the anticipated declines is challenging because data quantifying sea ice–demography relationships are lacking in most subpopulations[2]. Indeed, even in the best-studied subpopulations, abundance projections currently rely on extremely limited data (for example, in the Southern Beaufort Sea, where projections used a threshold of 127 ice-free days to distinguish between good and bad years, based on only 5 years of demographic data[14]). Moreover, today's sea-ice conditions differ substantially from anticipated low ice extremes, thus precluding empirical measurements of how reproduction and survival will change before these changes occur[3]. Previous projections for the future range and abundance of polar bears attempted to overcome such data gaps with expert judgement[1] and/or extrapolations from a few well-studied subpopulations[2], and consequently could only offer limited spatial and temporal forecast resolution with large uncertainties.

Timelines for declining survival and recruitment can be projected, however, even in subpopulations where demographic information is absent, by calculating the energetic needs of fasting polar bears and estimating when longer fasts will preclude meeting those needs[3,15]. Molnár et al. used such energy budget calculations to estimate the likely magnitude of future litter size[15] and adult male survival declines[3] in the Western Hudson Bay subpopulation, but other projections[16,17] incorrectly applied the estimates of Molnár et al., assuming, for example, a universal 180-d persistence threshold, without performing the necessary energy budget calculations, model tests or uncertainty analyses, to justify this choice and/or extrapolations beyond the Western Hudson Bay subpopulation. Here, we describe dynamic energy budget (DEB) estimates of fasting thresholds that limit offspring recruitment and adult survival. We test whether our estimated thresholds capture reported demographic changes in subpopulations where observations are available, project likely timelines for recruitment and survival declines in all SIE, DIE and CIE subpopulations (~80% of Earth's polar bears; Fig. 1) and evaluate the uncertainty surrounding these timelines.

The impacts of fasting on recruitment and survival depend on: the energy reserves of bears at fast initiation; their energy expenditures while fasting; and fast duration. We established baselines for each of these with measurements from bears that were already forced to fast annually for extended periods in the Western Hudson Bay subpopulation (SIE; Fig. 1), and applied sensitivity analyses to these baselines to assess associated uncertainties and

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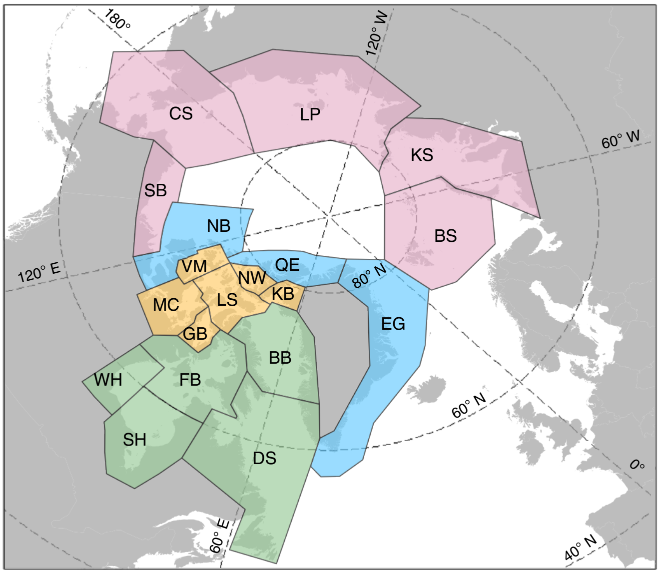

Fig. 1 | Polar bear ecoregions and subpopulations. Ecoregions were defined by temporal and spatial patterns of ice melt, freeze and advection, and by observations of how polar bears respond to those patterns[1]. Subpopulation boundaries follow ref. [1] and include only productive continental shelf waters of the Southern Beaufort Sea to maintain consistency with previous analyses of this subpopulation. Subpopulations in the AE were excluded from our analyses due to inadequate resolution of sea ice in both the PMW and CESM1 (Supplementary Fig. 1). SIE subpopulations (green): BB, Baffin Bay; DS, Davis Strait; FB, Foxe Basin; SH, Southern Hudson Bay; WH, Western Hudson Bay. DIE subpoopulations (red): BS, Barents Sea; CS, Chukchi Sea; KS, Kara Sea; LP, Laptev Sea; SB, Southern Beaufort Sea. CIE subpopulations (blue): EG, East Greenland; NB, Northern Beaufort Sea; QE, Queen Elizabeth Islands. AE (yellow): GB, Gulf of Boothia; KB, Kane Basin; LS, Lancaster Sound; MC, M'Clintock Channel; NW, Norwegian Bay; VM, Viscount Melville Sound.

account for known and potential among-subpopulation differences and within-subpopulation trends. Fast duration was defined as 24 d shorter than the summer period with ice extent below 30% (Extended Data Figs. 1 and 2), with ice extent estimated from passive microwave (PMW) satellite data[18] for the observational period and from large ensemble projections with the Community Earth System Model version 1 (CESM1)[4] for the future (Extended Data Fig. 3). The metabolic requirements of fasting were estimated from mass loss rates observed during the summer on-shore fast in Western Hudson Bay, and a DEB model[3,15] was used to estimate fast duration thresholds beyond which impaired lactation (and hence cub recruitment) and/or adult survival declines are likely (Fig. 2 and Extended Data Fig. 4). Thresholds depend on a subpopulation's distribution of body masses (M_0) and body lengths (L_0) at fast initiation in a given year, $G_{(M_0,L_0)}$(subpop,year), as these variables jointly determine each bear's energy reserves[3]. Data gaps regarding past and present $G_{(M_0,L_0)}$ distributions and the difficulties of reliably anticipating future $G_{(M_0,L_0)}$ (especially for subpopulations not yet experiencing prolonged fasts[3]) were overcome in two steps. First, we established thresholds for the Western Hudson Bay subpopulation during a 1989–1996 reference period (WH_{89-96}), using a representative sample of 76 adult males, 41 solitary adult females and 61 (22) females with dependent cubs (yearlings), to estimate $G_{(M_0,L_0)}(\mathrm{WH}_{89-96})$ (Fig. 2a–e). Likely thresholds for other time periods and subpopulations were estimated by systematically varying the $G_{(M_0,L_0)}(\mathrm{WH}_{89-96})$ baseline (Fig. 2f,g and Table 1) to account for among-subpopulation differences, within-subpopulation trends (Fig. 3) and uncertainties regarding future $G_{(M_0,L_0)}$ distributions (Fig. 4). Model performance was evaluated by intersecting estimated recruitment and survival thresholds with fasting period estimates for 1979–2016 and comparing the resultant demographic impact hindcasts against observations (Fig. 3). Estimates of future demographic impacts were obtained by intersecting projected fasting periods with the full range of biologically feasible impact thresholds, yielding timelines of risk for each subpopulation that account for the uncertainty arising from unknown future $G_{(M_0,L_0)}$ distributions (see below; Fig. 4).

Our DEB model suggests that prolonged fasting impacts cub recruitment first. Survival declines in yearlings, adult males and adult females with offspring follow, while solitary adult females succumb last (Table 1). High rates of recruitment and survival failure following threshold exceedance (Table 1 and Fig. 2) ensure that soon after thresholds are crossed population persistence will be jeopardized. Mother bears cannot fast as long as solitary females due to their reproductive burden; males cannot fast as long as solitary females due to the higher maintenance requirements and lower storage energy of their leaner bodies[3]; and cubs are more vulnerable than yearlings due to their higher reliance on maternal energy reserves[19]. With $G_{(M_0,L_0)}(\mathrm{WH}_{89-96})$, for example, impaired cub recruitment is expected when fasts exceed 117 d, followed by declines in yearling recruitment (185 d) and the survival of mother bears (as early as 117 d and no later than 228 d), adult males (200 d) and solitary adult females (255 d) (Table 1, Fig. 2 and Extended Data Fig. 4). These thresholds may vary by months depending on a subpopulation's $G_{(M_0,L_0)}$ (Extended Data Fig. 5), thus also highlighting the inaccuracy of previous projections[16,17] that relied on a universal 180-d threshold.

Model hindcasts capture the timing and nature of observed demographic changes when between-subpopulation differences and within-subpopulation trends in $G_{(M_0,L_0)}$ are accounted for (Fig. 3). For the Western Hudson Bay subpopulation, where lengthening fasts have progressively lowered body conditions[7] and thus impact thresholds (Fig. 3), the DEB model suggests unimpaired recruitment and survival before and during our 1989–1996 reference period but decreased reproductive success since the first crossing of the recruitment impact threshold in the late 1990s (Fig. 3). Hindcasts also suggest stable adult survival during the initial reproductive declines but an increasing likelihood of adult mortalities in recent years: in 2015, the fasting period reached 153 d, approaching the conservatively estimated impact threshold for male survival (now $\leq$171 d; Fig. 3), and possibly also for the survival of females with offspring (between 98 and 192 d in 2007; now possibly lower; Fig. 3). Rates and timelines of actual and modelled declines mirrored one another, with the Western Hudson Bay subpopulation transitioning from high recruitment during the 1980s to declines in juvenile, subadult and senescent adult survival in the late 1990s/early 2000s, while prime-age adult survival remained unaffected[8] (Fig. 3). It remains unclear whether the resulting ~22% abundance decline[8] has continued in recent years or whether the population may have temporarily stabilized at a lower abundance[12,20], but recruitment remains low[20] and female survival appears to have decreased in recent low-ice years[12,20], as hindcasted (Fig. 3). Male survival also may have declined, but limitations of the most recent census prevented disentangling fasting-related and other mortalities[12].

Elsewhere in the SIE, bears are of similar length[21,22] but greater mass[23] than in the Western Hudson Bay subpopulation, possibly because of shorter ice-free periods (Foxe Basin and Baffin Bay; Fig. 3), comparatively later ice break-ups that allow for additional pre-fast foraging opportunities (Southern Hudson Bay and Foxe Basin)[24] and/or an increasing availability of harp seals (*Pagophilus groenlandicus*) (Davis Strait and Baffin Bay)[25,26]. Nonetheless, body mass declines similar to those in the Western Hudson Bay subpopulation have occurred throughout the SIE[10,13,27], except possibly

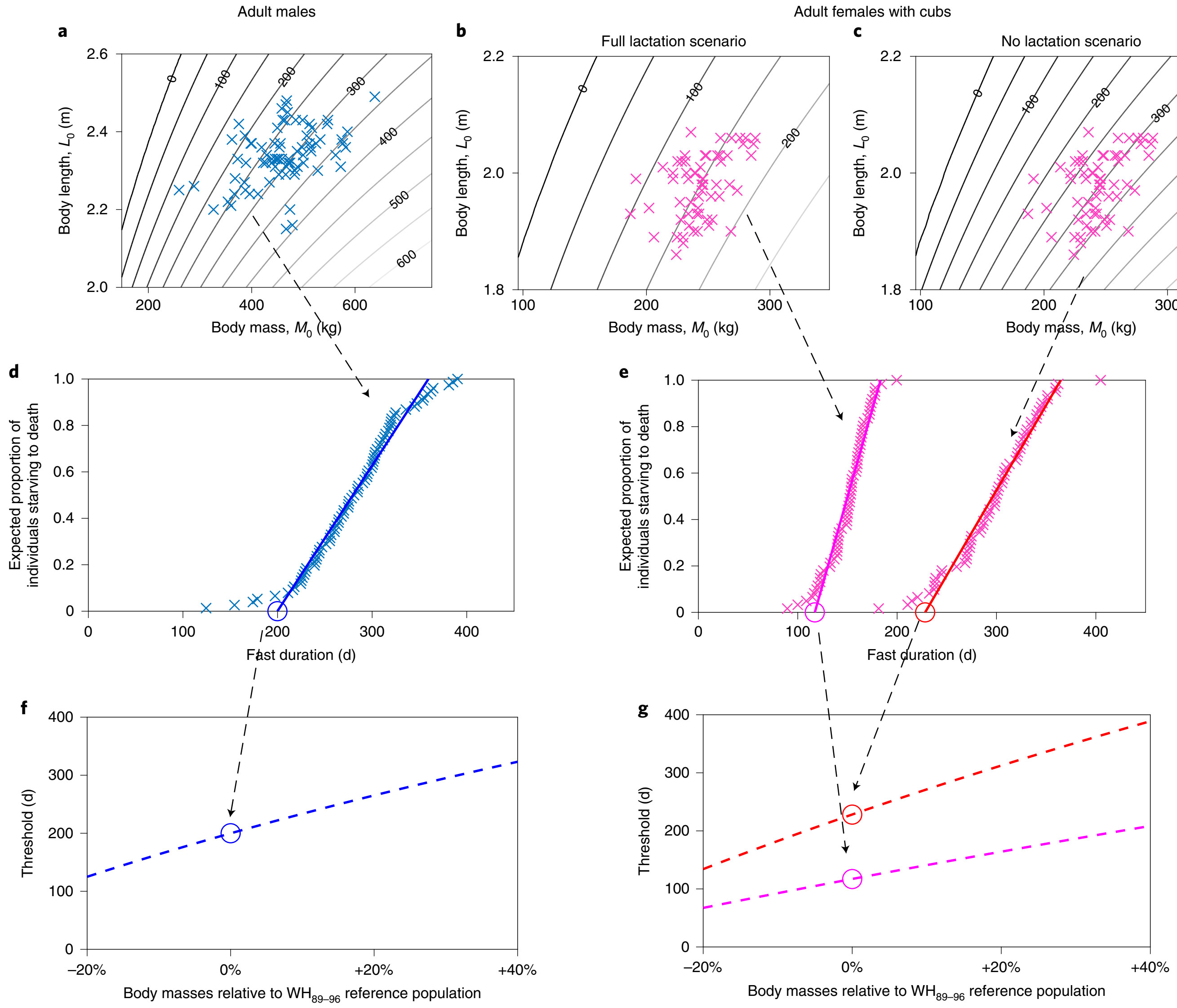

Fig. 2 | Method for estimating fasting impact thresholds beyond which cub recruitment and adult survival begin to decline rapidly. Thresholds were estimated by calculating the maximum number of fasting days that polar bears can survive, given their metabolic requirements and fast-initiating energy reserves. Arrows illustrate the logical flow of our analyses, progressing from individual samples to population-level threshold estimates. Threshold calculations are shown for adult males and adult females with cubs. Calculations for solitary adult females and females with dependent yearlings were performed the same way (Extended Data Fig. 4). **a**–**c**, Fast-initiating masses and lengths of adult males (**a**; blue crosses) and adult females with cubs (**b** and **c**; magenta crosses) in $WH_{89–96}$, relative to DEB estimates of the number of days to death by starvation (contour lines). Due to lacking data on how starvation impacts lactation, we estimated starvation times for females with cubs for two extreme strategies of reproductive investment that bracket the true time to female death: full lactation until death (**b**) and no lactation when fasting (**c**). **d**,**e**, Cumulative distributions of the estimated starvation times shown in **a**–**c**. *X*-intercepts (circles) of linear fits to the 5th to 95th percentiles of these distributions (solid lines) indicate: (**d**) a survival impact threshold for adult males (200 d) beyond which mortality increases by ~0.6% for each additional fasting day (regression slope); and (**e**) lower (magenta) and upper (red) estimates for the survival impact thresholds of females with cubs (117–228 d). In **e**, the lower estimate doubles as a recruitment impact threshold as longer fasts are only possible with reduced lactation, and thus compromised cub condition, growth and survival. **f**,**g**, Sensitivity analyses corresponding to **d** and **e**, respectively, illustrating the dependence of impact thresholds on the fast-initiating masses of bears, obtained by adjusting all $WH_{89–96}$ masses upwards or downwards by a specified percentage within biologically reasonable bounds.

in Foxe Basin where stability is assumed[28]. After adjusting impact thresholds accordingly, our model hindcasts suggest modest but persistent reproductive impacts in Southern Hudson Bay since the late 1990s, larger reproductive impacts in Davis Strait, potential reproductive impacts in Baffin Bay, no reproductive impacts in Foxe Basin and no impacts on adult survival anywhere (Fig. 3). In agreement with simulations, females in Southern Hudson Bay appear to be sacrificing their body condition to maintain lactation[13], and cub survival also has declined in recent years[24]; in Davis Strait, cub recruitment is among the lowest of all SIE subpopulations while adult survival nevertheless remains high[25]; in Baffin Bay, offspring recruitment has decreased since the mid-1990s while adult survival has remained stable[27]; and in Foxe Basin, no demographic impacts are apparent[28].

Model hindcasts are more difficult to evaluate for the DIE and CIE, where a lack of sampling (Kara Sea, Laptev Sea, East

Table 1 | Fasting impact thresholds for polar bear recruitment and survival

Bear class	Recruitment impact threshold (number of fasting days)				Survival impact threshold (number of fasting days)				Estimated decrease in survival for each additional fasting day beyond the survival impact threshold
	−20%	0%	+20%	+40%	−20%	0%	+20%	+40%	
Adult males	NA	NA	NA	NA	125	200	265	323	−0.6% per day
Solitary adult females	NA	NA	NA	NA	158	255	342	420	−0.4% per day
Adult females with cubs	67	117	164	208	LB: 67	LB: 117	LB: 164	LB: 208	
					UB: 134	UB: 228	UB: 313	UB: 389	−0.7% per day
Adult females with yearlings	108	185	255	320	LB: 108	LB: 185	LB: 255	LB: 320	
					UB: 138	UB: 232	UB: 317	UB: 394	−0.8% per day

Four estimates are shown for each bear class and threshold, corresponding to scenarios where bears begin fasting 20% lighter (−20% threshold), the same (0% threshold), 20% heavier (+20% threshold) or 40% heavier (+40% threshold) than $WH_{89–96}$ bears. Body conditions at the +40% limit are considered unrealistically high, but were included as a maximum conceivable upper bound under perfect conditions (see Extended Data Fig. 7). Due to uncertain energetic investment into lactation, the true survival impact threshold could only be bounded for females with dependent offspring (see Fig. 2e,g). LB, lower bound; UB, upper bound.

Greenland and Queen Elizabeth Islands) or predominantly spring sampling (Southern Beaufort Sea, Chukchi Sea, Barents Sea and Northern Beaufort Sea)[11,29,30] prevented reliable estimation of fast-initiating (late-summer) $G_{(M_0,L_0)}$ distributions[3,15] and, thus, of subpopulation-specific impact thresholds. Nonetheless, DEB hindcasts suggest possible declines in recruitment and, perhaps, adult survival for the Southern Beaufort Sea, Chukchi Sea, Kara Sea and Barents Sea from as early as the 1990s—if bears in these subpopulations are more reliant on a stable ice cover for hunting (Extended Data Fig. 6a), move more during fasting, and/or are lighter (lower energy reserves), longer (higher metabolic requirements), or both, than $WH_{89–96}$ bears (Fig. 3). Correspondingly, in the Southern Beaufort Sea subpopulation (characterized by declining body conditions[9], possibly greater skeletal sizes[21], additional movement costs imposed by ice fragmentation and drift during on-ice fasting[31]), both recruitment and survival (both sexes and all age classes) decreased with recent low ice, causing a 25–50% abundance drop[11]. In contrast, in the neighbouring Chukchi Sea subpopulation, demographic declines have not yet occurred[29], consistent with model outcomes for the reported good body conditions that are maintained by extraordinary marine productivity[29]. The Barents Sea subpopulation currently seems stable but with low recruitment[32], consistent with the energetic requirements of bears that are shorter but also lighter than $WH_{89–96}$ bears[23] (Fig. 3 and Extended Data Fig. 5), and no impacts have been observed in the Northern Beaufort Sea[30], as simulated (Fig. 3).

For estimates of future demographic impacts, we acknowledge but do not resolve uncertainties[3,15] regarding future subpopulation-specific $G_{(M_0,L_0)}$ distributions. Instead, we estimated fasting impact thresholds for the full range of biologically feasible $G_{(M_0,L_0)}$ (Extended Data Fig. 7), assuming that bears may begin fasting 20% lighter, the same, 20% heavier, or 40% heavier than $WH_{89–96}$ bears (henceforth, the −20%, 0%, +20% and +40% thresholds; Table 1). Intersecting these thresholds with projected annual fasting periods under business-as-usual (Representative Concentration Pathway to 8.5 $\mathrm{W\,m^{-2}}$ (RCP8.5)) or mitigated (RCP4.5) scenarios[33] yields timelines of risk for when recruitment and survival will likely begin declining (Fig. 4 and Extended Data Fig. 8): when fast duration remains below the −20% threshold in a subpopulation, we consider demographic impacts unlikely because short fasts are typically associated with good body conditions[7,9,13]; based on the observed impacts in the SIE and DIE (Fig. 3), we suggest that demographic impacts are likely to appear between exceedance of our −20% and +20% thresholds; and because high body conditions cannot be maintained with long fasts, effects become inevitable by the time the +40% threshold is crossed (Extended Data Fig. 8). Timeline uncertainties, arising from uncertainty in DEB parameters and uncertain ice availability–fasting relationships, were dealt with by evaluating how the timelines of risk would shift if our baseline assumptions were violated (Extended Data Figs. 6 and 9).

Estimated timelines of risk are shown in Fig. 4, illustrating how the physiological limits of fasting determine the polar bear's fate with unmitigated greenhouse gas emissions. Unlike previous projections that suggest ultimate large-scale declines but do not provide explicit timelines[1,2], our DEB approach provides previously unavailable mechanistic underpinnings that capture past demographic changes and quantify the timing, nature, order, and uncertainty surrounding future changes—even for data-scarce subpopulations. Despite timeline uncertainties, it is evident that demographic impacts will worsen in already affected subpopulations, and that similar impacts will occur over most of the species' range (Fig. 4). By 2100, following the RCP8.5 scenario, recruitment will be severely compromised or impossible everywhere except perhaps in the Queen Elizabeth Islands subpopulation. Most subpopulations will also experience dramatically increased adult mortality, making persistence unlikely throughout most of the polar bear range (Fig. 4). Ultimately, aggressive greenhouse gas emissions mitigation will be required to save polar bears from extinction, but moderating emissions to RCP4.5 would slow progressive extirpation, probably allowing some subpopulations to persist through this century—albeit with reduced recruitment (Fig. 4).

Potential errors and uncertainties remain with respect to the exact onset of demographic declines, both because of our reliance on a single Earth system model and because of uncertainties and variations in bear behaviour and energy usage among subpopulations. If many Earth system models were employed rather than just one, we would expect an increase in accuracy, but also an increase in uncertainty from accounting for structural uncertainty in Earth system model parameters and physics that we currently neglect. However, in the work presented here, the uncertainty in the onset of demographic declines is dominated by biological uncertainties, which is why we accept the underestimated uncertainty of fast durations that stems from using only one Earth system model at this time. More field data on polar bear characteristics could allow us to better constrain DEB model parameters, thereby increasing accuracy and reducing uncertainty in the demographic estimates, but filling these data gaps will probably not lead to more optimistic conclusions. Impacts could potentially occur decades sooner

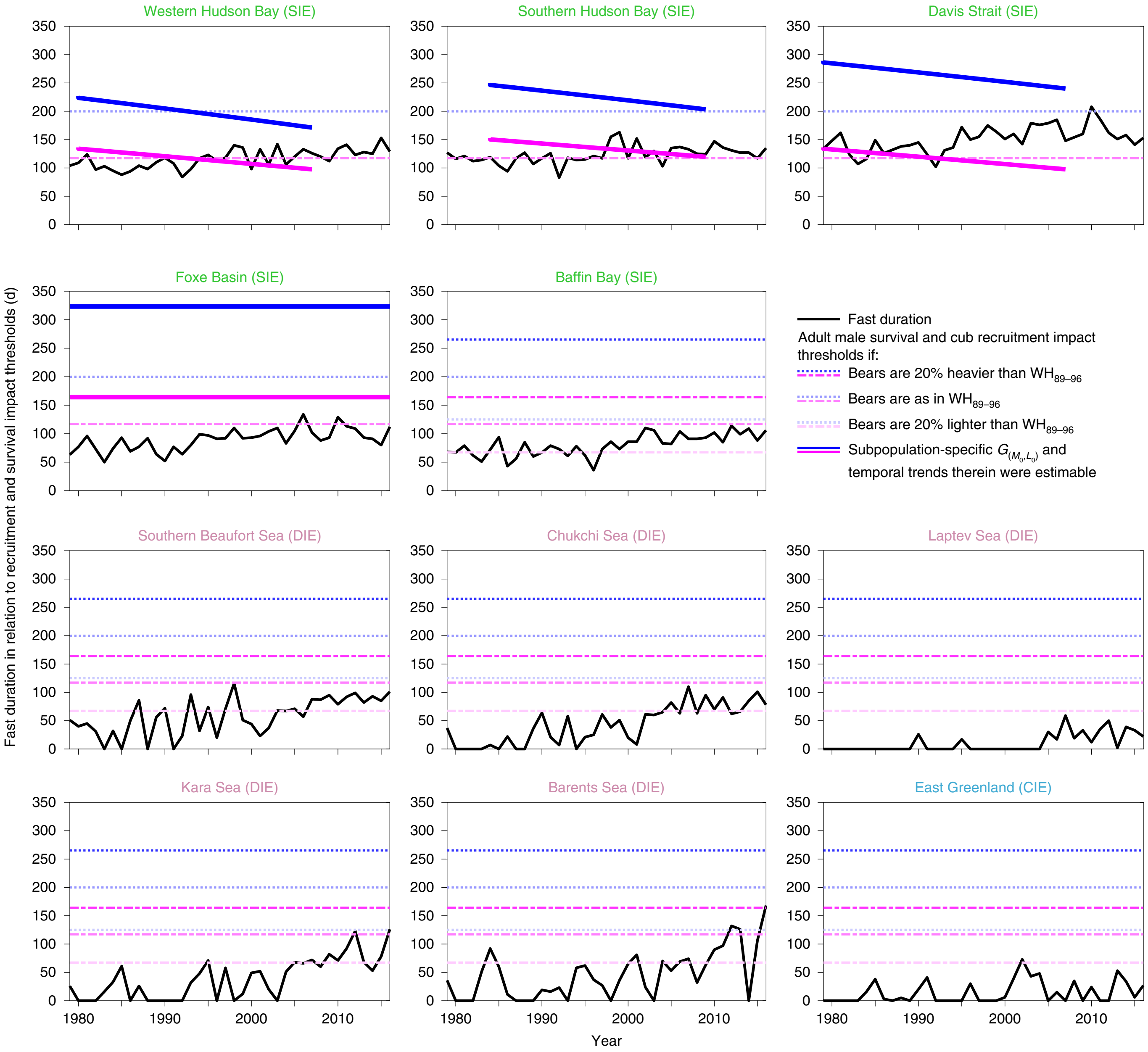

Fig. 3 | Estimated annual fasting period lengths of polar bears in the SIE, DIE and CIE from 1979–2016, in relation to estimated cub recruitment and adult male survival impact thresholds. For subpopulations where body lengths and fast-initiating body masses were estimable (Western Hudson Bay, Southern Hudson Bay, Davis Strait and Foxe Basin), we calculated subpopulation-specific impact thresholds by adjusting the $G_{(M_0,L_0)}(WH_{89–96})$ baseline (dot-dashed magenta line for recruitment; dotted blue line for adult male survival) for among-subpopulation differences and within-subpopulation trends in body mass[7,10,13,28] (thick solid magenta and blue lines). In the Western Hudson Bay subpopulation, for example, body masses declined by ~5.7% per decade during 1980–2007 (ref. [7]), leading to corresponding declines in the adult male survival (227 d in 1980; 171 d in 2007) and recruitment impact thresholds (136 d in 1980; 98 d in 2007). For subpopulations where fast-initiating masses and lengths were inestimable, we show a series of impact thresholds for cub recruitment (dot-dashed magenta) and adult male survival (dotted blue) for reference, assuming body masses that are 20% lower (light shade), the same (medium shade) or 20% higher (dark shade) than in $WH_{89–96}$. Fasting period lengths (solid black lines) were estimated as 24-d shorter than the summer period with ice extent <30%, and bears were assumed to be conserving energy while fasting, as observed in Western Hudson Bay. Recruitment and adult male survival declines are expected when the fasting period length exceeds the corresponding impact threshold. Impact thresholds for yearling recruitment and the survival of mother bears are not shown, but are similar to those for adult male survival (Table 1), and may thus also have been crossed occasionally in some SIE and DIE subpopulations in recent years. Only East Greenland is shown for the CIE, as the Northern Beaufort Sea and Queen Elizabeth Islands subpopulation regions have retained a perennial ice cover to date. Font colours of subpopulation names correspond to their ecoregion designation: green, SIE; red, DIE; blue, CIE.

than projected in Fig. 4 (Extended Data Figs. 6c and 9c), because all DEB model parameters and assumptions were chosen to yield optimistic threshold estimates in cases where data scarcity necessitated a choice. For example, we assumed that all bears follow an energy-conserving strategy of limited movement during fasting, as is observed in Western Hudson Bay, but higher movement costs combined with low hunting success may in some subpopulations drive bears into energy deficits well before they are forced to

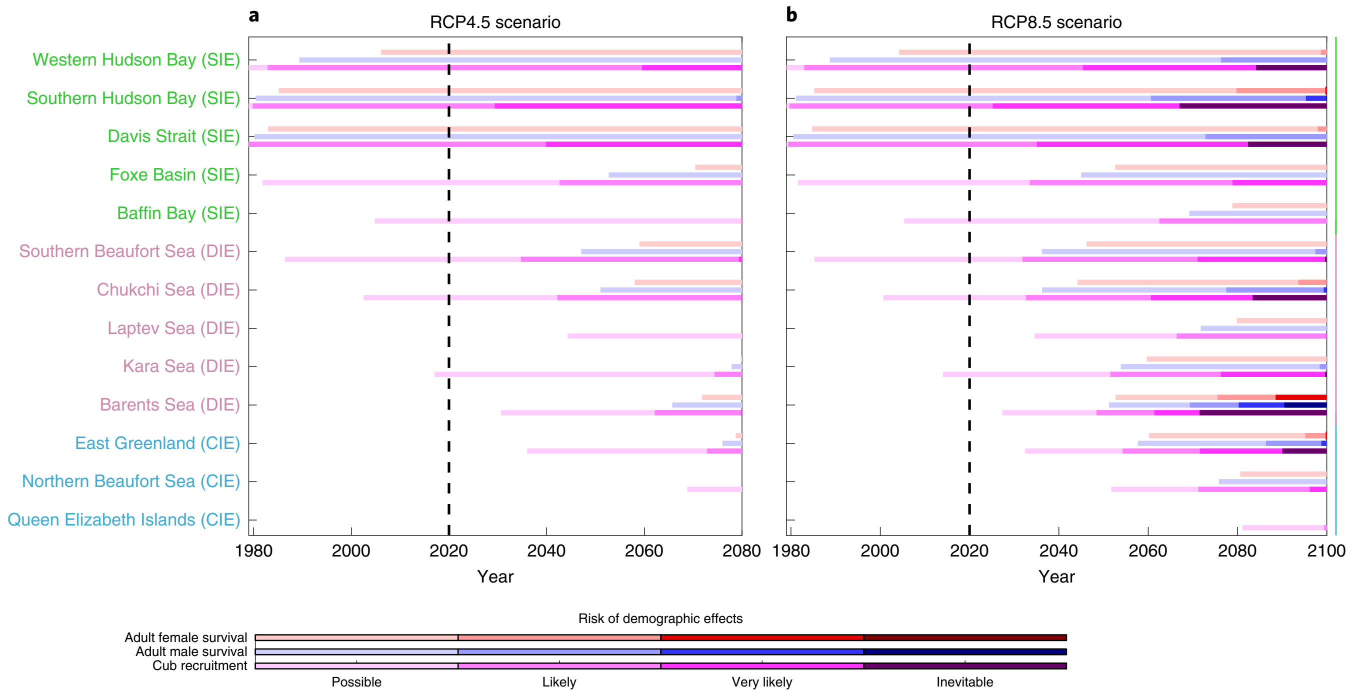

Fig. 4 | Modelled timelines of risk, as quantified by the years when projected annual fasting period lengths exceed cub recruitment and adult survival impact thresholds in different subpopulation regions. a,**b**, Years of first impact on cub recruitment (magenta), adult male survival (blue) and adult female survival (red) are shown for the RCP4.5 (**a**) and RCP8.5 scenarios (**b**), assuming fast-initiating masses that are 20% lighter (light shade), the same (medium-light shade), 20% heavier (medium-dark shade) or 40% heavier (dark shade) than in WH_{89-96}. The risk of demographic impacts increases with darker colours. Demographic impacts were considered possible when fast duration exceeds the −20% threshold, likely between exceedance of the 0% and +20% thresholds, and inevitable by the time the +40% threshold is crossed (see Fig. 3 and Extended Data Fig. 8). All thresholds were calculated conservatively by assuming metabolic rates and energy-conserving strategies while fasting as in the Western Hudson Bay subpopulation. Additionally, thresholds of adult female survival were calculated conservatively by using the upper bound estimates for the survival times of females with dependent cubs (Table 1). The year of first impact was defined conservatively as the first occasion when three of the next five years exceed a fasting impact threshold, thus avoiding triggering impact forecasts on a single low-ice year. Font colours of subpopulation names correspond to their ecoregion designation: green, SIE; red, DIE; blue, CIE.

abandon the sea ice completely[31]. Moreover, once thresholds are crossed, impact curves rise steeply (Fig. 2 and Table 1), meaning that a few extremely poor ice years could lead to non-recoverable population declines before such years are the rule. Demographic impacts we did not consider (for example, litter size declines[15], increased subadult mortality[8], and mate-finding difficulties[34] resulting from unequal impact timelines between sexes; Fig. 4) are likely to occur in concert with, and potentially earlier than[8], the outlined cub recruitment and adult survival declines. Land-based feeding is unlikely to occur at scales that shift the timelines for recruitment and survival declines by more than a few years, because foods that meet the energy demands of polar bears are largely unavailable on land[5]. Indeed, polar bears occurred as far south as the Baltic Sea at the close of the Pleistocene[35], but did not move onto land or adapt otherwise when ice-free periods grew during Holocene warming—they simply disappeared from the region. Avoiding continued sea-ice decline requires aggressively mitigating greenhouse gas rise[36], and our results explicitly describe the costs to polar bears of avoiding that mitigation.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-020-0818-9.

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Exhibit C: Cecilia Blitz Calculations

The purpose of this section is to describe how we estimate that polar bears in Alaska face an additional ice-free day by 2100 due to emissions from the SAFE II Rule alone. This quantity is estimated from the observational records of ice-free days each year and emitted CO_2 by fossil fuel combustion and industrial processes. The emitted CO_2 dataset is published in a peer-reviewed journal article written by 87 authors (Friedlingstein et al., 2020). The ice-free season length is based on sea ice concentrations estimated from satellite passive microwave remote sensing (Cavalieri et al, 1996). The period of analysis for our calculation is limited by the start date of the satellite record, which is 1979, and the most recent year available for CO_2 emission estimates, which is 2019.

A thorough explanation of our methods and assumptions to quantify the ice-free season length, and its effects on polar bears, are given in Molnár et al. (2020) (attached as Exhibit B). Here, we briefly summarize the method. We begin by computing daily sea ice areal extent from gridded sea ice concentrations for subdomains of the Arctic associated with polar bear subpopulations (see Amstrup et al., 2010; Molnár et al., 2020). We define sea ice extent as the area of all grid cells in the subdomain where concentration exceeds a 30% threshold (below this concentration polar bear foraging efficiency is known to be poor). The subdomain was considered ice-free when the extent in a subpopulation region is below a critical value taken as 30% of the March mean extent for the period 1979-1988. The ice-free season length is the continuous period in summer that meets the ice-free definition.

Ice-free season lengths were computed for the oceanic region adjacent to the arctic coastline of Alaska that is occupied by two polar bear subpopulations identified by region, specifically the Southern Beaufort Sea and Chukchi Sea (see Amstrup et al., 2010; Molnár et al., 2020). The ice-free season lengths were initially computed separately for the two subpopulations. Next, regression coefficients were computed for the two subpopulations to give an estimate of ice-free season length per CO_2 emitted by fossil fuel combustion and industrial processes. The regression coefficients were then inverted to give an estimate of the amount of CO_2 that was emitted to cause an additional ice-free day during the ice-free season. Results for the two subpopulations are an additional ice-free day in the Chukchi Sea region per 8.7 billion metric tons of CO_2 emitted and an additional ice-free day in the Southern Beaufort Sea region per 14.2 billion metric tons of CO_2 emitted. Finally, the quantities for these two subpopulations were combined in a weighted arithmetic mean, where the weights are the relative areal proportion of the regions, giving a single estimate for the two subpopulations that occupy coastal Alaska. Because the Chukchi Sea region is over ten times larger than the Southern

Beaufort Sea, the estimate for the Chukchi Sea dominates the area weighted arithmetic mean, and the combined regional estimate is one additional ice-free day per 9.0 billion metric tons of CO_2 emitted.

As the EPA and NHTSA estimate that the SAFE II Rule will increase carbon dioxide (CO_2) emissions by 7.8 billion metric tons between 2021 and 2100, we estimate that the SAFE II Rule alone will cause almost one additional ice-free day for polar bear subpopulations in coastal Alaska by 2100.

Exhibit C: References List

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