EMBARGOED UNTIL 2:00 PM ET THURSDAY 31 AUGUST 2023

CLIMATE AND ECOLOGY

Unlock the Endangered Species Act to address GHG emissions

For the first time, ESA evaluations can include impacts on polar bears from greenhouse gas emissions

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In 2008, projections that up to two-thirds of the world's polar bears could disappear by mid-century (*1*) led to polar bears becoming the first species listed under the US Endangered Species Act (ESA) because of threats from anthropogenic climate warming. Updated analyses (*2*) corroborated the 2008 projections and showed a linear but inverse relationship between Arctic sea ice extent and global mean temperature. Despite the relationship between warming and sea ice loss, absence of a quantitative link between anthropogenic greenhouse gas (GHG) emissions, sea ice loss, and declining polar bear vital rates has foiled full ESA implementation for polar bears. By quantifying the relationship between anthropogenic GHG emissions and polar bear recruitment, we show that sensitivities to cumulative anthropogenic emissions explain observed population trends, allow estimation of demographic impacts from new emissions sources, and enable ESA procedures to assess global warming impacts of proposed actions—along with impacts on the ground.

Section 7 of the ESA provides a process by which federal agencies ensure that actions they take, including those they fund or authorize through leasing activities or issuance of permits (e.g., oil and gas production), do not jeopardize the continued existence of listed species [see supplementary materials (SM)]. But in October 2008, then-Solicitor of the Department of Interior David Bernhardt issued a memorandum [M-Opinion M-37017 (see SM)] stating that Section 7 consultations would not be required "unless it is established that emissions from a proposed action would cause an indirect effect to listed species or critical habitat." Addressing his "unless" requirement, Solicitor Bernhardt concluded: "Any observed climate change effect on a member of a particular listed species or its critical habitat…would be the consequence of the collective GHG accumulation from natural sources and the worldwide anthropogenically produced GHG emissions since at least the beginning of the industrial revolution" and therefore "cannot be attributed to the emissions from any particular source." This inability to attribute negative consequences for polar bears to emissions from anthropogenic GHG sources has prevented the ESA from considering anthropogenic GHG emissions when evaluating impacts on polar bears from proposed actions. This limitation eviscerated the ESA with regard to the global warming threat that justified the 2008 listing of polar bears.

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POLAR BEARS, SEA ICE, EMISSIONS

Polar bears occur in 19 somewhat distinct subpopulations within four major ecoregions (see SM). Throughout their range, they rely on sea ice over productive continental shelf waters to catch their prey (*1*–*3*). When sea ice concentration falls to levels preventing effective foraging, polar bears are forced onto land or onto ice that has retreated far from shore and over deep unproductive waters. In both situations, they are largely food deprived (*4*, *5*). During these forced fasting durations (FDs), polar bears survive on accumulated fat reserves and lose nearly a kilogram of body mass each day (*6*). Anthropogenic climate warming shortens the period during which polar bears can forage from sea ice to build up their fat reserves and lengthens their fasting periods.

The fundamental dependence of polar bears on sea ice (*1*–*6*) and the documented relationship between declining sea ice and cumulative anthropogenic carbon dioxide (CO_2) emissions (*7*) assures that polar bear distribution and abundance ultimately can only decline as cumulative emissions increase. Yet, a quantifiable link between polar bear demographics and sea ice attributes such as extent, area, thickness, and volume has previously evaded discovery. In the absence of such a quantifiable link, previous polar bear studies have depended on associations between modeled future sea ice changes and present demographic or population viability estimates, or assumptions based on the general relationship between demographic performance and sea ice availability (*8*, *9*).

By contrast, Molnár *et al.* (*10*) recognized that demographic performance is determined by energy reserves of bears at fast initiation, their energy expenditures while fasting, and fast duration. The polar bear's physiological constraints, unlike demographic estimates derived from current population assessments, will remain unchanged, even as sea ice is changing, and provide a more robust foundation for assessment of future impacts. Molnár *et al.* (*10*) established two critical features of FD: (i) fasting impact thresholds—FDs beyond which the percentage of recruitment and survival failure increase rapidly—and (ii) the demographic "sensitivity" when FD exceeds the fasting impact thresholds (determined by the regression intercept and slope of increasing recruitment and survival failure—versus FD; see fig. S2a). Molnár *et al.* (*10*) defined FD as 24 days shorter than the number of ice-free days (IFD). Because IFD determines FD, IFD is the critical sea ice attribute providing the previously missing quantifiable link between observed sea ice decline and the polar bear's ability to maintain physiological and reproductive health.

Molnár *et al.* (*10*) showed that survival of cubs (recruitment into the next generation), determined by the mother's declining ability to provide enough milk for a cub's early survival, is the first demographic threshold crossed as FD increases (see SM). Because populations that are not successfully recruiting young can only decline, and because the recruitment impact threshold is the most sensitive to FD, we focused on the sensitivity of cub recruitment to emissions (see SM).

Armed with new knowledge of FD impacts on polar bear recruitment (*10*), here we link FD to cumulative anthropogenic GHG emissions. This reveals a causal connection between emissions from proposed actions and impacts on polar bears and helps explain recent population trends. Further, by quantifying polar bear impacts from anthropogenic GHG emissions rather than atmospheric concentrations, we disproved claims in M-37017 that consequences from current anthropogenic GHG emissions cannot be separated from natural sources or past accumulation of anthropogenic emissions.

Because climate warming and its associated sea ice loss result from all anthropogenic GHG emissions, not just CO_2, we considered CO_2 equivalent (CO_2-eq) emissions—the combination of GHG pollutants that contribute to climate warming—adjusted for their global warming potential. Considering CO_2-eq also is important because emissions and impacts

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of some GHGs can be more quickly and easily mitigated than CO_2.

We set FD to 24 days less than the number of IFD in the Seasonal Ice Ecoregion and equal to IFD elsewhere (see SM). As in Molnár *et al.* (*10*), we defined crossing the recruitment impact threshold as the first time FD exceeds 117 days for at least three of five consecutive years (*10*). This decision rule recognizes that FD is increasing on average with increasing cumulative emissions, that bears cannot recover from clusters of years above the impact threshold, and that future FD will increase on average as anthropogenic emissions increase. Detailed methods, including uncertainty estimates, are described in the SM.

Sensitivity of FD and recruitment failure to cumulative CO_2-eq emissions

Sensitivity to cumulative CO_2-eq emissions of FD (γ_1) and recruitment failure ($\beta_1\gamma_1$) for all polar bear subpopulations that have experienced at least 10 years with ice-free seasons from 1979 to 2020.

SUBPOPULATION	OCCUPIED AREA (km²) A	FD/CO_2-eq (d Gt^{-1}) γ_1	CO_2-eq/FD (Gt d^{-1}) $1/\gamma_1$	AREA WEIGHTED FD/CO_2-eq (d km² Gt^{-1}) $A\gamma_1$	RECRUITMENT FAILURE/ CO_2-eq (% Gt^{-1}) $\beta_1\gamma_1$
South Beaufort Sea	135,000	0.043 (0.024, 0.065)	23 (15, 41)	5800 (3300, 8800)	0.065 (0.037, 0.099)
Chukchi Sea	1,280,000	0.073 (0.056, 0.096)	14 (10, 18)	93,000 (71,000, 120,000)	0.11 (0.084, 0.15)
Laptev Sea	1,610,000	0.048 (0.036, 0.065)	21 (16, 28)	77,000 (57,000, 100,000)	0.073 (0.054, 0.098)
Kara Sea	980,000	0.067 (0.048, 0.091)	15 (11, 21)	65,000 (47,000, 89,000)	0.010 (0.073, 0.14)
Barents Sea	786,000	0.064 (0.035, 0.098)	16 (10, 29)	51,000 (27,000, 77,000)	0.098 (0.052, 0.15)
East Greenland	617,000	0.023 (0.009, 0.098)	43 (25, 113)	14,000 (5,400, 24,000)	0.035 (0.013, 0.060)
Kane Basin	48,200	0.029 (0.016, 0.044)	35 (23, 62)	1,400 (770, 2100)	0.043 (0.024, 0.067)
Lancaster Sound	229,000	0.12 (0.002, 0.025)	84 (39, 360)	2,700 (550, 5700)	0.018 (0.0035, 0.038)
Baffin Bay	616,000	0.027 (0.016, 0.040)	38 (25, 63)	16,000 (9,800, 25,000)	0.040 (0.024, 0.061)
McClintock Channel	133,000	0.018 (0.006, 0.033)	54 (30, 159)	2,500 (830, 4400)	0.028 (0.0094, 0.051)
Gulf of Boothia	61,000	0.037 (0.023, 0.052)	27 (19, 43)	2,300 (1,400, 3,200)	0.056 (0.035, 0.079)
Foxe Basin	502,000	0.023 (0.011, 0.037)	44 (27, 88)	12,000 (5700, 19,000)	0.034 (0.017, 0.056)
West Hudson Bay	176,000	0.017 (0.005, 0.031)	60 (32, 199)	2,900 (840, 5400)	0.025 (0.0072, 0.046)
South Hudson Bay	399,000	0.010 (0.000, 0.023)	93 (44, inf)	4,100 (0, 9100)	0.016 (0.00, 0.035)
Davis Strait	554,000	0.024 (0.009, 0.042)	44 (24, 115)	13,000 (4,800, 23,000)	0.036 (0.013, 0.064)
Total	8,120,000			366,000 (319,000, 420,000)	

OUTCOMES

Emissions and fasting duration

Molnár *et al.* (*10*) found an essentially linear relationship between FD and recruitment impact (*10*). We found that the relationship between FD and cumulative CO_2-eq emissions, for subdomains where polar bears occur, is also largely linear—by estimating the regression relationship between FD and each gigatonne (Gt) of cumulative emissions (see the figure, table, figs. S1 and S2, and SM). For ease of interpreting impact on polar bears, we took the reciprocals of regression line slopes to reveal the emitted amount of CO_2-eq that prolongs FD by one additional day (see the table). Emission levels that add 1 day to FD varied greatly among polar bear subpopulations. FD in areas historically covered by perennial sea ice showed the most rapid change with increasing emissions (steepest FD/CO_2-eq slopes). In the Chukchi Sea, for example, FD increased from ~12 days when satellite imagery of sea ice first became available in 1979 (see SM) to ~137 days in 2020 (table S2), and another day of fasting was added for each 14 (*10, 18*) Gt CO_2-eq (hereafter 95% confidence intervals appear in parentheses after central estimates) released into the atmosphere (see the table). Contrary to what might have been expected, the Seasonal Ice Ecoregion, where sea ice always has melted entirely during summer, saw the slowest rate of FD increase. The most gradual slope was observed in southern Hudson Bay, where FD increased from ~139 days to ~157 days since 1979, and 93 Gt CO_2-eq were emitted for each day added to FD (see the figure, table S2, and SM).

Emissions and demographic impact

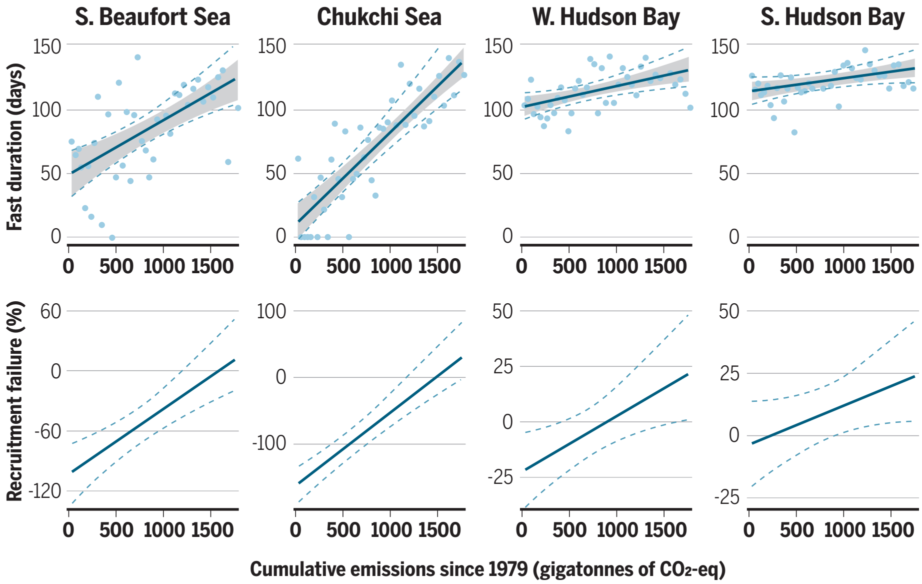
The relationship between FD and cumulative CO_2-eq emissions can be combined with the relationship between declining recruitment and FD [from Molnár *et al.* (*10*)] to calculate the rate at which polar bear recruitment has declined with cumulative emissions. The relationship between declining recruitment (increasing percentage recruitment failure) and cumulative emissions not only explains observed recruitment trends but also allows estimating the recruitment response to emissions from proposed future actions (see SM methods and fig. S2).

The sensitivity (regression slope) of recruitment to cumulative emissions ranges from 0.11 (0.084, 0.15) % Gt^{-1} in the Chukchi Sea to 0.016 (0.0, 035) % Gt^{-1} in southern Hudson Bay (see the table). These sensitivities, when multiplied by the emissions accumulated since each subpopulation region crossed the 117-day recruitment impact threshold, suggest recruitment impacts that are consistent with independent estimates of population status and trend.

For example, in western Hudson Bay (WHB), the best-known of all polar bear subpopulations, the 117-day recruitment impact threshold was reached in 1994 (table S1). The 1193 Gt of CO_2-eq emitted from 1994 to 2020 and the recruitment failure rate of 0.025 (0.0072, 0.046) % Gt^{-1} emissions (see the table) would mean an ~30 (9, 55) % decline in recruitment since crossing the threshold. This percentage decline would mean that the annual cub survival rate in WHB, which was estimated as ~70% during the 1980s (*11*), would now be ~49%. Such a decline in annual cub survival is consistent with the low proportion of yearlings observed in recent years and population estimates suggesting an ~30% decline in numbers between 1987 and 2016 (*12*). The most recent (2021) estimate, however, suggests that the WHB population may have declined by nearly half since the late 1980s (*11*). The recruitment sensitivity to emissions in WHB, therefore, may be closer to the upper end of our confidence interval than to the middle, meaning a current annual cub survival rate of ~32%. Alternatively, a larger numerical decline may mean that WHB crossed the recruitment impact threshold earlier. Molnár *et al.* (*10*) estimated that the effect of not including the 24-day adjustment to the onset of fasting would mean threshold crossings 10 to 30 years earlier than with the adjustment. Indeed, if WHB bears begin to fast as soon as sea ice extent drops below 30%, they would have exceeded the 117-day recruitment impact threshold before 1979, suggesting a 44 (13, 81) % decline in recruitment and a current annual cub survival rate of 40%. Crossing the recruitment impact threshold earlier is consistent with reduced body condition in females, disappearance of early weaning of cubs, and reduced cub recruitment reported

Linking CO_2-eq to polar bear fasting and recruitment failure

Shown are annual observations (dots) and regressions (solid lines) by subpopulation. Dashed lines are mean 95% confidence intervals (CIs) for sampling plus observational uncertainty. Shading illustrates sampling uncertainty only for comparison. See table for regression slopes and 95% CIs, and supplementary materials for details.



before 1994 (*13*). With or without the 24-day offset in FD, the recruitment declines that we estimate corroborate recent observations of poor cub survival and major population decline in WHB. See also the table and figure, fig. S3, and SM.

As when evaluating surface disturbances or toxic chemical releases, impacts of GHGs emitted from individual actions may appear small. This emphasizes the importance of assessing cumulative impacts at the programmatic rather than individual action level. For example, emissions from each of the many new actions anticipated to occur on US public lands between 2020 and 2050 may appear to have minimal impact on polar bears in isolation. Cumulatively, however, their projected 24.1 Gt of CO_2-eq emissions (see SM) will decrease polar bear cub recruitment by 0.6 (0.17, 1.1) % in WHB and by 2.7 (2.0, 3.6) % in the Chukchi Sea. Similarly, although each of the hundreds of power plants in the US make a relatively small contribution to emissions, together their nearly 2 Gt annual CO_2 emissions (see SM) and 60+ Gt emissions over 30+ year life spans reduce recruitment in the southern Beaufort Sea by ~4% (see SM).

Interpreting demographic impacts of individual actions can be likewise confounded by propagation of uncertainties through our estimation process—resulting in wide interval estimates. We therefore cannot overemphasize the need to refine emissions estimates at all levels of reporting, as well as to fill the gap in measurements of body masses at which polar bears in most regions initiate summer fasts (*10*).

OTHER SPECIES AND SYSTEMS

We focus on polar bears because the Bernhardt memo (M-37017) was prompted by the ESA listing of polar bears and because we have the energetics data (*10*) to make the quantitative link between emissions, sea ice, and polar bear demographics. But ramifications of our findings go far beyond polar bears and sea ice. In presenting this polar bear case history, our outcomes show by example how the impact of emissions can be determined and included in Section 7 consultations for other species and habitats threatened by climate warming. For example, although we personally lack data, it is logical to believe that links between GHG emissions, sea level rise, and nesting habitat for marine turtles and beach nesting birds could be established. Also, it seems reasonable that similar regression links could be established between emissions, water temperature change, and impacts on both freshwater and marine species of plants and animals. We are confident that our polar bear example will lead other investigators to uncover parallels in their data, providing numerous other species with previously unavailable ESA protections from climate warming. It is also reasonable that GHG emissions could be similarly linked to other phenomena—beyond the purview of the ESA.

We have confirmed the direct link between CO_2-eq emissions and polar bear demography. In addition to aiding interpretation of observed population trends, this allows estimation of impacts from proposed GHG-emitting actions. Because the ESA requires following the best available science, the Department of the Interior now has the scientific justification and duty to rescind M-Opinion M-37017—allowing the US Fish and Wildlife Service to include anthropogenic GHG emissions in Section 7 consultations and meet its responsibility under the ESA to protect polar bears as well as other species imperiled by climate warming. This will provide the government an important and previously unavailable tool for addressing anthropogenic climate warming.

Small impacts of most individual actions emphasize that GHG emissions are the epitomic cumulative impacts issue—requiring mitigation at programmatic, regional, national, and international levels. We must remember, however, that the growth in cumulative GHG emissions by over 1750 Gt from 1979 to today happened largely one action at a time without regard for cumulative effects in the atmosphere or on the ground. In addition to broad-scale efforts, if future impact assessments require separate evaluations, decisions must be based on merit, contribution to cumulative impact, and the best available science.

Rescinding M-37017 goes beyond consideration of polar bears and sea ice—adhering to President Biden's mandate for a "Government-wide approach that reduces climate pollution in every sector of the economy" (SM). The role of the Arctic sea ice system in moderating global climate means that protecting polar bears from anthropogenic climate warming also will benefit the rest of life on Earth—including humans. ■

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ACKNOWLEDGMENTS

S.C.A. received funding from Polar Bears International. C.M.B. received funding from National Science Foundation grant OPP-2237964. The authors thank T. McDonald for advice on statistical procedures, and P. Molnár for providing data for recruitment failure as a function of fasting duration (*10*). Data and code for replication are available at Zenodo (*14*).

SUPPLEMENTARY MATERIALS

science.org/doi/10.1126/science.adh2280

10.1126/science.adh2280