How is climate change affecting polar bears and giant pandas?

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Introduction

Anthropogenic greenhouse gas emissions are the primary cause of climate change (Rosenzweig *et al.* 2008; Kokic *et al.* 2014) and an estimated increase of 3.7 to 4.8 °C is predicted by the year 2100 if emissions continue at current levels (IPCC 2014). Main predictions for physical impacts of climate change include changes in precipitation, humidity, and sea level, with higher temperatures over land and oceans leading to decreased snow cover, glaciers, and sea ice (Rosenzweig *et al.* 2007; Overland *et al.* 2018;). While climate effects are spatially heterogeneous, varying in scale, magnitude, and type (IPCC 2018), their impacts are widely recognized as disruptive to ecological processes and a major threat to biodiversity globally. Changes to phenology (Lane *et al.* 2012), relationships and interactions within ecological communities (Post *et al.* 2013), and species ranges (Barnosky *et al.* 2003; Parmesan & Yohe 2003; Guralnick 2006) are predicted or already underway. Shifts in climatic niches can lead to trophic mismatches and phenological desynchronization that threaten species survival (Thackeray *et al.* 2016). Range shifts of terrestrial species to higher latitudes and altitudes have already been observed in the Northern Hemisphere, in addition to alterations in routes and timing of bird migrations in Europe, North America, and Australia, and changes in the composition of ocean communities from cold- to warm-adapted species (IPCC 2007).

The Arctic is warming two to three times faster than temperate regions (IPCC 2018), and polar ecosystems are likely to be the first to undergo rapid alterations in climatic niches, with trophic shifts and impacts to biodiversity already occurring (Rosenzweig *et al.* 2007; Yurkowski *et al.* 2018).

Polar bears (*Ursus maritimus*) and giant pandas (*Ailuropoda melanoleuca*) provide an interesting comparison study of the impact of climate change on bear species. While belonging to the same evolutionary clade, polar bears are the most recently divergent of the extant bear species, while giant pandas are the oldest (Yu *et al.* 2007). Both species are considered Vulnerable (Wiig *et al.* 2015; Swaisgood *et al.* 2017) and are conservation icons, polar bears in particular for climate change. Wildlife species with inflexible life histories and physiologies tightly regulated by the environment are most likely to experience declines in fitness associated with a changing climate. Examining how the environment structures life histories and physiology of polar bears and giant pandas can inform our understanding of threats posed by climate change to both species' persistence.

Polar bears have a circumpolar distribution, living in an extreme and dynamic sea ice environment. As such, their physiology and life histories have evolved to cope with a habitat that changes on multiple temporal scales, from hourly to annually. Their physiology is adapted for a feast and famine regime, including the ability to rapidly gain energy-rich fat deposits during hyperphagia (April-October; Watts & Hansen 1987), while slowing metabolism to prolong fasting capacity during hypophagia (October-May; Pilfold *et al.* 2016). Polar bears also synchronize reproductive activities to resource seasonality (see also Chapter 14). Mating occurs April-June, and implantation occurs August-October, provided sufficient fat stores exist (Derocher *et al.* 1992). Cubs are born in November-January (Ramsay & Stirling 1988), and are nursed in a den until February-March (Yee *et al.* 2017) when they follow their mothers onto the sea ice to hunt vulnerable ringed seal (*Pusa hispida*) pups born during the period when polar bear hyperphagia peaks (Pilfold *et al.* 2012). The ringed seal whelping period is vital to polar bear cub survival, and changes in availability of ringed seal pups correlates to declines in polar bear reproductive output (Stirling 2002; see also Chapter 14). These changes have been linked to region-wide environmental changes (Rode *et al.* 2018), indicating tight bottom-up regulation of polar bear populations.

Traits that make a species more vulnerable to disturbance include having a restricted geographic range, limited dispersal, low reproductive rates, and high dietary and habitat specialization (Peters & Darling 1985; Reid *et al.* 1989; McDonald & Brown 1992; IUCN 2008; Isaac *et al.* 2009). Giant pandas have a narrow geographic range, do not disperse over large distances, produce one cub every two to three years, and depend on bamboo for 99% of their diet (Reid *et al.* 1991; Zhao *et al.* 2013; Wei *et al.* 2015), suggesting vulnerability to change. Giant pandas live in temperate montane forests of central China and, though bamboo is widely available, they select it in discrete patches based on accessibility and nutrient quality (Wei *et al.* 2015). Giant pandas shift feeding to favor bamboo leaves from June-December and culm and shoots from February-May (Hansen *et al.* 2010), and their seasonal movements, in part, reflect this selection (Zhang *et al.* 2014). Mating occurs from February-April and birthing from July-September (Zhu *et al.* 2001) (see Chapter 6 for details on the species biology).

Giant panda ancestors were once carnivorous and, while evolution to a bamboo diet allowed them to exploit an abundant resource, their gastrointestinal system is

inefficient at digesting highly fibrous, low-calorie bamboo. Their behavior and physiology have evolved to maintain a positive energy balance while feeding on a nutrient poor resource (Zhu *et al.* 2011). Despite morphological adaptations to aid in bamboo consumption (e.g. pseudo-thumb, mandible and jaw modifications, microflora in gut) giant pandas must spend much of their time feeding (Schaller *et al.* 1985) and their population dynamics are sensitive to stochastic changes in bamboo supply (Carter *et al.* 1999). Past bamboo die-offs due to flowering events have led to significant mortality (Reid *et al.* 1989), suggesting giant panda population dynamics are also regulated by bottom-up processes.

While polar bears and giant pandas are arguably the most distant of the bear species with regard to life histories and behavior, both are likely to be significantly impacted by the broad-scale changes to their environment that are predicted to result from climate change. Herein, we review the conservation status of both species and their habitats, and present current and predicted evidence of the impacts of a changing climate on polar bear and giant panda survival.

Polar Bears

Current Status of Polar Bears and Their Habitat

Polar bears are dependent on sea ice for nearly all aspects of their life history (see Chapter 14). Climatic warming has caused significant declines in sea ice, the primary habitat of polar bears. In 2018, Arctic sea ice extent maximum (14.48 million km^2) and minimum (4.59 million km^2) were estimated to be 7.4% and 26.2%, respectively, below the mean maximum and minimum extents for 1981-2010 (https://nsidc.org). Since 1979, annual maximum and minimum Arctic sea ice extent decreased 47,000 (3.1% $decade^{-1}$) and 75,000 (10.4% $decade^{-1}$) km^2 $year^{-1}$, respectively (Figure 21.1). Rates of sea ice loss have varied throughout the ranges of the estimated 20,000–25,000 wild polar bears in 19 recognized subpopulations (Figure X.X; http://pbsg.npolar.no/) , with ice-covered days declining by 7 to 19 days $decade^{-1}$ since 1979, depending on the subpopulation (Stern & Laidre 2016).

Polar bear habitat preferences are driven by the composition and distribution of sea ice relative to the annual timing of critical life history requirements. Critical habitat includes medium-to-high concentration sea ice near edges, frequently near land, and over continental shelves or shallow waters (Durner *et al.* 2009). In the polar basin (where six subpopulations range), optimal habitat declined annually from 1% to 14% between 1985–1995 and 1996–2006 (Durner *et al.* 2009), and continued to 2015 in some regions (Lone *et al.* 2018). Despite losses in optimal habitat, the preference by polar bears for particular sea ice types and its distribution (i.e. concentration, proximity of ice edges, shallow seas) has remained relatively unchanged (Laidre *et al.* 2015; Wilson *et al.* 2016). Habitat loss, however, has impacted polar bears in several ways, including behavioral changes (Cherry *et al.* 2013; Rode *et al.* 2015a; Atwood *et al.* 2016a), diminished body condition, reduced survival, and numerical declines for some subpopulations (Regehr *et al.* 2007; Rode *et al.* 2010; Bromaghin *et al.* 2015; Lunn *et al.* 2016; Obbard *et al.* 2016, 2018). Future declines in sea ice will increase energetic costs to polar bears using the remaining ice due to ice fragmentation, increased swimming between floes, and increased movement to compensate for faster ice drift (Pagano *et al.*

2018). Hence, subpopulations currently showing no negative effects may be adversely impacted should habitat loss continue (Stirling *et al.* 2011).

The status of some polar bear subpopulations may be a response to biological productivity rather than ice declines. The Davis Strait subpopulation increased from 1971 to 2007, despite deteriorating sea ice, due to an increasing prey base (Peacock *et al.* 2013). Low reproduction in Davis Strait and body condition declines in Baffin Bay bears, however, could be due to combined effects of high population density and sea ice declines (Rode *et al.* 2012; Peacock *et al.* 2013). Reproduction and body condition of Chukchi Sea polar bears remained stable between 1986-1994 and 2008-2011, despite an annual 44-day increase in ice-free days, because of high biological productivity in that region (Rode *et al.* 2014). This likely explains the high annual survival and abundance of Chukchi Sea polar bears (Regehr *et al.* 2018). While studies demonstrate that biological productivity may lessen impacts of sea ice loss on polar bears in some regions, those mitigating effects will be moot if current rates of sea ice loss continue through the 21st century.

Future Impacts of Climate Change on Polar Bears and Their Habitat

The greatest 21st century threat to polar bears is anthropogenic greenhouse gas (GHG) - induced loss of sea ice (Atwood *et al.* 2016b) as this threatens extirpation of many subpopulations by 2100 (Amstrup *et al.* 2008). Climate models show Arctic surface air temperatures surpassing 1986-2005 levels by 2.2 °C (mitigated GHG) to 8.3 °C (unabated GHG) at century's end, with sea ice reductions of 8% to 34% in February and 43% to 94% in September (Collins *et al.* 2013). Ninety percent of unabated GHG scenarios project a September ice-free Arctic Ocean for five consecutive years before 2100 (Collins *et al.* 2013). If GHG emissions continue unabated, in any year beyond 2090, the Arctic Ocean could be ice-free for 5 consecutive months (Douglas & Atwood 2017).

Ice loss will impact some polar bear subpopulations more than others. For subpopulations in the Convergent Ice (CE) and Divergent Ice (DE) ecoregions (Figure X.X; (Amstrup *et al.* 2008; Castro de la Guardia *et al.* 2013), Durner et al. (2009) predicted decreases in optimal habitat between 0.9-6.5% decade^{-1} by 2099 compared to 1985-1995 based on moderately-abated GHG scenarios. The annual cumulative extent of optimal habitat declined 32% (from 1.5 million to 1.0 million km^2) in the CE and DE by 2100. Castro de la Guardia *et al.* (2013) used a moderately-abated GHG scenario to predict increased duration between annual breakup and freeze-up for sea ice habitat occupied by the Western Hudson Bay (WH) subpopulation (the period during which bears are forced ashore). Using ≥180 days on land as the threshold at which polar bear reproduction and survival would be compromised (Molnár *et al.* 2010, 2011), Castro de la Guardia *et al.* (2013) projected that this critical state would occur in 35 years between 2051 and 2100 and would jeopardize the persistence of WH polar bears. Unabated GHG emission scenarios had even more dire outcomes, with 41 years between 2051 and 2100 exceeding the critical threshold of 180 days.

Amstrup *et al.* (2008) projected that diminishing sea ice will reduce numbers of animals in polar bear subpopulations within all ecoregions by 2100. In the near-term (i.e. within 25 years) subpopulations in the CE and the Canadian Arctic Archipelago Ecoregion (AE; Figure X.X) had a relatively high probability of either remaining

unchanged or increasing. Amstrup *et al.* (2008) suggested that the AE could provide refugium for polar bears in the late 21st century. However, this optimistic outlook contrasts with model projections based on aggressive emission scenarios that suggest the AE could change from a multiyear to annual ice environment, be ice-free 2-5 months annually, and therefore unable to support polar bear populations by 2100 (Hamilton *et al.* 2014). SE and DE subpopulations have a high probability of being reduced or even extirpated in the near-term (Amstrup *et al.* 2008). Beyond 50 years, extirpation was the dominant outcome for the SE and DE subpopulations, and the dominant outcome for the CE subpopulation after 75 years.

Conservation Implications and Mitigation Strategies for Polar Bears

Projections suggest that the circumpolar abundance of polar bears is likely to decline by 30-66% by mid-century if sea ice habitat loss continues unabated (Amstrup *et al.* 2008; Atwood *et al.* 2016a; Regehr *et al.* 2016). However, short-term (i.e. 10-20 years) responses to environmental changes may be mediated by a variety of factors, including regional differences in ecosystem productivity, anthropogenic stressors, and transient habitat improvements (Peacock *et al.* 2013; Rode *et al.* 2014; Jenssen *et al.* 2015).

Since the long-term persistence of sea ice and polar bears are inextricably linked, actions that stop global warming and minimize sea ice loss must be a priority, but should not be the sole focus, of polar bear conservation efforts. Diminishing sea ice is enabling greater human access to the Arctic, facilitating expanded oil, gas, and mineral extractions (Gautier *et al.* 2009), establishing new shipping lanes (Smith & Stephenson 2013), and providing more recreational opportunities (Rode *et al.* 2018). Noise associated with industrial development and recreation could cause polar bears to avoid impacted areas and lead to changes in the distribution and productivity of prey (Kelly *et al.* 1988). Increasing human activities could increase exposures to pollutants and emerging pathogens (Nuijten *et al.* 2016; Atwood *et al.* 2017a), as well as increase the risk for detrimental human-polar bear interactions (Atwood *et al.* 2017b). While such near-term stressors are inherently more tractable to mitigate than sea ice loss, they are likely to have far less direct influence on long-term population outcomes (Atwood *et al.* 2016a). Nevertheless, any reduction in short-term population declines may prove crucial for maintaining viable polar bear subpopulations until such time that sea ice loss has ended.

The best long-term conservation action for minimizing reductions in the number of polar bears and the amount of sea ice habitat upon which they rely would be to hold the global mean temperature to ≤2°C above pre-industrial levels. With prompt, aggressive, and sustained mitigation of GHG emissions, most climate models project that Earth's average temperature would not rise more than 2°C and Arctic sea ice would persist all summer (Allen & Stocker 2014; Figure 21.2). Reductions to keep warming below 2°C would require immediate action as peak warmth from CO_2 (a prevalent and long-lived GHG) emissions occurs a decade or more after release (Ricke & Caldeira 2014), and sea ice will require even more time to stabilize (Amstrup *et al.* 2010). Timely intervention in the current global warming trajectory, along with focused management

of near-term stressors, will likely assure the persistence of polar bears through the 21st century (Amstrup *et al.* 2010).

Giant Pandas

Current Status of Giant Panda and Their Habitat

Giant pandas were once distributed across the Yellow, Yangtze, and Pearl river basins in southeastern China, from Zhoukoudian in Beijing in the north to neighboring Vietnam, Thailand, and Myanmar in the south. Late Pleistocene climate changes and millennia of human development have reduced their geographic distribution to <1% of their prehistorical range (Schaller *et al.* 1985; O'Brien *et al.* 1994; Loucks *et al.* 2001;). Currently, giant pandas remain in six mountain ranges (Qinling, Minshan, Qionglai, Xiaoxangling, Daxiangling, and Liangshan) across three provinces. According to the 4th National Giant Panda Survey (NGPS), Sichuan Province comprises most of the remaining suitable habitat with ~ 2.03 million ha (79% of total), Shaanxi Province has ~ 0.36 million ha (14%), and Gansu Province has ~0.19 million ha (7%; Tang *et al.* 2015). The amount of suitable habitat expanded from 1.39 to 2.58 million ha between the 1980s and 2013 due primarily to expanded conservation efforts by the Chinese government and international organizations.

By the end of 2013, 1,864 giant pandas survived in the wild, an increase of 17% since the 3rd NGPS in 2003, with individuals distributed across the provinces in proportions similar to remaining suitable habitat (74% in Sichuan, 19% in Shaanxi, and 7% in Gansu Province; State Forestry Administration of China 2006; Tang *et al.* 2015). Giant pandas are isolated into 33 subpopulations and only six of them support >100 individuals. Those larger populations are found in the northern half of the range – in the central Qinling, central Minshan, and northcentral Qionglai mountains. In the Minshan Mountains, 22 subpopulations have <30 individuals, of which 18 have <10 individuals (see also Chapter 6). There are 67 giant panda protected areas, comprising 54% of giant panda habitat and supporting 1,246 individuals (68% of total estimated population).

Over the past 3,000 years, main threats to giant panda populations came from anthropogenic activities, including broad-scale agricultural conversion, road construction, logging, mining, and hydroelectric development, along with smaller-scale threats from poaching and collection of forest products such as bamboo shoots. More recently, increased tourism brings people and impacts to an expanding number of protected areas. By 2013, there were 319 hydropower stations, 1,339 km of roads, 269 km of high-voltage transmission lines, 984 residential areas, 479 mines, and 25 scenic spots found in the giant panda range (Tang *et al.* 2015). These developments further exacerbate habitat fragmentation and reduce gene flow between subpopulations, potentially decreasing genetic diversity and making populations less resilient to environmental changes (Schaller *et al.* 1985; O'Brien *et al.* 1994), such as those brought on by climate change (Lu *et al.* 2001).

Future Impacts of Climate Change on Giant Pandas and Their Habitat

Many studies have modelled impacts of climate change on geographic distributions of bamboo species and giant panda habitat, both across the geographic range of this species and within individual mountain ranges (Songer *et al.* 2012; Tuanmu *et al.* 2013; Fan *et al.* 2014; Li *et al.* 2015b; Wang *et al.* 2018; Wei *et al.* 2018a), though results can vary widely (e.g. Figures 21.3 and 21.4; also see *Uncertainties* section of this chapter). Many bamboo species consumed by giant pandas are sensitive to climate change: 6 of the 16 main bamboo species found within the range are projected to disappear from giant panda habitats as climate change progresses, resulting in a significant reduction in bamboo forest area (Li *et al.* 2015b). Tuanmu *et al.* (2013) predicted three dominant bamboo species would face a substantial reduction within the Qinling range during the 21st century. Both alpha (the number of species and their proportion in a habitat or community) and beta (the dissimilarity of species composition between two habitats or communities) diversity of bamboo forest is predicted to be severely reduced in most of the range if current climate trends continue, and the proportion of single-species bamboo forest is predicted to increase (Tuanmu *et al.* 2013; Li *et al.* 2015b; Tuanmu *et al.* 2013), suggesting that giant pandas will have reduced availability of habitat with multiple bamboo species in the future. The reduction in bamboo forest and diversity would be most drastic in Qinling, Daxiangling, and Qionglaishan mountains, however, the amount of bamboo and bamboo diversity could increase in parts of the Minshan and Liangshan mountains (Li *et al.* 2015b). The projected warmer and drier climate in China could also shorten bamboo flowering cycles and increase the frequency of mass flowering events (Li *et al.* 2015b), which have been disastrous to the giant pandas in the past (Feng *et al.* 1991).

Projections indicate that climate change could reduce the amount of suitable habitat for giant pandas throughout most of the range (Figures 21.3 and 21.4; Songer *et al.* 2012; Jian *et al.* 2014; Li *et al.* 2015a). An ensemble forecasting method combining both biotic (bamboo availability) and abiotic (climatic and geographic) variables projected that climate change will reduce current habitats by 50%, and 20% of the current protected areas could lose all suitable habitat in this century (Li *et al.* 2015a). Songer *et al.* (2012) integrated current giant panda habitat data with general circulations models and found that climate change could reduce habitat by nearly 60% by 2080 and predicted a shift of habitat towards higher elevation and higher latitudes, leading to an increased number of suitable habitat patches with a sharply decreased average patch size. While new areas may become suitable outside the current geographic range, only 15% of these areas fall within the current protected area system (Songer *et al.* 2012). Wu *et al.* (2009) found similar results, predicting that the total suitable habitat of giant pandas will be reduced by 70% and become more fragmented by 2100 if current climate trends continue.

Several studies have focused on the impacts of climate change on giant panda habitats within different mountain ranges (Wang *et al.* 2010; Zhang *et al.* 2018). In the Minshan Mountains, which support the largest remaining giant panda population (43% of the total giant panda population) projected habitat gains to the west and losses near the center of the mountain range would produce an overall westward shift of giant

panda habitat (Figures 21.4; Li *et al.* 2015a). In the same mountain range, Shen *et al.* (2015) predicted that climate change could lead to 67% of giant panda habitat shifting to higher altitudes and latitudes, with a 16 % reduction in habitat. The Minshan giant panda habitat is also projected to become more fragmented and isolated, with the average patch size decreasing from a current average of 843 km^2 to <46-75 km^2, depending on the emission scenario (Songer *et al.* 2012).

In the Qionglaishan Mountains, home of the second largest giant panda population (28% of the total population) suitable giant panda habitat could decrease by 5-37% by 2070, while the northern and lower elevation limits of current suitable habitat for giant pandas could decrease (Yan *et al.* 2017). Climate change is predicted to bisect the future habitat range into two isolated patches, creating a major barrier to animal movement and an obstacle to gene flow in this region (Li *et al.* 2015a). The third largest giant panda population, found in the Qinling Mountains at the northernmost part of the range, could face a substantial contraction of habitat areas according to several studies (Fan *et al.* 2014; Gong *et al.* 2016; Li *et al.* 2015a). Climate change could reduce the extent of a suitable habitat for giant pandas by up to 62% and the minimum elevation of giant panda habitat could rise by 500 m (Fan *et al.* 2014). However, the predicted shift of habitat to northern latitudes would mean the far northern Qinling range would be less impacted than any of the other mountain ranges (Songer *et al.* 2012). In addition, Wang *et al.* (2018) found that incorporating biotic interactions reveals potential climate tolerance of giant pandas, and the biotic models predicted less habitat loss compared with climate-only models of panda distributions in this mountain range.

The three southern mountain ranges (Daxiangling, Xiaoxiangling and Liangshan mountains) taken together support 10% of the remaining giant panda population. There are no studies targeting these mountain ranges specifically, however, range-wide studies predict that climate change will cause the most drastic reductions to both available bamboo resources and habitat in these three mountain ranges, partly due to the latitudinal northward shift in suitable habitat (Wu *et al.* 2009; Songer *et al.* 2012; Li *et al.* 2015a;).

Conservation Implications and Mitigation Strategies for Giant Pandas

Numerous studies project that rapid climate change will adversely affect giant panda habitat, putting at the population at risk and potentially reversing conservation successes of recent decades. There is a critical need to rethink the current conservation approach to incorporate planning for impacts of climate change and development of adaptive management strategies for giant panda. First, effective conservation of giant panda habitats requires protection and restoration of bamboo forest, particularly for old-growth forests where bamboo forms the understory. Human-assisted restoration efforts to accelerate the return of bamboo and increase species diversity to previously logged areas can help ensure food security of the giant panda in a changing climate (Li *et al.* 2015b). Second, based on the prediction of reduced and more fragmented habitat throughout the species range under most climate change scenarios, forestry planning and management should focus on enhancing habitat connectivity by establishing habitat corridors and strengthening matrix management outside the reserves to promote gene

flow and increase population viability (Wang *et al.* 2014). In addition, suitable habitat strongholds along within areas predicted to become suitable in key locations should be identified throughout the range and prioritized for protection, restoration, and reduction of human impact (Songer *et al.* 2012). Finally, an adjustment of the existing reserves may be necessary in cases where significant habitat changes within and around reserves are expected, e.g. by manipulating size, shape, and spatial orientation of reserves (Li *et al.* 2015a).

Giant panda conservation efforts should not only seek to ensure the recovery of giant panda population, but also share important co-benefits to maximize return on conservation investment (Li *et al.* 2017; Wei *et al.* 2018). Giant panda habitats support 293 rare and endangered species, according to the IUCN Red List, of which 133 are endemic to China and 19 are endemic to the giant panda range (Li & Pimm 2016). Giant panda habitats also play a critical role in the provision of multiple ecosystem services, with a value of US$2.6 and US$6.9 billion/year gained from giant panda services and reserves in 2010 (Wei *et al.* 2018a). Approximately 90% of the giant panda reserves are more effective in increasing carbon sequestration compared to lands not declared as reserves from 1988–2012 (Li *et al.* 2017).

Though the downlisting of giant pandas from Endangered to Vulnerable is an indicator of conservation success, existing efforts should not be relaxed (Swaisgood *et al.* 2017). Instead, it is time to shift from traditional conservation approaches to new models, including a more expansive view of potential habitat, innovative approaches to enhancing connectivity and protection, and developing integrated plans that address multiple objectives to consider social, environmental, and resource management perspectives. The government of China is establishing a Giant Panda National Park spanning three provinces and all existing reserves. Therefore, setting regional conservation priorities should receive special attention during park planning, to foster synergies between ecosystem services and biodiversity, and to maximize the potential of species and carbon co-benefits under global change (Li *et al.* 2017).

Challenges

Dealing with Uncertainties of Climate Change Modelling

The modelling of future climate change is intrinsically variable. Choice of emission scenario, initial conditions such as species occurrence, model classes and parameters, and combinations of variables can all affect projections (Araújo & New 2007) and call for different conservation solutions (Heikkinen *et al.* 2006; Huang *et al.* 2018). For giant pandas, just within the Qinling range estimates of habitat loss by 2080 ranged from 1-17% (Songer *et al.* 2012), to 16-42% (Wang *et al.* 2018) and 37-62% (Fan *et al.* 2014). For polar bears, habitat is predicted to decline by 2.7% decade^{-1} to 4.9% decade^{-1} for moderate and unabated emission scenarios, respectively (Durner *et al.* 2009).

Several methods are used to account for, and parse out, model uncertainty. Ensemble models are employed to compute multi-model means (Durner *et al.* 2009) or produce cumulative weighted averages based on each individual model's performance (Thuiller *et al.* 2009). Ensemble modeling can improve on robustness over single models, though composition of the model suite is important (Overland *et al.* 2011). Studies have examined how different modeling factors contribute to variability in richness and "turnover rate" (Diniz-Filho *et al.* 2009; Buisson *et al.* 2010). New methods have also been developed to compare similarities between gridded probabilities/suitability of a single species (Huang *et al.* 2018). However, translating variable model prediction to practical conservation policies with a high likelihood of success remains a challenge.

Other factors can contribute to model uncertainties, including biotic interaction with conspecifics and co-dependent species, and adaptability to climate change (Araújo & New 2007). For example, the future distribution of polar bears may be influenced by combinations of differential accessibility of prey (ice seals), conspecific predation risk (Pilfold *et al.* 2014), and low nutritional value of terrestrial foods (Rode *et al.* 2015a), in addition to sea ice declines (Amstrup *et al.* 2010). Studies have revealed giant panda's aversion to human infrastructure, which is found at lower elevations (Wang *et al.* 2014), though historically they were present in low elevation regions in southeast China and part of Southeast Asia (Loucks *et al.* 2001). It is reasonable to assume that giant panda and bamboo physiology might be resilient enough to tolerate moderate temperature increases, however, empirical studies are lacking.

While much of the existing literature focuses primarily on the impact of increased average temperatures, climate change will also increase the frequency and severity of extreme climate events which might have significant impacts on species distribution (Huang *et al.* 2017). Giant pandas are found in one of the most tectonically active places on earth and extreme weather events could cause further disturbances. Understanding is lacking on the impacts of extreme heat, flooding, and drought on giant panda and bamboo distributions, the impacts of summer storms and rain events on maternal dens for giant pandas, and the impacts of more fragmented and declining amounts of sea ice distribution on polar bears. Further research is urgently needed to test and validate numerous climate change predictions on polar bears and giant pandas, to understand the adaptability of both species and to better inform conservation decisions.

Data Availability and Access

The Chinese government allocates tremendous resources to NGPS approximately every decade. The survey provides valuable information on wild populations dating back to 1974. The most recent NGPS (3rd and 4th) have similar methods and are the most comparable (Zhang *et al.* 2011; Wei *et al.* 2018b). However, they still have somewhat different extents and transect density (Yang *et al.* 2017). The change in survey design creates a challenge for direct comparison and application of results to population recovery (Qiu 2015). Giant pandas are not directly counted, but abundance is inferred through estimates of spoor densities and by distinguishing individuals through bite mark sizes found on bamboo (State Forestry Administration of China 2015), and results

often lack sufficient documentation on data pre-processing and error propagation methods. The lack of a variability or error estimate in population numbers was raised as a significant issue within the research community (Harris *et al.* 2014; Qiu 2015). In addition, NGPS raw data are not publically available, but owned by the State Forestry Administration of China and only available to scientists who sign agreements for access. Population assessments also lack estimates for age-class survival, which reduces the mechanistic inference of factors driving population changes, thus limiting use in adaptive management planning.

By contrast, data reporting and sharing from polar bear research is considerably more transparent. The International Union for the Conservation of Nature's Polar Bear Specialist Group meets on a quadrennial basis to share information and publishes their proceedings (e.g. Durner, Laidre & York 2018), providing a compendium of openly available data. Additionally, some agencies make data from publications available to the public (Office of Science and Technology Policy 2013). The vast and remote circumpolar range of polar bears makes data deficiency a greater obstacle than data access. Among the 19 recognized sub-populations of polar bears, 11 currently have a data-deficient status. There remains tremendous disparity in the amount of empirical data and knowledge about their sizes and statuses due to the logistical challenges and expense of conducting fieldwork in the Arctic. This has led to an unequal amount of research across subpopulations, with the majority of empirical climate change research coming from the four subpopulations with better accessibility: western Hudson Bay, southern Beaufort Sea, Chukchi Sea, and the Barents Sea. A lack of spatial variation in measuring the response of a broadly distributed species has the potential to bias inferences about the rate or type of biological response range-wide. Of the limited studies comparing regional responses of polar bears to sea ice change, both have shown marked variation between subpopulations (Rode *et al.* 2014; Pilfold *et al.* 2017).

Conclusion

Polar bears and giant pandas are predicted to be highly susceptible to the impacts of climate change based on their life history, specialized habitat requirements, and unique geographical distributions. Habitats of both species will likely be significantly altered through reductions in area and shifts of suitable habitat. Both species are listed as Vulnerable, though giant pandas have less than a tenth of the remaining population size of polar bears. The disparity in the scale of the species' spatial distributions creates different challenges for conservation planning. Polar bears range over vast Artic terrestrial and marine areas of 23 million km^2, while giant pandas cover less than 26,000 km^2 in mountain forests surrounded by human communities, agriculture, and roads. Giant pandas benefit from the top-down approach of the Chinese government's policies expanding protected area, creating incentives for returning cropland to forest, and investing in research and conservation. In contrast, polar bear conservation is built on international collaboration among nations bordering the Arctic Ocean, which is more complex, but leads to synergies and resources of many nations working together towards shared goals, sometimes despite the existence of higher-level political conflicts (e.g. United States and Russia).

The most pressing question for the conservation of both species is: What can and should be done to facilitate adaptive management despite the uncertainties and variability of future climate models and emission scenarios? One of the greatest challenges posed by climate change for conservation is the shifting and dynamic changes expected for wildlife habitat. Conservation tools that depend on habitat protection may result in protected areas that do not cover key habitats in perpetuity as habitats and the species that inhabit them shift spatially due to climate change. Therefore, it is vital that adaptive management plans are based on the best available science and grounded in ongoing ecological studies that can be verified with empirical data.

Existing climate commitments complicate predictions and mitigation planning for climate change. Global mean temperature rose approximately 0.8 °C between 1880-2012, resulting in oceanic warming and sea level rise (Rummukainen 2015). However, there is a lag in realized climatic impacts from oceanic warming, resulting in a commitment to more climate change on top of what has already exists (Wigley 2005; Meehl *et al.* 2012; Rummukainen 2015; Overland *et al.* 2018). Non-linear changes such as the melting of ice sheets and release of permafrost carbon could have impacts for centuries to come. Our historical emissions and current socio-economic investments such as long-lasting energy infrastructure commit us to future climate change, even in the unlikely event that our emissions are reduced to zero in the near-term. Given existing climate commitments, GHG emissions would have to go below our current levels in order to stabilize global mean temperature commitments (Wigley 2005; Meehl *et al.* 2012; Rummukainen 2015). These climate commitments create further uncertainty about the impacts of climate change, and a greater urgency for reducing our emissions.

However, uncertainty in future ecological scenarios and the immense challenges posed by climate change are not justification for inaction. Increasing protections, limiting development in critical areas, and enhancing connectivity among individuals within remaining habitat are priorities for both species and may buffer against the effects of change. Most importantly, limiting the continuing increase of GHG emissions is urgently needed to slow the effects of climate change already underway. This requires action at local, national, and global levels, ranging from the choices of individuals to the governance of societies. Due to their charismatic appeal, polar bears and giant pandas inspire global support of research and conservation actions. Harnessing this inspiration and raising awareness of the risks and opportunities is key for countering the predicted impacts of climate change.

Taken together polar bears and giant pandas provide a glimpse into the wide range of challenges species are already undergoing in the face of climate change. Conservation actions and research designed to inform protection of these bears will also serve to protect their ecosystems and other vulnerable species, including other bear species that are also threatened by climate change but are not as well known. Leveraging support for polar bears and giant pandas can serve as a means to expand research on the potential effects of climate change, generate funds for research and conservation, and galvanize conservation actions to mitigate adverse impacts of climate change to wildlife populations.

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