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Projections of future population decline indicate the need to designate the emperor penguin as an Antarctic Specially Protected Species

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Summary

Loss of suitable breeding habitat is the most important challenge that emperor penguins face. Whilst global endeavours seek to fight human-induced climate change arising from increasing greenhouse gas emissions, it would be precautionary to reduce or eliminate other stressors that could otherwise add to the burden that emperor penguins face. Consequently, it is important to develop management options that are informed by the best available scientific evidence. Listing emperor penguins as a Specially Protected Species would enhance management options.

Background

The emperor penguin (*Aptenodytes forsteri*) is the largest extant penguin species. Measured from the tip of the beak to the end of their tail, adults measure 110 to 120 cm and body mass varies seasonally, ranging from about 23 to 45 kg. Males tend to be slightly larger than females. As with many seabirds, emperor penguins are long-lived; their age of first breeding is usually 5 or 6 years although some birds attempt to breed at age 3 years (Jenouvrier et al., 2005). Emperor penguins have a circumpolar distribution and the vast majority of colonies are located on the land-fast sea ice (Fretwell & Trathan, 2020).

Emperor penguins are the only vertebrates that breed in Antarctica during the winter. Breeding commences in March/April when the adults return to their coastal breeding grounds, and all colonies so far studied have a similar annual schedule (see review by Trathan et al., 2020). Courtship takes about 6 weeks (Ancel et al., 2013), and laying starts in May and continues into June. Females produce only one egg in a season. The eggs are incubated on the feet of the males while the females leave the colonies to forage, and after about 65 days, the eggs hatch. Females start to return in mid-July and take over the care of the egg or the freshly hatched chick. Males go to sea to forage and build up body reserves after a fast that lasts nearly 4 months. Chicks are unable to adequately regulate their own body temperature, and so are dependent upon their parents for warmth for about 50 days. Once the chicks are able to withstand the prevailing environmental conditions, their development and growth requires both parents to hunt and supply food. Chicks fledge in December/January, and the adults that have bred go to sea to build up resources prior to the annual moult that lasts for about one month. Thus, emperor penguins require stable fast ice for at least 9 months to rear their chicks successfully (Jouventin, 1971).

The diet of emperor penguins is diverse, and its composition varies between years, and with colony, season, and foraging location. For example, at the Drescher Inlet (72°52'S, 19°25'W), the summer diet of emperor penguins was dominated by squid species *Allurotheuthis antarcticus*, *Moroteuthopsis longimana* and *Psychroteuthis glacialis* (~93%) followed by fish, krill, amphipods and isopods (Piatowski & Pütz, 1994). Some years later at the same colony, the penguins' summer diet was largely Antarctic krill *Euphausia superba* (~75%); the remaining diet was fish (~17%), as well as some amphipods and small numbers of various squid species (Pütz, 1995). In contrast, emperor penguins at Amanda Bay (69°17'S, 76°46'E) mainly consumed Antarctic silverfish *Pleuragramma antarcticum* (~78%), some squid species and amphipods, but hardly any euphausiids (Gales et al., 1990). Most prey species of emperor penguins are pelagic, but demersal and benthopelagic species are also consumed (Kirkwood & Robertson, 1997; Wienecke & Robertson, 1997). Emperor penguins also forage at the under-surface of the sea ice (e.g. for the bald rockcod *Pagothenia borchgrevinki* (Ponganis et al., 2000)).

Emperor penguins are formidable divers, foraging mostly at depths of 50 to 250 m (Wienecke & Robertson, 1997; Zimmer et al., 2010). Occasionally, emperor penguins dive deeper and can reach depths in excess of 500 m. For example, in Wienecke et al. (2007), of nearly 130,000 dives only 264 (or 0.2%) were deeper than 400 m, and only one of 93 birds dived to > 500 m (Wienecke et al., 2007). Generally, dives last 3 to 6 min, thus remaining within their aerobic dive limit (Kooyman & Kooyman, 1995). However, extremely long dive durations can occur when emperor penguins are diving under fast ice or get trapped under pack ice; dives exceeding 20 and even 30 min are exceedingly rare (Goetz et al., 2018; Wienecke et al., 2007).

Emperor penguins are very well adapted for life in the ice in terms of their behaviour, morphology and physiology (Kooyman et al., 1971; McCafferty et al., 2013). Their highly social, non-territorial character enables them to huddle and share body warmth, an effective strategy to reduce energy expenditure. When resting or incubating, the plantar surfaces of the feet are lifted off the ice and the toes are tucked into the belly feathers. Body fat reserves (up to 30% of the body mass), and a reduction in the basal metabolic rate also limit energy expenditure. Furthermore, their extremities are very small in relation to their round bodies and give a low surface to volume ratio. The feathers are greatly reduced in size, overlap extensively, and are very dense (Williams et al., 2015). The plumage can reach nearly ambient temperatures at the outside but accounts for about 85% of the resistance to heat transfer from the body. Counter-current heat exchange warms the venous blood and cools the arterial blood in the nasal passages, the flippers and legs. All these adaptations keep the core temperature around 38°C (McCafferty et al., 2013).

The most recent global survey of emperor penguins by VHR satellite imagery, revealed that the population comprised ~238,000 breeding pairs, or ~595,000 birds (Fretwell et al., 2012), calculated across 46 colonies. Notably, of those 46 colonies seven were discovered or confirmed by VHR. Since 2009, more apparent breeding locations have been discovered, also by satellite, bringing the total to 61 colonies with probably ~250,000 breeding pairs (Fretwell & Trathan, 2020). Interestingly, emperor penguin colonies are evenly distributed around the Antarctic continent along the fast ice (mean separation distance ~220 km ± 17 km), which suggests interspecific competition for resources (Santora et al., 2020). Although many colonies are predictable in locations (Robertson et al., 2014), VHR image analysis has also indicated that entire colonies can appear or disappear from year to year, suggesting movement among colony locations (see below; LaRue et al., 2015; Jenouvrier et al., 2017), and colonies may relocate on nearby glaciers or ice shelves in years of poor sea ice conditions (Fretwell et al., 2014) or particular wind conditions (Zitterbart et al., 2014). Prior to the emperor penguin “satellite era” of research (e.g., since about 2009), only ~30 colonies of emperor penguins were known to exist (Wienecke, 2010), as research on the status and distribution of the species was largely conducted in relative proximity to research stations, and on colonies accessible by foot or by air. Remote access by VHR has allowed unprecedented views of the coastline and enhanced data collection about the status, distribution, and insights into behaviour that now allows for population monitoring.

Work to improve population estimates is important for refining population trend analyses at the global and regional scales. A key requirement is to improve satellite ground validation (see draft Action Plan). Colonies are known to spread and contract, depending upon prevailing weather conditions (Richter et al., 2018). Thus, work to better characterise population estimates should include campaigns to enhance satellite image acquisition for selected colonies where ground counts are feasible. Movement between colonies appears to occur (LaRue et al., 2015; Cristofari et al., 2016), whilst individual colony population counts within a region are known to rise and fall in differing ways (Kooyman & Ponganis 2017). Improved understanding of linkages is therefore key (see draft Action Plan, Annex A).

In addition to large-scale population estimates using VHR satellite imagery, it is important to support long-term longitudinal monitoring to understand the mechanisms by which climate variability affects population dynamics. At present, individual life histories of emperor penguins are only monitored on an annual basis at Taylor Glacier (since 1988) and Pointe Géologie, the longest continuously observed of all emperor colonies, and monitored since its discovery in 1952. Only a few other long-term time series of colony size exist at other sites, but are critically needed (see draft Action Plan, Annex A) for comparative studies to better understand and project the regional and global population responses to future climate change.

Key findings

For the purposes of considering the emperor penguin as an Antarctic Specially Protected Species, SCAR identifies climate change to be the single most important threat, coupled with projected changing climatic

conditions over the coming century (Ainley et al., 2010; Jenouvrier et al., 2009; 2012; 2014; 2017; 2020; Trathan et al., 2011; 2020; Fretwell & Trathan 2019; 2020). Measurement (and modelling) of fast ice remains challenging at the circumpolar scale (e.g. Massom et al., 2009; Fraser et al 2021) and trends in coastal fast ice may be independent of what might be happening with sea ice extent; for example, altered winds may lead to more extensive large-scale sea ice, but possibly reduced fast ice (Ainley et al., 2010). However, sea ice extent is a convenient correlation, or proxy for other, more-difficult-to-quantify factors that have a bearing on emperor penguins, and in the long-term, sea ice at the large-scale probably determines the ultimate condition of fast ice as a breeding platform. Changes to or loss of fast ice, or early ice break-out can cause massive breeding failure and even adult mortality in emperor penguins (Barbraud & Weimerskirch, 2001; Jenouvrier et al., 2009). Also, unusually extensive fast ice cover in the vicinity of a colony during the rearing period can also lead to reduced breeding success, as breeding adults are forced to cover long distances on fast ice to reach foraging grounds. Increased energetic expenditures of adults decreases chick feeding frequencies and growth, and ultimately increases chick mortality at the colony (Massom et al., 2009; Barbraud et al., 2015) with important consequences for emperor penguin population recovery (Jenouvrier et al., 2009). The importance and medium-term impact of occasional massive perturbations are only now becoming apparent (Kooyman & Ponganis, 2017; Fretwell & Trathan, 2019).

In addition to buffering and protecting fast ice, seasonal sea ice (pack ice) is important in other ways for emperor penguins, as they spend much of their time foraging within the pack ice or in polynyas, both during the breeding season (Kirkwood & Robertson, 1997; Wienecke & Robertson, 1997; Labrousse et al., 2019), and post breeding (Rodary et al., 2000; Kooyman et al., 2004; Goetz et al., 2018). The diet of emperor penguins comprises species that are tied to sea ice habitats (see review by Trathan et al., 2020), at least during important parts of their life cycle. Emperor penguins are subject to locally- and regionally-contrasted sea ice trends due to climate change and variability (Parkinson & Cavalieri, 2012; Meredith et al., 2019). Since the start of regular satellite monitoring in 1979, Antarctic sea ice cover has shown regional variation as well as considerable inter-annual variability (Parkinson, 2019). Given the complexity of the main drivers of Antarctic sea ice, greater understanding about the threats associated with sea ice changes are important, given the reliance of emperor penguins on their specialized breeding habitat and ultimately the species' persistence. Increases in Antarctic sea ice extent were observed during almost three decades until 2016 when the circumpolar Antarctic sea ice extent dramatically decreased (Fig 1a in Meehl et al., 2019). The reduced sea ice extent was maintained through 2017 when it reached its record minimum. Different atmospheric and oceanic factors were responsible for these changes highlighting the complexity of the processes driving emperor penguin habitat. The cooling of the near-surface subpolar waters over 25 years (-0.07 ± 0.04 °C per decade; Auger et al., 2021) is likely associated in part with the melting of the ice sheets. This cooling of subpolar waters is also accompanied by a freshening of the surface waters over the same period, which is one of the drivers for the increase in sea-ice cover until 2016 (e.g. Morrow and Kestenare, 2017). The unusual decrease of sea ice cover in 2016 has been explained by multiple factors such as record sea surface temperature, precipitation, and convective heating anomalies in the eastern tropical Indian and far-western Pacific oceans. Both the warmer ocean temperatures and the direct effects of surface wind forcing on the sea ice produced the rapid and sustained decrease of the Antarctic sea ice extent (Meehl et al., 2019).

Assessment of changes in sea ice as a major threat to emperor penguins is supported by modelled colony population forecasts, which are now available over the entire species range (Jenouvrier et al., 2014; 2020). Consequently, legal recognition of future climate change impacts on the species are now urgent (Trathan et al., 2020), given continued increases in greenhouse gas (GHG) emissions (Friedlingstein et al., 2020; Ganesan et al., 2019; Nisbet et al., 2019). Schwalm et al. (2020a; 2020b) highlight that these are equivalent to CMIP (Coupled Model Intercomparison Project) scenario RCP8.5 (Representative Concentration Pathway 8.5) or to a projected mean global temperature increase of 3.7°C (range 2.6° to 4.8°) by the late-21st century.

Multiple anthropogenic forcing factors (ozone and GHG) and the complicated processes involving the ocean, atmosphere, and adjacent ice sheets, are leading to large uncertainties in projections of Antarctic sea ice (Meredith et al., 2019). Regional trends of Antarctic sea ice during the historical period are not captured by models, especially the decrease in the Bellingshausen Sea and the expansion in the Ross Sea (Hobbs et al., 2016). Moreover, model responses are widely divergent in the Weddell Sea (Hobbs et al., 2016; Ivanova et al., 2016), a region with complex ocean-sea ice interactions that several models were unable to replicate (de Lavergne et al., 2014). Although there is large uncertainty in the magnitude of future sea ice decline, a loss of Antarctic sea ice in the future is almost certain given increasing greenhouse gas concentrations and rising global temperatures. Importantly, the range of Antarctic sea ice conditions relevant for the emperor penguin

simulated by the Community Earth System Model (CESM) and used in the most recent penguin population forecasts, overlaps very well with the range of observations over the historical period. The only exceptions are in a few regions and seasons of the penguin life cycle for which the sensitivity of the population growth rate to sea ice conditions is small (see Figures 1 and 2 in Jenouvrier et al., 2020).

Emperor penguins are vulnerable to different kinds of sea ice perturbation. The most obvious is the early loss (break-out) of the fast ice in spring on which a colony is located. Other perturbations include late formation of sea ice in the autumn, that can delay the onset of breeding or prevent breeding attempts altogether, or trigger the relocation of colonies onto icebergs or ice shelves. Relocations often result in a longer commute to the fast ice edge (often several more kilometres each way) and may have consequences for breeding productivity. It is not yet possible to estimate the frequency of this sort of event, but for some colonies in marginal locations (such as at Ledda Bay), ice failure is a regular event, and based on observations from the satellite record, has happened in multiple years. Approximately 9 out of ~61 colonies are known to ‘blink’ (disappearing some years, reappearing in others) within the 13 years of the satellite record (LaRue et al., unpublished). In addition, when ice shelves calve, very large, tabular icebergs may also disrupt breeding success due to the increased distance to feeding areas resulting from blocked pathways, as seen in the Ross Sea in 2001 leading to mortality of both chicks and adults and low breeding performance for several consecutive years (2001- 2004, Kooyman et al., 2007).

The consequences of ‘blinking’, and of massive perturbation events for emperor penguin colonies are only now being evaluated, but highlight the challenges associated with modelling future population states. Levels of uncertainty remain high, but could be reduced through precautionary action, coupled with an improved understanding of life history parameters (see draft Action Plan). To estimate the frequency of such extreme events, the number of colonies with true absences can be estimated using satellite imagery. It is important to note that such estimates of extreme perturbation may be conservative; massive breeding failures have already occurred (e.g. in 2013 at Pointe Géologie, Barbraud et al., 2015; Cape Crozier in 2018, Schmidt and Ballard, 2020), but some have only been detected from satellite imagery. Consequently, a true absence of a colony likely reflects a major perturbation. Based on the number of true absences over the last 10 years for all colonies, researchers estimated a frequency of 3.6% (LaRue et al., unpublished).

Whilst aspects of the natural history of emperor penguins remain data deficient, particularly at sea, further work to explore life history characteristics and geographic distribution will be important. Focused work on their spatial overlap with human activities (see draft Action Plan) may reveal additional threats as more knowledge is accumulated. However, based on existing data, emperor penguin populations are thought to experience little direct interaction with human activities, apart from those associated with research, tourism and their sea ice obligate life history. Activities associated with tourism and scientific research are regulated through national permitting authorities, as is the collection of eggs or adults for zoos which is generally rare (Trathan et al., 2020). Other important threats at local scales are also regulated and require international oversight through comprehensive environmental evaluations under the Antarctic Treaty System (ATS) to ensure that wildlife breeding sites remain unaffected by developments of future infrastructure, such as new aircraft runways. Threats at sea, such as fisheries by-catch (e.g. Crawford et al., 2017) and fisheries resource competition, are currently virtually non-existent as the regional commercial fishery for Antarctic krill (*Euphausia superba*) is highly localised and operates far from emperor breeding sites. Currently, there is no commercial harvest of Antarctic silverfish (*Pleuragramma antarctica*; e.g. Trathan et al., 2020). However, increasing global demands for marine resources are likely to lead to the expansion of commercial fisheries in the Southern Ocean (e.g. Liu & Brooks, 2018). Changes in extent and duration of sea ice are likely to enable fisheries to move farther south than in the past, and hence, operate closer to emperor penguin colonies.

Threats to non-breeding animals are poorly understood at the moment, but as juveniles and non-breeding birds often range far from the continent (Kooyman et al., 1996; Barber-Meyer et al., 2008; Wienecke et al., 2010; Thiebot et al., 2013; Goetz et al., 2018; Labrousse et al., 2019), birds could be subjected to yet undocumented threats. As emperor penguins are not dietary specialists, possible threats to be explored in greater detail include their susceptibility to plastics and other pollutants, pathogens that may jump species in a warming ocean, interactions with fisheries particularly if preferred fishing locations also change with climate change, and changes in prey distribution/availability associated with changes in ocean properties and structures.

In recognition of these threats, the emperor penguin has been listed by the IUCN as Near Threatened under Red List criterion A3, sub-criterion c^[1], however, the species is projected to undergo a rapid population decrease as Antarctic sea ice begins to change (thinning, reducing in extent, etc.) within the next few decades. Under current levels of CO₂ emission (business-as-usual GHG emissions), 80% of colonies are projected to be quasi-extinct by 2100, whilst the total abundance of emperor penguins is projected to decline by at least 81% relative to its current size (Jenouvrier et al., 2020), although major changes in sea ice prevalence are projected to begin only in mid-century (e.g. Bronselaer et al., 2018). Including extreme perturbations in models increases the rate of population decline, such that up to 100% of colonies are projected to be quasi-extinct by 2100, and the total abundance of emperor penguins is projected to decline by at least 99% relative to its current size (Jenouvrier et al., 2021). The extent to which climate change is controlled by international efforts will determine whether a smaller proportion of the existing population is lost (Jenouvrier et al., 2020). Despite uncertainties over future climate change, in the best-case (so far unlikely) lowest emissions scenario, the population is likely to decrease by 31% (37% when including extreme events) by the end of this century as a result of existing and ongoing change.

Within the next three generations (generation length ~16 years; Jenouvrier et al., 2014), the population is estimated to decline by ~27 to 89% under current emission scenarios by 2070, depending upon the demographic and climate scenario. For RCP8.5: between 58% (no extreme events) to 89% (extreme events related to sea ice that affects reproduction and survival) decrease in population are projected by 2070 (Jenouvrier et al., 2021). Thus, under Red List criteria, emperor penguins are now close to being classified as Vulnerable but given that uncertainties remain about future GHG emission scenarios, and because the assessment also depends upon a degree of model verification against population trend, the species remains listed as Near Threatened. Nevertheless, the rapid rate of population decrease, particularly from mid-century onwards, means the species will quickly become Vulnerable, or even Endangered, if important threats (loss of sea ice habitat, alteration in food availability, major changes to the currents in the Southern Ocean, extreme storm events) continue unabated. Model projections by Jenouvrier et al. (2020; 2021) integrated important uncertainties (in a way that is rarely achieved in ecology); their results are probabilistic. In choosing a period for climate-scenario or population-response projections, it is important not to confuse the uncertainty in rate or magnitude of change with uncertainty in directionality (McClure et al., 2013). Although the precision of estimates of global temperature increase is low, an increase in mean global temperature increase is virtually certain. Similarly, although there is large uncertainty in the magnitude of future sea ice decline, a loss of Antarctic sea ice in the future is almost certain given increasing GHG concentrations and rising global temperatures. Therefore, when the direction of change is clear, projections of species status under climate change should not be discounted solely because the magnitude of projected change at a particular time is highly variable.

¹ IUCN (2019) Red List criteria are used to evaluate whether a species belongs in a threatened category (Critically Endangered, Endangered or Vulnerable). For emperor penguins, criterion A3 is used (A3: population size reduction measured over 3 generations, either projected, inferred or suspected to be met, up to a maximum of 100 years into the future. Sub-criterion c is then relevant (c: population reduction based upon a decline in the area of occupancy, extent of occurrence and/or habitat quality). The cut point between Vulnerable and Near Threatened is 30% population reduction over 3 generations.

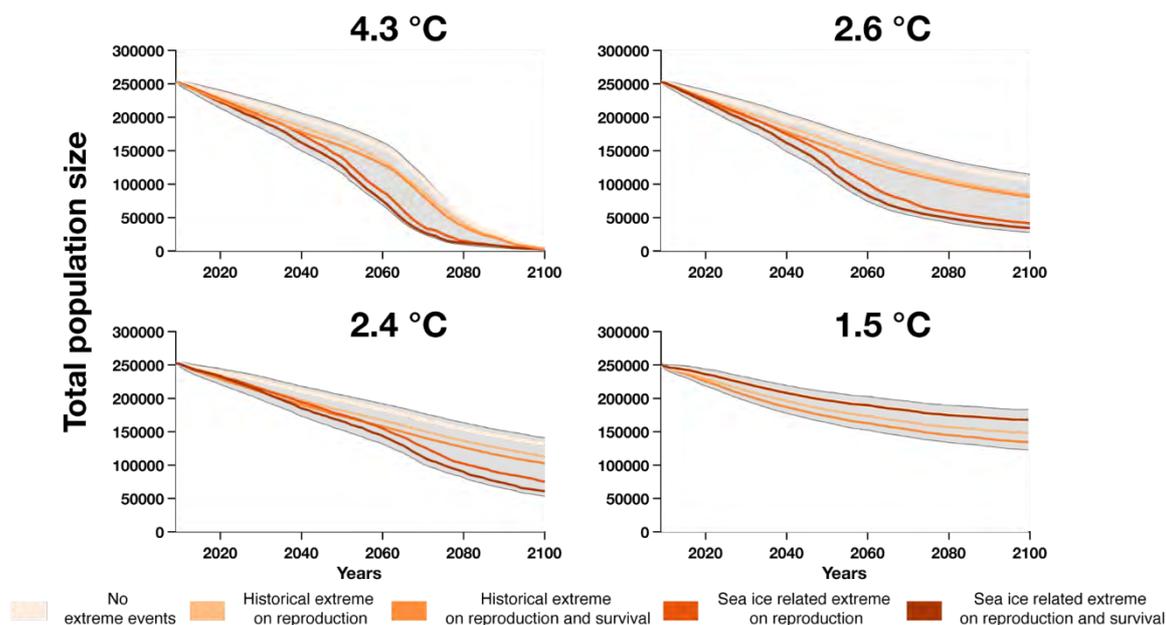


Figure 1. The total number of breeding pairs of emperor penguins between 2009 and 2100 projected for various climate scenarios (panels) for various demographic scenarios of extreme events (coloured lines). These global population sizes are calculated using sea ice concentration anomaly projections from the Community Climate System Model using RCP8.5, an optimistic scenario that meets the emissions pledges and targets pathway that includes governments' Nationally Determined Contributions, Paris Agreement's 2°C goal. The thick lines are the median combining population trajectories from demographic scenarios and the coloured areas are the 90% envelopes from stochastic simulations of all population trajectories under a given climate scenario. The four demographic extreme events scenarios are (1) Extreme events with the historical observed frequency that will produce a massive breeding failure at a colony a given year; (2) Extreme events with the historical observed frequency that will reduce adult survival by 10% and produce a massive breeding failure at a colony a given year; (3) Extreme events that will increase in frequency in the future proportionally to the loss of sea ice and produce a massive breeding failure at a colony a given year; (4) Extreme events that will increase in frequency in the future proportionally to the loss of sea ice and will reduce adult survival by 10% and produce a massive breeding failure at a colony in a given year.

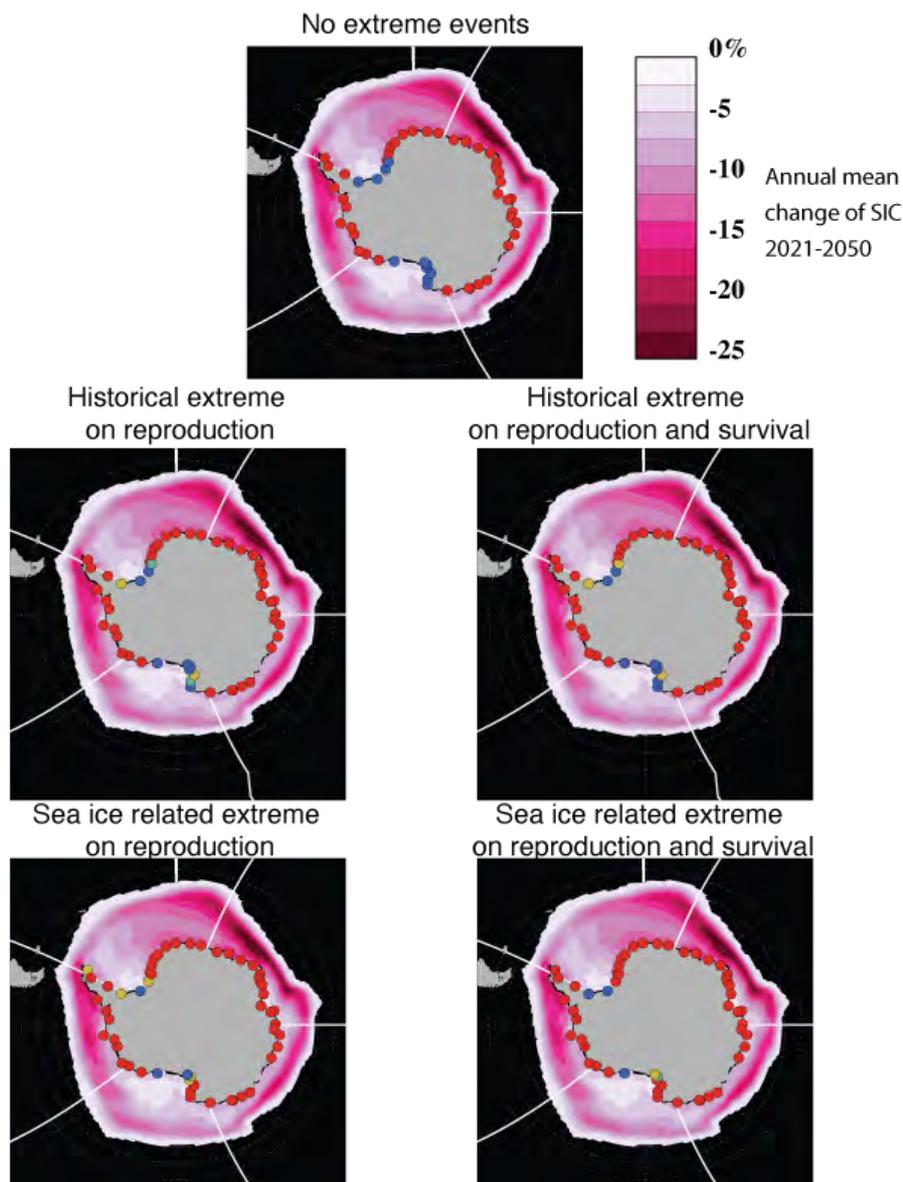


Figure 2. Conservation status of emperor penguin colonies by (a) 2080 and (b) 2100 and annual mean change of sea ice concentrations (SIC) between the 20th and 21st centuries. Panels show each climate scenario with all demographic scenarios combined. SIC projections were obtained from the Community Earth System Model using RCP8.5, the special scenario, RCP4.5 (only for 2080), Paris Agreement's 2°C goal, and Paris Agreement's 1.5°C. Dots show the location of colonies (see Figure S1; Table S1 of Jenouvrier et al. 2020). Dot colours show the conservation status. Following Jenouvrier et al. (2014, 2020), 'vulnerable' (green) is a likely population decline by more than 30%; 'endangered' (yellow) is a likely population decline by more than 50%; 'quasi-extinct' (red) is a likely population decline by more than 90%. Blue colour refers to populations that are not likely to decline by more than 30%. A likely outcome is defined by IPCC as a probability >66%. AS, Amundsen Sea; BS, Bellingshausen Sea; IO, Indian Ocean; RS, Ross Sea; WPO, Western Pacific Ocean; WS, Weddell Sea.

Conclusions

Based on the evidence from the scientific literature, SCAR recommends that precautionary action is warranted because sea ice projections, which depend upon the climate scenario of projected socioeconomic global changes up to 2100, suggest that even if we stopped emitting all GHG today, global warming and climate change will continue to affect sea ice for decades to come. Taking a longer perspective is therefore important for considering climate change threats. According to Ridley & Hewitt (2014), it takes sea ice longer to recover if CO₂ levels decline, and the reversibility of sea ice loss is less and slower in Antarctica than in the Arctic. Specifically, they showed that sea ice minimum extent lags peak CO₂ by ~20 years followed by a 30 year pause in sea ice decline, while atmospheric concentrations of CO₂ are returned to preindustrial levels. In addition, the loss of the Antarctic sea ice area is irreversible with a substantial loss of sea ice, which would not recover after a further 150 years at preindustrial CO₂.

Since emperor penguins are a long-lived species with a generation time of ~16 years, it is especially important to use long assessment periods, as this and other life history traits buffer climate variability. Even as sea ice conditions deteriorate and reduce breeding success, adult penguins are likely to continue to survive, unless adults suffer mortality in extreme events. However, at some point the lack of recruitment will potentially lead to a rapid decrease of the population. For species with delayed reproductive maturity, population growth will reflect conditions further in the past than short-lived species that mature rapidly, and present population growth can mask current deteriorating conditions for reproduction or recruitment (McClure et al., 2013). Protection of all genetically distinct meta-populations might be important for future resilience to environmental change; certainly, protection of the climate change refugial meta-populations is likely to be vital (Younger et al., 2015; 2017; Cristofari et al., 2016).

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Annex A: Development of a draft Species Action Plan for the Emperor Penguin

Unambiguously, the largest threat to emperor penguins is the loss of Antarctic sea ice as result of global climate change. Mitigation of this threat will require coordinated and unified global action that is beyond the remit of this draft Action Plan. Nonetheless, there are several actions that can be taken to offset and reduce the effects of climate change. This draft Plan aims to manage all direct and indirect potentially harmful human interactions with free-living emperor penguins to reduce threats at every stage of their life cycle, and thereby ensure their continued existence in the wild until such time that risks posed by climate change are mitigated.

Specific Objectives

- Establish within SCAR's EG-BAMM an Emperor Penguin Working Group focused on the delivery of this draft Action Plan through liaison with all interested and affected parties, facilitating the provision of regular synthetic updates on the status of emperor penguins.
- Engage across the international science community to develop best practice guidelines for specific scientific procedures relevant to emperor penguins (e.g., Code of Conduct on using Antarctic Animals for Scientific Research, adopted by CEP in 2019). It is critical that all research is conducted ethically and we aim to seek collaborative opportunities to science facilities close to emperor penguin colonies, to increase awareness about the risks and threats to the species and to promote such ethical guidelines. Engage with Treaty Parties and their national Competent Authorities and with the Council of Managers of National Antarctic Programs to provide advice and recommendations and where appropriate facilitate distribution of new guidelines, including translations thereof to the predominant language used at a given facility.
- The Working Group will also convey the outcomes of relevant scientific assessments, with advice and recommendations to facilitate development of management actions to the ATCPs on a regular basis, or as any substantial changes might suggest, via Working Papers submitted either via the CEP or directly by SCAR in keeping with Article 10.2 of the Protocol on Environmental Protection to the Antarctic Treaty.
- As part of the five-yearly update of this draft Action Plan, provide information, advice and recommendations on the effectiveness of the management actions for emperor penguins and provide suggestions or recommendations for changes to management actions if these are required. Doing so should involve best practice decision-science and engage all stakeholders for maximum efficacy, and should be preceded in the year prior to the update by an online forum or meeting to assess the effectiveness of actions.
- Continue and expand demographic studies to improve documentation of the functional relationships between demographic parameters across different life history stages and environmental fluctuations.
- Build on analyses by Ainley et al. (2010), Jenouvrier et al. (2014; 2017; 2019, 2021) and Abadi et al. (2017) to develop new analyses of how emperor penguins are projected to respond to climate change using CMIP5 data, and when sufficiently mature, CMIP6 data. Consider the full circumpolar extent of emperor penguins with a special focus on inter-annual variation in breeding propensity (i.e. frequency of occurrence of breeding at colony sites) across different parts of the species range. Highlight the need for regional climate models that provide robust ecological projection capability at scales relevant to the ecology of emperor penguins. Develop modelling capacity to provide projections beyond the next 100 years.
- Undertake population assessment studies to monitor emperor penguins at the colony scale, the regional scale and the circumpolar scale. Liaise with and coordinate with interested parties to initiate ground counts and aerial counts to ground-truth and improve satellite remote-sensing population estimates. Evaluate population assessments based on satellite remote-sensing, with particular emphasis on short-term colony movement (see e.g. Richter et al., 2018), repeated observation within the same breeding season, and improved image analysis techniques.
- Collate all available tracking data to undertake a gap analysis. Then, if deemed necessary, undertake new telemetry studies to better document the preferred habitats of emperor penguins at different times of the year and across different life history stages.

- Better understanding of the energetic, physiological constraints and behavioural capacity of emperor penguins to adapt to new breeding conditions and altered food web interactions, including altered prey availability and changed predation risks.
- Identify and collate information on other potential threats to emperor penguins, especially those associated with human activities, such as fishing, plastic pollution, other pollutants, habitat degradation of the oceans, pathogens, etc. Quantify all such threats, both spatially and temporally, to determine where and how management actions can mitigate the impacts of these threats and improve the survival of emperor penguin breeding populations.
- Continue liaison with the Antarctic community, including Treaty Parties, their national competent authorities and International Association of Antarctica Tour Operators (IAATO) as required, to provide expert advice on responsible visitor management at emperor penguin colonies. Promote exchange of information across the Antarctic community to raise awareness about responsible visitation, conservation and reducing and offsetting global emissions. Identify collaborative opportunities to communicate this information and Antarctic Treaty System efforts to the wider public. Assess feasibility for research and monitoring using 'ships of opportunity' and other operators.
- Liaise with relevant Associations of Zoos and Aquaria about living collections and breeding programmes, including the identification of wild-caught specimens of emperor penguins. Link with such bodies to increase public awareness and need for conservation.
- Assess and revise this draft Action Plan every five years.