*Antarctic Science 36(1), 3–5 (2024)* 
doi:10.1017/S0954102024000130

# Short Note

# A 6 year assessment of low sea-ice impacts on emperor penguins

**PETER T. FRETWELL**

*British Antarctic Survey, Cambridge, UK*
*ptf@bas.ac.uk*

Received 16 January 2024, accepted 7 February 2024

## Introduction

Sea ice, and particularly land-fast sea ice, is crucial for emperor penguins as a breeding and moulting platform and foraging habitat (Barbraud & Weimerskirch 2001). Emperor penguins use land-fast sea ice as a breeding platform to raise their chicks, from egg hatching in late July to mid-August until fledging, typically between mid-December and early January.

Current population models, linked to Intergovernmental Panel on Climate Change (IPCC) climate change predictions, based upon the relationship between emperor penguins and sea-ice concentration suggest that the emperor penguin population will decline dramatically across Antarctica by the end of this century (Jenouvrier *et al.* 2020). In a scenario in which greenhouse gas emissions continue to rise at current levels, predictions suggest that the population of the species will fall by 99% by 2100 (Jenouvrier *et al.* 2021). Over the last 7 years, spring and summer sea-ice extent and concentration in all seasons around Antarctica have fallen significantly, with four of the lowest sea-ice extent minima recorded since 2016. Both 2022 and 2023 have had record low summer sea-ice extents (Purich & Doddridge 2023). These years were the first in the satellite record (1979–2023) during which the area of Antarctic sea ice dropped below 2 million km$^2$. In 2022, the then-record low sea-ice extent in the Antarctic spring led to the first recorded regional breeding failure in emperor penguins (Fretwell *et al*. 2023). In 2023, sea-ice extent levels throughout the year were tracking substantially lower than in any previous year; the only exception was in November, when the sea-ice extent briefly rose above the respective previous low in 2016, before dropping back to a record low in early December (https://nsidc.org/data/seaice_index). Recording these events provides important evidence for future assessment of the conservation of this species.

The aim of this study was to briefly assess whether these low sea-ice years had had an immediate adverse effect on emperor penguins and to update the known locations of colonies. A 6 year assessment of the impact of low sea ice and early fast-ice break-up on emperor penguin colonies around Antarctica is presented.

## Methodology

The Copernicus Programme's Sentinel-2 satellite is free to access and download; it has a high temporal resolution (typically more than once per week around the Antarctic coastline) and an archive stretching back 6 years to 2018 (https://dataspace.copernicus.eu/browser/). The spatial resolution is 10 m ground sample distance for the visible and near infrared bands, and, at this resolution, emperor penguin colonies can be located by the brown staining on the ice as a result of their guano, which is a unique identifier in this environment (Fretwell & Trathan 2021). This combination of reasonably high spatial and temporal resolutions enables the identification of colonies and timing of fast-ice break-up events at those sites that affect emperor penguin breeding success. We assume that if sea ice breaks up totally before fledging, leaving a clear sea without the presence of large, stable icefloes or substantial pack ice, this will result in total or almost total breeding failure (Schmitt & Ballard 2020, Fretwell *et al.* 2023). Often if large, stable floes exists chicks can successfully survive, although it has been suggested that if these floes become mobile and move considerable distances from the colony location, adults will not be able to find their chicks (Schmitt & Ballard 2020). If ice breaks up during the fledging period, then this is likely to have an impact on fledging success, but the severity of that impact cannot be assessed purely by satellite imagery. Therefore, we define three classes of break-up: break-up before fledging, break-up during fledging and break-up after fledging. The exact dates of fledging at each colony are not precisely known, as limited assessments have only been published for two colony locations (Pointe Géologie and Cape Crozier), so here we assume a conservative date for the

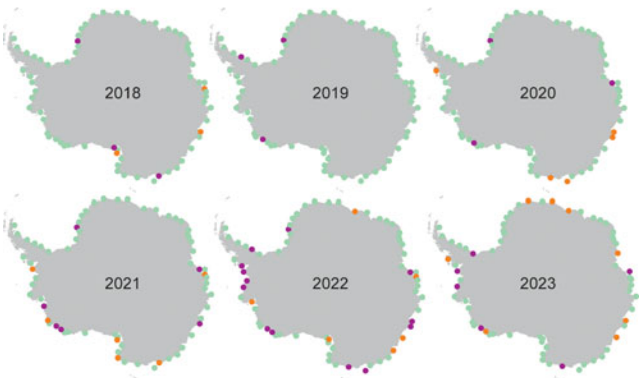


**Figure 1.** Maps showing the locations of colonies affected by early fast-ice loss over the period of Sentinel-2 image acquisition (2018–2023). Purple dots show sites where the ice broke up before 5 December; orange dots show sites where the ice broke up between 5 December and 1 January; and light green dots show sites that were not affected.

beginning of fledging of 5 December, well before the published mean fledging date of 23 December recorded in the Ross Sea (Schmitt & Ballard 2020), and an end date of fledging of *c.* 31 December. Scientific and tourist visits to Cape Washington, Snow Hill Island, Rothschild Island, Jason Peninsula and Atka Bay observe fledging occurring in mid- to late December but often ending in early January (G. Kooyman, P.T. Fretwell, A. Boutet and S. Graupner, personal communication and observation 2023). Occasional fledging may occur outside of these dates, with some instance at Pointe Géologie being recorded as early as late November or as late as mid-January (C. Barbraud, personal communication 2023), but from the limited data collected these instances are rare.

To assess sea-ice extent, we used National Snow and Ice Data Center (NSIDC) Antarctic sea-ice extent data, which considers sea-ice extent to be represented by areas of > 15% ice concentration (https://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/).

## Results

Satellite data show that over the 6 year period there was an increasing trend of colonies affected by early ice loss from 2018 until 2022 (Fig. 1). The year 2022 demonstrated by far the largest loss, with 19 colonies affected by early sea-ice loss before the end of December and 13 colonies lost before 5 December. In 2023, fewer sites were impacted, breaking the trend of increasing loss, with 14 colonies affected in total and 6 sites lost totally before fledging. However, 2023 still represented the second worst year in the record. Between 2018 and 2020, an average of 5.66 colonies per year experienced early ice loss, with 2.66 colonies per year experiencing full ice loss before the fledging period. Between 2021 and 2023, this rose to 15 colonies per year affected by the end of December and 8.33 colonies per year experiencing ice loss before 5 December. These data indicate a marked increase in the numbers of colonies affected over the 6 year period.

## Discussion

The link between sea-ice extent and early fast-ice break-up has been made previously (Barbraud & Wimerskirch 2001, Fretwell *et al.* 2023). The 2 years with the lowest spring sea-ice extents (2022 and 2023) had the two highest numbers of colonies impacted by early sea-ice break-up events leading to presumed breeding failure. But although 2023 had a lower sea-ice extent than 2022 in all months of the breeding season except December, the number of sea-ice break-up events was not a high as in 2022, and therefore the detrimental impact on emperor penguin breeding success was less than predicted. It may be that other factors besides total sea-ice extent are important, and this probably points to the impact of more regional patterns such as the anomalously low sea ice in the Bellingshausen Sea in 2022. This particular event might have been caused by the persistence of a strong La Niña between 2020 and 2022; the first recorded triple-year La Niña (Turner *et al.* 2022). These events are known to reduce sea ice in the Bellingshausen Sea and western Antarctic Peninsula, and the season-on-season weakening of fast ice for three successive years may have led to the extremely early loss of emperor penguin breeding platforms in the 2022 season. Although 2023 had a persistently lower sea-ice extent through the winter and spring, the geographical pattern of the sea-ice anomaly was very different, with the change in El Niño-Southern Oscillation (ENSO) switching to a positive sea-ice extent anomaly in the Bellingshausen Sea and western Antarctic Peninsula region but a negative sea-ice extent anomaly around East Antarctica. However, that anomaly in East Antarctica in 2023 was more dispersed than the concentrated anomaly of 2022 in the Bellingshausen Sea, and the single season of poor sea-ice extent might not have been as detrimental as three successive years of poor sea-ice extent in a geographically concentrated area.

## Conclusion

Over the 6 year record of Sentinel-2 analysis, we have seen an increasing number of emperor penguin colonies affected by early fast-ice loss, culminating in 19 out of 66 colonies (29%) being impacted in 2022. In 2023, this number decreased to 14 colonies (21.2%), which, although lower, was still the second worst year in this short record. This decrease was unexpected as the sea-ice extent in spring 2023 was at an all-time low, but this did not influence the breeding success as much as anticipated. The link between sea ice-related breeding failure and overall Antarctic sea-ice extent should be considered to be indicative rather than a direct relationship, with regional and local effects and climatological considerations such as ENSO strength and persistence also being important.

### Data availability

Data on colony locations and changes are available from: Fretwell, P. 2024. Emperor penguin colony locations derived from satellite remote sensing across Antarctica, 2023 (Version 1.0) [dataset]. NERC EDS UK Polar Data Centre. Retrieved from https://doi.org/10.5285/fb0547e4-d2c1-4580-8c98-182f1da7d9ae.

### Acknowledgements

I would like to thank Dr Norman Ratcliffe for his reading and suggestions on the manuscript. I would also like to thank the reviewers and editor for their timely review and processing of the paper.

### Financial support

This work is partially funded by WWF/BAS grant NEB2181 and NERC core funding to the British Antarctic Survey.

### Competing interests

The author declares none.

### Author contributions

All work on this project, including conception, data collection, satellite image analysis, writing and revision, was conducted by Peter T. Fretwell.

### References

Barbraud, C. & Weimerskirch, H. 2001. Emperor penguins and climate change. *Nature*, **411**, 183–186.

Fretwell, P.T. & Trathan, P.N. 2021., Discovery of new colonies by Sentinel2 reveals good and bad news for emperor penguins. *Remote Sensing in Ecology and Conservation*, **7**, 139–153.

Fretwell, P.T., Boutet, A. & Ratcliffe, N. 2023. Record low Antarctic sea ice led to catastrophic breeding failure of emperor penguins. *Communications Earth & Environment*, **4**, 10.1038/s43247-023-00927-x.

Jenouvrier, S., Che-Castaldo, J., Wolf, S., Holland, M., Labrousse, S., LaRue, M., *et al*. 2021. The call of the emperor penguin: legal responses to species threatened by climate change. *Global Change Biology*, **27**, 10.1111/gcb.15806.

Jenouvrier, S., Holland, M., Iles, D., Labrousse, S., Landrum, L., Garnier, J., *et al*. 2020. The Paris Agreement objectives will likely halt future declines of emperor penguins. *Global Change Biology*, **26**, 10.1111/gcb.14864.

Purich, A. & Doddridge, E.W. 2023. Record low Antarctic sea ice coverage indicates a new sea ice state. *Communications Earth & Environment*, **4**, 10.1038/s43247-023-00961-9.

Schmidt, A. & Ballard, G. 2020. Significant chick loss after early fast ice breakup at a high-latitude emperor penguin colony. *Antarctic Science*, **32**, 10.1017/S0954102020000048.

Turner, J., Holmes, C., Caton Harrison, T., Phillips, T., Jena, B., Reeves-Francois, T., *et al*. 2022. Record low Antarctic sea ice cover in February 2022. *Geophysical Research Letters*, **49**, 10.1029/2022GL098904.