Antarctic Science 36(4), 277–279 (2024) doi:10.1017/S0954102023000329

Four unreported emperor penguin colonies discovered by satellite

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Predictions of the future emperor penguins population, linked to anthropogenic climate change, are stark. Current models suggest that if CO_2 emissions continue to rise at present rates, almost all colonies will be quasi-extinct by the end of the century (Jenouvrier *et al.* 2021). The monitoring of populations is crucial to tracking these changes and, if possible, implementing conservation measures. Recent work using satellite imagery to discover, track and monitor emperor penguin populations has proved to be a key technology in understanding the locations, numbers and trends of the species (Barbraud & Weimerskirch 2001, Trathan *et al.* 2020, Jenouvrier *et al.* 2021). It also enables the discovery of unrecorded breeding sites (Fretwell *et al.* 2009), although there are inherent difficulties in determining what constitutes a new or undiscovered breeding colony (see Supplemental Material S1). In 2019, eight previously unreported emperor penguin breeding sites were found using the European Space Agency's Sentinel-2 satellite, a medium-resolution satellite with a spatial resolution of 10 m per pixel (Fretwell & Trathan 2021), bringing the number of known extant breeding locations to 61. Here, I report on the discovery of a further four breeding sites using Sentinel-2 and Maxar WorldView-2 imagery.

The first of the four sites is on the northern side of the Lazarev Ice Shelf (latitude -69.38, longitude 14.64), on the Dronning Maud Land coast, which I tentatively name 'Lazarev North'. There is already one colony associated with this ice shelf. That site, which is located 64 km south-east of the newly reported site (latitude -69.75, longitude 15.55), was first recorded by Lendev in 1959 (Wienecke 2010), and although it has been noted several times in the satellite record, the colony has not been seen at this original site since 2014. Hence, the colony was recorded as extinct in 2019 (Fretwell & Trathan 2021). It seems highly probable that the newly reported site is a movement of the old Lazarev colony, possibly due to the extension of the ice tongue or a change in sea-ice conditions. It was first seen at the new location in 2018, and although it is not visible in all images, it is visible in at least one image in 2019, 2020, 2021 and 2022. The newly reported Lazarev North colony is small, and although no very-high-resolution (VHR) imagery yet exists that would be suitable for estimating its population size, it seems unlikely to be as large as the 4500 pairs estimated for the original site (Fretwell *et al.* 2012).

The second unreported site is at Verleger Point on the coast of Marie Byrd Land in West Antarctica (latitude -74.71, longitude -136.07). This is a small colony, and an estimate from Maxar WorldView-3 imagery (image ID 104001006FA1DA00, 18 October 2021, spatial resolution 0.31 m) suggests ~500 pairs by manually counting of individual dots on the image. The accuracy of this method of counting needs further calibration (currently in progress), so this estimate should be regarded as provisional and dependent upon further results. The colony is visible in all years of the Antarctic Sentinel-2 imagery archive from 2018 to 2022. The site is 50–60 km east of the abandoned Russian research station of Russkaya (latitude -74.75, longitude -136.66), which was operational between 1980 and 1990. However, no records of emperor penguin sightings from the research station have been published.

The third newly reported site is north of the eastern side of the West Ice Shelf (latitude -66.08, longitude 86.53). The site is located 30–40 km north of the ice edge amongst large icebergs that typically ground in shallow waters and aid in the formation of stable fast ice. The colony is visible in all years of the Sentinel-2 record (2018–2022). The site was probably missed in previous surveys due to its distance from the coastline. Estimates from VHR satellite imagery suggest ~5000 pairs in late November 2022. Similarly to the estimate for Verleger Point, this estimate was derived by counting individual dots on the imagery, and similar caveats on the accuracy of the count should apply until future calibration of the method (see Fig. S3 for an example of the image).

The nearest colonies to this newly reported site are those located at the Karelin Bay colony ~65 km to the west and the Burton Glacier Ice Shelf ~180 km to the east (Fig. S2). Satellite imagery shows that all three of these colonies existed at the same time. It has been noted that a recorded sighting of emperor penguins at Gaussberg by Korotkevich in 1958 (Wienecke 2010) could be related to this site, but as Gaussberg is much closer to the Burton Glacier Ice Shelf site (60 km rather than 150 km), it seems reasonable that this is indeed a newly reported site. Naming this site is difficult, as no officially named features

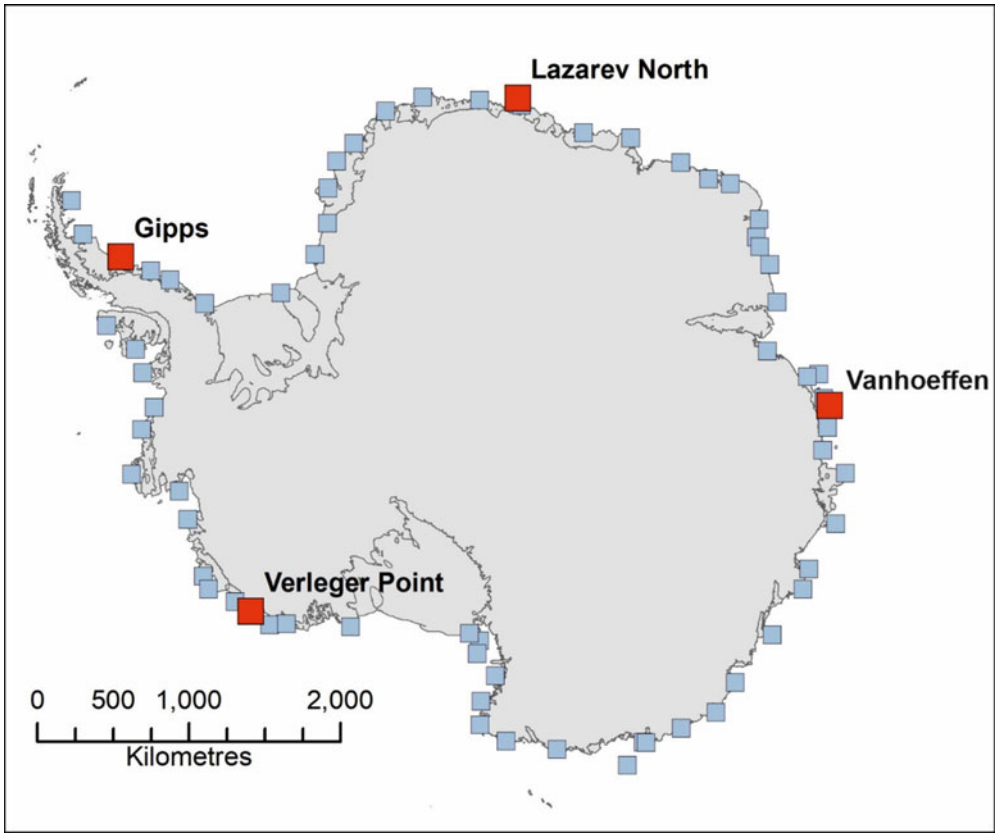

Figure 1. Newly reported emperor penguin colonies, shown in red boxes. Light blue boxes denote other known extant colony sites.

exist nearby, and the extensive West Ice Shelf already has a colony named after it 220 km to the west. After consultation with scientists from the Australian Antarctic Division, I propose the name 'Vanhoeffen Colony' after Ernst Vanhoeffen, the biologist on board the First German South Polar Expedition led by Dagobert Erich von Drygalski on the ship *Gauss*. Many other placenames in the area are also named for members of this expedition.

The fourth site is on the northern side of the Gipps Ice Rise, a feature that bounds the southern edge of the Larsen C Ice Shelf (latitude -68.68, longitude -60.86). This colony is located in a gap in the continental

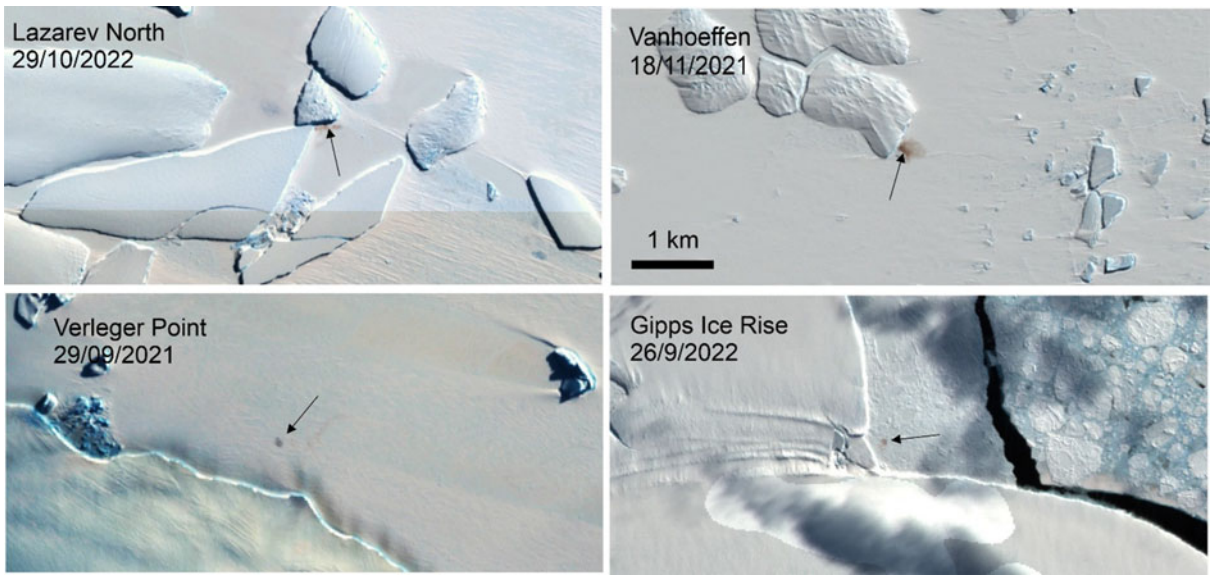

Figure 2. Sentinel-2 images of the four new sites taken at consistent scale. Arrows show locations of emperor penguin colonies.

https://doi.org/10.1017/S0954102023000329 Published online by Cambridge University Press

distribution of the species between Jason Peninsula and Dolleman Island (Ancel *et al.* 2017). The area has been searched for colonies several times before (Fretwell & Trathan 2021), but the colony that has been found is extremely small, being only just visible in the Sentinel-2 record, and, until recently, it was located against ice cliffs or in a small ice creek north of the ice rise. The calving of a large berg in 2021 changed the ice-shelf topography, destroying the ice creek and forcing the colony out onto the open fast ice. This has helped with the discovery of this breeding site. The site is often cloudy, and few recent VHR images exist in the archive, but a count using Maxar WorldView-2 imagery from October 2016 suggests ~200 pairs.

One other colony, Umbeashi, which was marked as no longer extant in the 2019 survey, reformed in 2021 and 2022 and should be classed as extant. The four newly found colony sites and Umbeashi bring the total number of extant sites to 66 (Fig. 1), and they fill several distribution gaps mentioned in previous works (Ancel *et al.* 2017). They increase the global population estimate by up to 5700 pairs. However, as the newly reported Lazarev site is much smaller than the estimate from the previous site (4500 pairs; see Fig. 2), the overall contribution to the global population is probably minimal. It is difficult to assess whether any more colony locations will be found. Few if any of the significant gaps noted in the distribution now remain. But as the resolution of satellites becomes greater, it may be that some very small, unreported breeding aggregations may still be found that have been missed by coarser imagery.

Acknowledgements

I would like to thank the reviewers for their constructive and helpful reviews.

Financial support

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

Competing interests

The author declares none.

Author contributions

All work on this manuscript was envisioned and completed by Peter Fretwell.

Supplemental material

Five supplemental figures will be found at https://doi.org/10.1017/S0954102023000329.

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