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Extreme snowstorms lead to large-scale seabird breeding failures in Antarctica

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Climate change increases the frequency and intensity of extreme weather events that negatively impact wildlife, from individuals to whole ecosystems[1]. In polar environments, such events include heat waves[2], anomalous sea ice concentrations[3] and storms[4]. Polar seabirds are adapted to withstand harsh conditions, and although extreme weather events affect their breeding success and other demographic rates, they are thought to affect only a part of the population. Complete breeding failure of an entire population due to extreme environmental conditions is rarely observed[5]. Here we report how exceptional storm activity in Dronning Maud Land (DML), Antarctica, in the austral summer of 2021/2022 caused almost complete and large-scale breeding failures of the area's three most common seabird species — Antarctic petrel (*Thalassoica antarctica*), Snow petrel (*Pagodroma nivea*) and South polar skua (*Stercorarius maccormicki*).

Svarthamaren (71° 54'S, 5° 10' E) and Jutulsessen (72° 3'S, 2°40'E) are two of the world's largest Antarctic petrel colonies situated 90 km apart in DML[6]. During the 2021/2022 breeding season, extreme storm activity (Figure S1) led to an almost complete absence of breeding Antarctic petrels, snow petrels and south polar skuas (Figure 1). At Svarthamaren, only three Antarctic petrel and no polar skua nests were active in January. This strongly contrasts with other years, during which 20,000 to 200,000 nests of Antarctic petrels (1985–2020 time period) and 38–68 nests of polar skuas (nest numbers in the core study area in the 2011–2020 time period) were active[7,8] (Figure 1). At Jutulsessen, no active nests of Antarctic petrels were detected in January 2022 (Figure 1), whereas the colony held 41,000 and 57,000 breeding pairs in 1989/90[6] and 2017/2018, respectively (Descamps, unpublished). Similarly, no skua nests were active at Jutulsessen in 2021/2022, whereas >10 were active in previous years (2016 and 2018). At Svarthamaren, the mean occupancy of monitored snow petrel nests (n = 85) was 57% (range 37–65%) in 2011–2020, but in 2021/2022 it was only 4% (n = 113). Similarly, occupancy of monitored nests in late January close to Jutulsessen was 33% (range 14–53%; n = 70 to 80 nests depending on the year) between 2008 and 2021, but only 3% (n = 80) in 2021/2022 (Figure 1). Together, these results indicate that nest occupancy in 2021/2022 was virtually nil by mid-January and far below the range observed over the past few decades for all three species. Seabird breeding activity was also much reduced in central

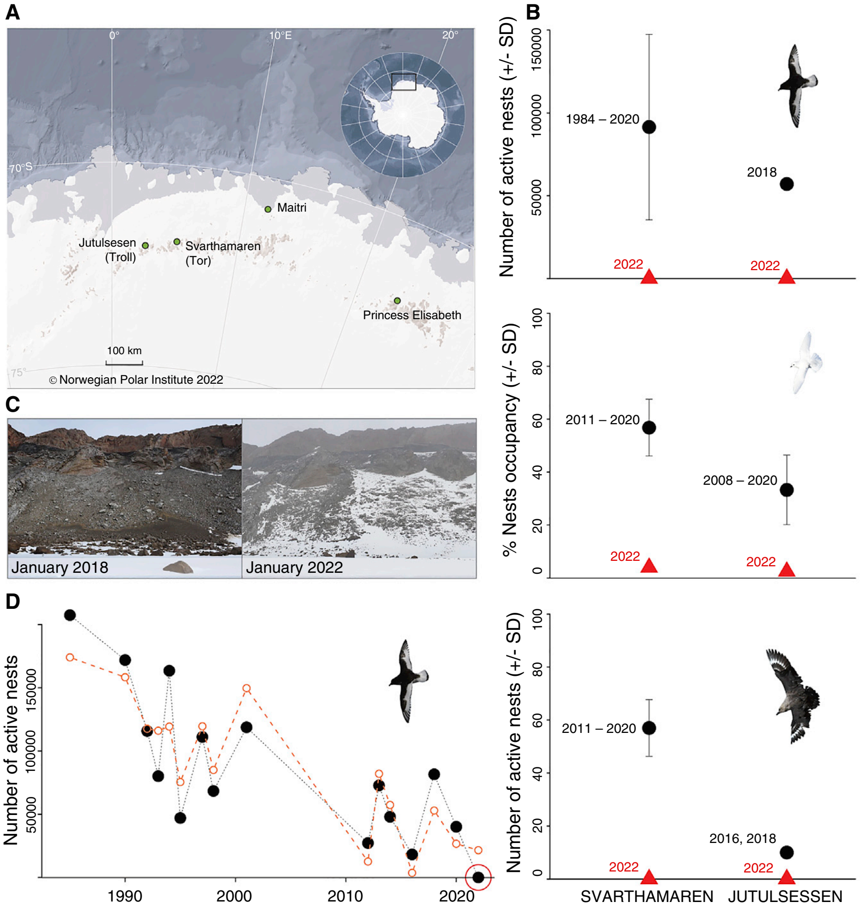

Figure 1. Seabird reproduction in Dronning Maud Land, Antarctica.

(A) Locations of the breeding sites mentioned in the text. (B) Breeding success metrics for the three most common species breeding in Dronning Maud Land (top, Antarctic petrel; middle, snow petrel; and bottom, south polar skua). The left symbols are results from Svarthamaren and the right ones from Jutulsessen. The red triangles show the results from the 2021/2022 breeding season and the black filled circles the mean (±SD) for all previous years monitored. The number for the skuas at Svarthamaren in the period 2011–2020 is the average number of active nests in the core monitoring area. In 2022, there was no active skua nests in the entire colony, including this area. The number of skuas at Jutulsessen in 2016 and 2018 (filled circle symbol) represents the minimum number of active nests. (C) Snow coverage at Svarthamaren Antarctic petrel colony in January 2018 (i.e. a "normal" year) and January 2022 after extreme snow storm activity. (D) Observed (black filled symbols) and predicted (orange open symbols) numbers of Antarctic petrel breeding pairs at Svarthamaren since the 1984/85 season. Predictions were made by a linear model including the total duration of storm conditions in December and January, the spring Southern Oscillation Index and a linear trend as predictors (Table S1). The large red circle highlights the 2021/2022 breeding season.

and eastern DML in 2021/2022. The number of birds observed in flight around the Maïtri Station (70°46’S, 11°44’E), was much lower than in previous years (H. Nageshwar Singh, Maïtri station leader, personal communication) and around the Princess Elisabeth Station (71°57’S, 23°21’E), occupancy was lower than average, and several snow petrel colonies were deserted (Henri Robert, International Polar Foundation, personal communication). These two stations are located 260 and 600 km away from Svarthamaren (Figure 1). Hence, although these observations are not quantitative, they suggest that seabird breeding failure probably occurred over a broad area (>700 km wide) in 2021/22.

These massive failures coincided with a series of storms, with extreme winds and heavy snowfall during December and January (Figure S1). This timeframe corresponds to the seabirds’ laying, incubation and early-chick rearing periods. Both snowfall and accumulation were higher in December 2021–January 2022 at Jutulsessen, Svarthamaren, Maïtri and Princess Elisabeth than in previous years. In January 2022, more than 50% of the Antarctic petrel breeding area at Svarthamaren was covered with snow (mean depth 25 cm, n = 159 measurements at snow-covered locations; Figure 1), which may have prevented birds from laying as Antarctic petrels normally deposit their eggs on bare ground. Together with the increased thermoregulatory costs imposed by storms, this likely explains the complete absence of breeding Antarctic petrels.

The total duration of storm conditions in the region (defined as length of time in December and January during which mean wind speed was ≥12 $m.s^{-1}$ and mean atmospheric pressure was ≤975 hPa; see[4] for details) had a significant negative effect on Antarctic petrel productivity (Figure 1; Table S1). Together, the total duration of storm conditions, plus the spring Southern Oscillation Index (a proxy of seabird foraging profitability[9]) and a linear trend (included to model an unexplained long-term linear decline in colony size), explained 83% of inter-annual fluctuations in the number of breeding pairs at Svarthamaren (Figure 1; a model including only the total duration of storm conditions as explanatory variable explained 33% of the variance). Despite this very strong relationship, the model overestimated the predicted number of breeding Antarctic petrel pairs in 2021/22 (Figure 1). One potential explanation could be that our storm index underestimated the severity of extreme storms. Indeed, the 2021/22 breeding season was not characterized by an exceptionally high number of storm days (fewer stormy days than in 2011/2012, for example) but these storms were especially violent (Figure S1), a nuance not captured by our index. Furthermore, this index did not consider snow precipitation, which appeared to have been exceptionally high. These results support the hypothesis that storms in the 2021/2022 breeding season, potentially combined with poor feeding conditions at sea (as indicated by the spring Southern Oscillation Index effect on Antarctic petrels and the known relationship between Southern Oscillation Index and marine productivity[7,9]), were responsible for observed massive breeding failures, notably in Antarctic petrels (insufficient data were available for the two other species to fit equivalent models). Similar mechanisms may explain the catastrophic snow petrel breeding success, even if some snow petrel nests may have been protected from the storms (snow petrels breed in cavities). Antarctic petrel eggs and chicks are the main prey of south polar skuas breeding at Svarthamaren. A complete absence of this food source, combined with intense snowstorms, likely explained why no skua nests were active during the 2021/2022 season.

Antarctic weather conditions are changing, with mean wind speeds increasing and extreme wind events becoming more frequent. IPCC model predictions also indicate that temperature will likely increase throughout Antarctica, leading to increased snowfall, most of which occurs during episodic storms[10]. Considering the adverse impact that snowstorms have on Antarctic seabird reproduction, these predictions are worrying. Several important Antarctic seabird populations are already declining, and the intensification of storm activity could lead to their extirpation.

SUPPLEMENTAL INFORMATION

Supplemental information containing one figure and one table can be found at https://doi.org/10.1016/j.cub.2022.12.055.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

The authors support inclusive, diverse, and equitable conduct of research.

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