Brevia

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# A complete breeding failure in an Adélie penguin colony correlates with unusual and extreme environmental events

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**Among the outcomes of the drastic changes affecting the Earth's ecosystems, nothing is more telling than a complete failure in the reproductive success of a sentinel species: a 'zero' year. Here, we found that unusual environmental conditions in the Terre Adélie sector of Antarctica disrupted the breeding activity of Adélie penguins *Pygoscelis adeliae* on land – but also their foraging activity at sea – to such a degree that no chicks survived in the 2013/2014 breeding season. Uncommonly heavy precipitation for this normally dry desert killed chicks en masse, while weak katabatic winds maintained a persistent sea ice around the colony, thereby impacting chick provisioning by adults. Extreme events such as this have direct repercussions for the species in question, and may also affect the wider sea-ice dependent food web. Understanding the nature, frequency, and consequences of such events are central to the management and conservation of this remote yet crucial ecosystem.**

Adélie penguins are one of the most important predators in Antarctic sea-ice ecosystems, totalling up to 3.79 million pairs (Lynch and LaRue 2014). Their foraging and breeding ecology is highly related to the status of the sea ice (Ainley 2002), and increasing (Ross Sea, Smith et al. 1999) or decreasing (Antarctic Peninsula, Wilson et al. 2001) population trends have been related to winter sea-ice conditions or occurrence of polynia in the vicinity of colonies. While the populations in the Terre Adélie sector of east Antarctica are generally increasing, the colony of ca 34 000 Adélie penguins from Pétrels Island (66°40′S, 140°01′E) has experienced a complete breeding failure for the first time since the early monitoring began in the 1950s. Not a single chick on this island survived the summer, despite a 55% hatching success (relative to e.g. a 77% hatching success and a total of 0.65 chicks per breeding pair in 2012/2013, Centre d'Etudes Biologiques de Chizé unpubl.). To put this into perspective, the lowest breeding success recorded between 1992 and 2003 on Pétrels Island before the 2013/2014 season was ca 30% in 2001 (Jenouvrier et al. 2006). Zero – or near zero – breeding success years have been reported on other high latitude species, like in black-browed albatrosses *Thalassarche melanophris* in the Sub Antarctic (Xavier et al. 2003, and papers cited therein) but they remain rare events. Similarly, such events for Adélie penguins have been recorded occasionally in other regions of the Antarctic continent (e.g. at Béchervaise Island, Irvine et al. 2000) but the causes for these events appear to be diverse according to the study site and season considered.

The year 2013 saw the greatest sea-ice extent around the Antarctic continent since 1979 (ca 19.5 million km$^2$ in 2013 for an 18.0–19.4 million km$^2$ range between 1979–2012, NOAA: <http://earthobservatory.nasa.gov/IOTD/view.php?id=82160>), which was also observed in the Adélie Land region (IFREMER: <wwz.ifremer.fr/institut>). Monthly data from the Dumont d'Urville meteorological station (<www.antarctica.ac.uk/met/READER/>) showed that autumn and winter 2013 were among the coldest since recording started in 1956 (Supplementary material, Appendix 1). However, the trend reversed completely in August 2013 so that air temperatures in spring and summer became warmer than usual. Perhaps more importantly, the wind direction was predominantly and unusually blowing from the east throughout the year and wind strength was low at the start of the breeding season. Normally, strong katabatic winds blow from the continent towards the north in this region, helping to push the sea ice away from the coast (Adolphs and Wendler 1995) and create access to open water, usually polynyas, which is critical to penguin breeding success (Massom et al. 1998).

Thus, in the 2013/2014 season penguins suffered from two contrasting plagues: an extensive sea-ice cover that forced them to walk more often on compact ice, hampering their efforts to forage for themselves and their

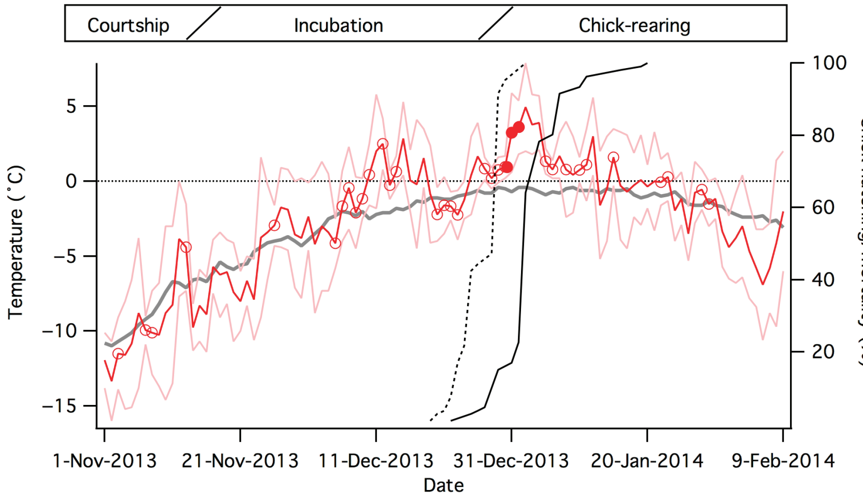


Figure 1. Daily temperature (average, maximum and minimum in red and pink lines, respectively) and snow/rainy episodes (open and filled red circles, respectively) at Dumont d'Urville during the 2013/2014 breeding season show a progressive deterioration of the weather around the turn of the year that culminated into intensive rainfall on 31 December and 1 January. Average temperature evolution over 1981–2010 is shown in grey for comparison. Finally, cumulative Adélie penguin hatching success (dotted black line) and chick mortality (solid black line) are also indicated.

chicks, and a warm and wet summer with alternating periods of snowfall and especially rain – an extremely rare feature in east Antarctica (Fig. 1). GPS devices (Cottin et al. 2012) attached to chick-rearing birds revealed that the extreme sea-ice extent affected foraging behaviour and success in a variety of ways. Penguins were forced to travel twice the distance they covered in the previous season (217.5 ± 56.1 km, n = 35 birds in 2013/2014; 117.7 ± 73.0 km, n = 38 birds in 2012/2013, student t-test t = –6.91, p < 0.001). Adults started their foraging trips with a lower body mass (4.0 ± 0.4 kg, n = 40 birds in 2013/2014; 4.3 ± 0.5 kg, n = 42 birds in 2012/2013, t = 3.0, p = 0.004) and they also spent longer at sea (5.3 ± 3.3 d, n = 41 birds in 2013/2014; 3.3 ± 3.7 d, n = 43 birds in 2012/2013, t = –2.60, p = 0.011). As a result, the chicks were not adequately provisioned and emaciated chicks were a common sight throughout the summer. Yet, extensive sea-ice cover was perhaps the lesser of two evils: relatively warm temperatures in the summer provoked unprecedented rainy episodes and snowmelt. Small chicks are covered with a downy plumage that has little – if any – waterproofing ability (Duchamp et al. 2002). With unusual rain in this normally dry and cold desert, the chicks' thermoregulation capacities weakened rapidly and the rainy episode that took place just around the turn of the year led to the death of 49% of the chicks in the colony we monitored (Fig. 1). The rest of the chicks were taken by starvation, additional precipitation and predators/scavengers.

This complete breeding failure was a result of multiple factors: several temporal and spatial scales need to be considered to understand its ramifications. This clearly highlights the need to monitor the breeding and foraging activity of polar species both on land and at sea simultaneously. What ecophysiological mechanisms are triggered in response to such a catastrophic year, especially at the hormonal level where the endocrine responses to stressors are known to affect foraging performances and/or parental care? Although a zero year has relatively little immediate impact on the survival of long-lived species, we can wonder how population dynamics may be affected by the absence of an entire cohort over the long term? What will be the long-term effects on other species and trophic levels of the regional ecosystem? Extreme events like those reported here are indeed likely to have direct repercussions on other levels of the sea-ice dependent food web. These fundamental questions echo those voiced at the 1st Horizon Scan (Kennicutt et al. 2014) of the Scientific Committee on Antarctic Research (SCAR). These are research priorities for SCAR, as well as for the Antarctic Treaty Consultative Meetings and the Commission for the Conservation of Antarctic Marine Living Resources, especially since predictions from the Intergovernmental Panel on Climate Change announce the coming of an era with more frequent extreme events (IPCC 2007). In this context, the recent breakdown of a giant iceberg in Antarctica and the resultant havoc it created for the ecosystem (Lescroël et al. 2014), the increasing frequency of storms and rainfall (Dee Boersma and Rebstock 2014), or the extreme event reported here bode ominously for the future of these remote and fragile ecosystems.

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Supplementary material (Appendix ECOG-01182 at <www.ecography.org/readers/appendix>). Appendix 1.