EFFECTS OF WEATHER AND SEA-ICE ON THE REPRODUCTIVE PERFORMANCE OF THE ADÉLIE PENGUIN AT EDMONSON POINT, ROSS SEA

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Abstract

The breeding biology of the Adélie penguin (*Pygoscelis adeliae*) was studied at Edmonson Point, Victoria Land, during the 1999, 2001 and 2003 breeding seasons. Weather and sea-ice regimes varied notably, especially in 2003, which was characterised by extensive and persistent sea-ice and strong winds with snowfalls in December. First incubation trips by females were significantly longer than in 1999 and 2001, which in turn delayed the mean departure date of males on the second incubation trip. A high number of chicks died during the post-hatching stage and the breeding success was low with 0.3 chicks crèched per nest with eggs. The mean crèching date was also delayed compared to dates recorded in 1999 and 2001. The average weight of adults rearing chicks was lower in 2003. It is suggested in this paper that the ability of penguins to cope with severe short-term weather events could be reduced when longer-term events, such as anomalies in the persistence of sea-ice, have affected body condition.

Résumé

La biologie reproductrice du manchot Adélie (*Pygoscelis adeliae*) a été étudiée à la pointe Edmonson, en Terre Victoria, pendant les saisons de reproduction de 1999, 2001 et 2003. Les conditions météorologiques et les régimes des glaces de mer variaient considérablement, principalement en 2003 qui se distinguait par des glaces de mer étendues et persistantes, ainsi que des vents forts et des chutes de neige en décembre. Pendant l'incubation, la première sortie des femelles était nettement plus longue qu'en 1999 et en 2001, ce qui causait un retard dans la date moyenne de départ des mâles pour la deuxième sortie. Un grand nombre de poussins sont morts dans la période qui suivait l'éclosion et le succès reproductif était faible, correspondant à 0,3 jeune en crèche par nid pourvus d'œufs. La date moyenne d'entrée en crèche était, elle aussi, retardée par rapport aux dates enregistrées en 1999 et 2001. Le poids moyen des adultes élevant des jeunes était moins élevé en 2003. Ce document laisse entendre que la capacité des manchots de supporter les événements climatiques rudes pourrait être réduite lorsque des événements à long terme, tels que la persistance anormale des glaces de mer, ont affecté leur condition.

Резюме

Исследование репродуктивной биологии пингвинов Адели (*Pygoscelis adeliae*) проводилось на мысе Эдмонсон (Земля Виктории) в течение сезонов размножения 1999, 2001 и 2003 гг. Метеорологические и ледовые условия сильно различались, особенно в 2003 году, который отличался обширным и устойчивым ледовым покровом и сильными ветрами со снегопадами в декабре. Первые походы самок во время инкубационного периода были значительно длиннее, чем в 1999 и 2001 г., что в свою очередь привело к отсрочке средней даты убытия самцов во второй поход за пищей во время инкубационного периода. Большое количество птенцов погибло после вылупления и репродуктивный успех был низким (0.3 птенца ясельного возраста на гнездо с яйцами). Средняя дата вступления в ясельную стадию была также позже, чем даты, зарегистрированные в 1999 и 2001 гг. Средний вес выводящих птенцов взрослых особей в 2003 г. был ниже. В статье предполагается, что способность пингвинов переносить краткосрочные опасные метеорологические явления может снижаться, когда более долгосрочные явления, такие как аномалии в продолжительности существования морского льда, отрицательно повлияли на их физиологическое состояние.

Resumen

Se estudió la biología de la reproducción del pingüino adelia (*Pygoscelis adeliae*) en el Cabo Edmonson, Tierra Victoria, en las temporadas de reproducción de 1999, 2001 y 2003. Las condiciones meteorológicas y del hielo marino variaron notablemente,

especialmente en 2003, año que se caracterizó por una capa extensa y persistente de hielo marino y por fuertes ventiscas en diciembre. La duración del primer viaje de alimentación durante la incubación de las hembras fue significativamente mayor que en 1999 y 2001, y esto a su vez retrasó la fecha promedio de partida del macho en el segundo turno de incubación. La mortalidad de los polluelos después de salir del cascarón fue alta, y el éxito de la reproducción fue bajo, llegándose a una tasa de 0,3 polluelos por nido con huevos que alcanzaron la etapa de guardería). Asimismo, la fecha promedio en la cual se alcanza la etapa de guardería se retrasó en comparación con los años 1999 y 2001. El promedio del peso de los adultos que criaban polluelos fue menor en 2003. Este estudio concluye que la capacidad de los pingüinos para sobrellevar condiciones meteorológicas extremas de corta duración disminuye cuando las condiciones prevalecientes por largo tiempo, como la persistencia anómala de la capa de hielo, han afectado la condición corporal.

Keywords: Adélie penguin, *Pygoscelis adeliae*, breeding success, weather, Ross Sea, sea-ice, CCAMLR

Introduction

Weather is known to affect seabirds on both a long-term and short-term basis (Schreiber, 2002). Such effects include changes in at-sea behaviour (Mori, 1999; Spruzen and Woehler, 2002), the cost of foraging, the ability to find food and the availability of food itself (Finney et al., 1999). Weather can also alter the timing of the reproduction, chick growth and thermoregulation, and breeding success (Schreiber, 2002). Generally the effects of weather are easier to observe at colonies during reproduction than when birds are at sea (Ainley and Divoky, 2001).

Penguins living in extreme environments, such as the high-latitude Antarctic, must cope with particularly severe weather conditions (Williams, 1995). The Adélie penguin (*Pygoscelis adeliae*) breeds in Antarctic coastal areas and frequently has to deal with snow, wind storms and variable sea-ice regimes (Ainley, 2002). Sea-ice may vary in persistence, concentration and extent from year to year. Storms also occur (short-term factors) and their timing is unpredictable. Short-term weather effects such as severe microclimates are probably of secondary importance to adult Adélies, but may become limiting factors in chick survival, e.g. when storms occur at a critical time, such as hatching, when chicks are ectothermic. The presence and aggregation of penguins may modify the microclimate at nest sites, reducing wind velocity and increasing temperature (Moczydlowski, 1986). Nevertheless, when high winds and cloud cover are persistent, the thermal advantage is strongly reduced (Yeates, 1975). Mortality due to waterlogged nests or severe storms is often a significant source of egg and chick loss (Muller-Schwarze, 1984).

The Adélie penguin breeding cycle is strictly constrained by the shortness of the austral summer and shows a highly coordinated breeding schedule (Taylor, 1962; Ainley, 2002). Factors such as reduced food availability and ice cover extension will cause lengthening of foraging trips (Irvine et al., 2000). However, the degree to which trips lengthen is constrained by the need to relieve the mate, especially during incubation (Miller and Davis, 1993), and may force penguins to return to the nest regardless of how much food is taken. Sea-ice conditions are clearly linked with feeding capability (Croxall et al., 1988; Whitehead et al., 1990; Trivelpiece et al., 1990; Ainley et al., 1998; Ainley, 2002).

Comparisons between breeding cycles of Adélie penguins breeding in various localities with differing sea-ice regimes reveals that this species has developed the capacity to adjust its feeding and breeding behaviour to local environmental conditions (Ainley and Le Resche, 1973; Watanuki et al., 1993; Watanuki et al., 1997; Ainley et al., 1998; Ainley, 2002; Rodary et al., 2000; Kato et al., 2003). However, sea-ice conditions (e.g. late break-out or greater extent) is one of the main factors that affect breeding success (Taylor, 1962; Emison, 1968; Ainley and Le Resche, 1973; Spurr, 1975; Yeates, 1975; Irvine et al., 2000; Ainley, 2002) and annual population size (Wilson et al., 2001; Kato et al., 2002).

This study focuses on the reproductive performance of a small Adélie penguin colony at Edmonson Point, Victoria Land, over three seasons characterised by variation in sea-ice and weather conditions. The aim was to investigate whether the penguins' capacity to cope with short-term weather events, such as storms, is reduced when seasonal factors, including sea-ice regimes, are also unfavourable.

Methods

Study area

Observations were carried out at the Edmonson Point CCAMLR Ecosystem Monitoring Program (CEMP) site (74°21′S 165°10′E) located on the shores of Wood Bay, 60 km north of the Italian station of Terra Nova Bay on the Victoria Land coast (Ross Sea, Antarctica). The Adélie penguin colony consists of approximately 2 000 nests and has been monitored since the 1994/95 austral summer.

The present study includes data from the 1998/99, 2000/01 and 2002/03 austral summers (hereafter referred to as the 1999, 2001 and 2003 CEMP study seasons respectively) when sea-ice regimes and local weather varied notably. The Ross Sea is normally covered by pack-ice in winter except for recurring leads and polynyas. In August, a large area of open water appears in the southwestern Ross Sea. Known as the Ross Sea Polynya (Ainley, 2002), it continues to widen toward the north and to a lesser extent toward the east as spring progresses. At the same time, the northern edge of the large-scale pack-ice field recedes southward and eastward. By late summer–autumn, pack-ice usually remains only along the Victoria Land coast and in a large tongue that extends northwestward from the King Edward VII Peninsula (Ainley et al., 1984).

Data collection and analysis

Data were collected according to CEMP standard methods (CCAMLR, 2003). About 400 penguins of known sex were individually marked by implanted passively interrogated transponders. Their movements into and out of the colony and body mass were recorded by a specially designed automated penguin monitoring system, the APMS (Kerry et al., 1993). Only the mass of chick-rearing adults from monitored nests was included in the analysis, and of these, only those within the range 2 900–6 000 g was included since values outside this range are extremely unlikely for breeding Adélie penguins.

Breeding chronology, breeding success and first and second incubation shift duration were measured for at least 100 nests each year (i.e. CEMP Methods A9, A3, A6 and A2 respectively). Annual counts include a mid-incubation count of all nests with eggs and a chick count when two-thirds of the chicks were in crèche. Annual breeding success was defined as the number of chicks successfully reared to the crèche stage (measured when two-thirds of the chicks had crèched, according to CEMP Method A6) divided by the number of nests with eggs.

Weather data were collected by an automatic weather station located in the proximity of the penguin colony for the whole study period except in November 1998 when these data were recorded manually. Data were recorded at 10 min intervals and averaged for a one-day period. Wind speed was measured at 2 m above the ground, and wind-chill temperature was calculated by applying an equation from the Australian Antarctic Division Data Centre (http://aadc-maps.aad.gov.au/aadc/aws/weather_parameters.cfm).

Fast-ice extent off the coast of Edmonson Point was measured from satellite images (PNRA, Meteo-climatological Observatory) taken about the same time each year (29 December 1998, 1 January 2001 and 31 December 2002). Images were geo-referenced and linear distance from the colony to the fast-ice edge was measured using GIS (ENVI and ArcView 3.2).

Before performing statistical analyses, data were tested for normality and non-parametric statistics were employed when no adequate transformation was found. All tests were two-tailed and statistical significance was set as $\alpha = 0.05$.

Results

Weather

The weather conditions varied during the three seasons (Figure 1). In 1999 maximum wind speed exceeded 30 knots on a few occasions only in November and December, and the climate was relatively mild. In contrast, the 2001 breeding season was characterised by strong wind storms, mostly in November, when penguins were incubating, and by fair weather thereafter. Storms occurred throughout summer of 2003 when the climate was characterised by strong winds from the south and snowfall. A particularly severe storm occurred from 19 to 22 December 2002 and coincided with the beginning of hatching. During this period the mean windchill temperature was about –18°C with dips to –32°C.

Sea-ice

Due to the topographical features of Wood Bay, fast-ice off the Edmonson Point colony usually lasts until late January (Figure 2). In 1999 the fast-ice edge was about 15 km away during the guard and crèche stages of the penguin breeding

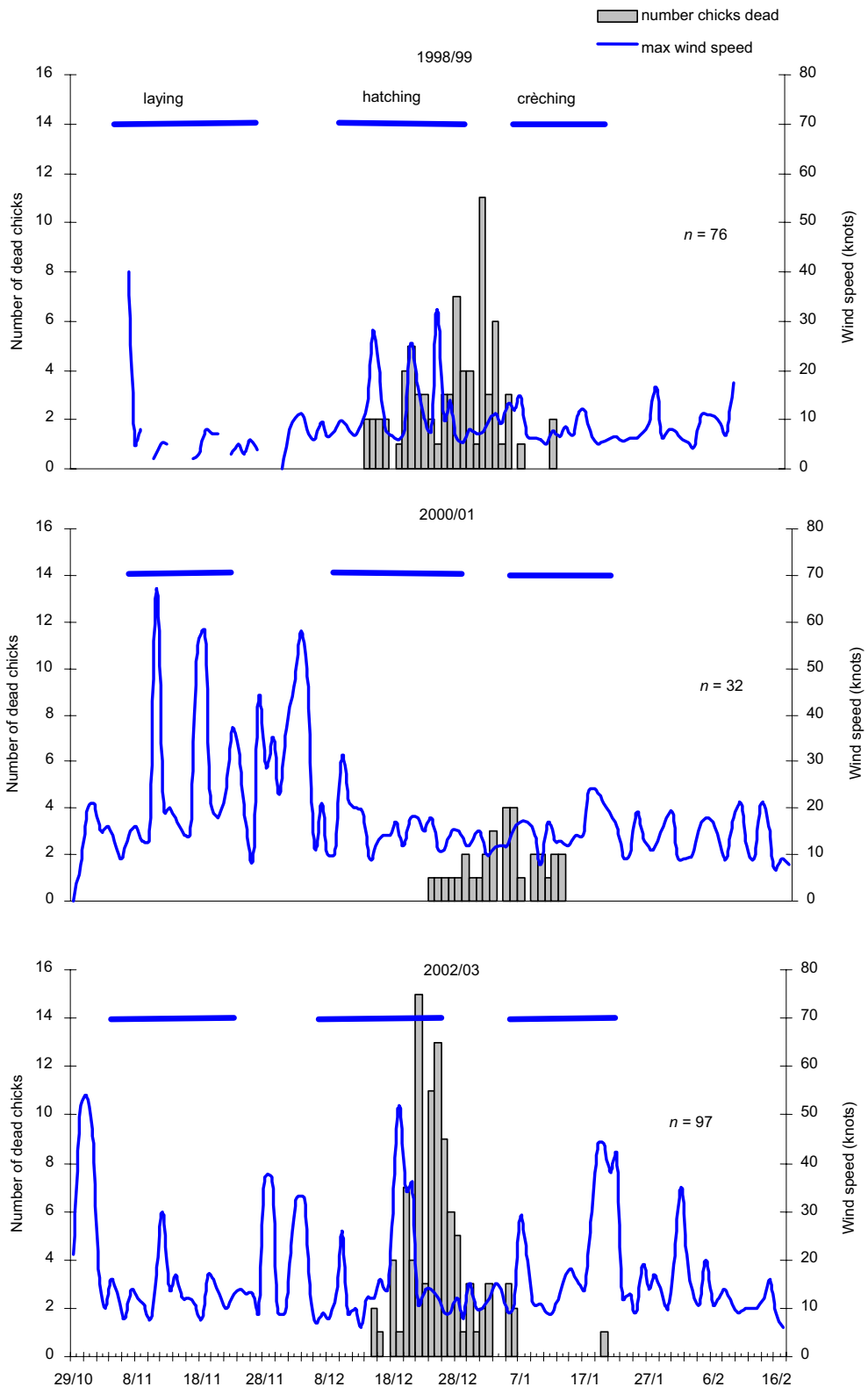

Figure 1: Number of dead chicks in relation to wind speed in 1999, 2001 and 2003 at Edmonson Point (breaks in the wind-speed line indicate discontinuous collection of data; see text).

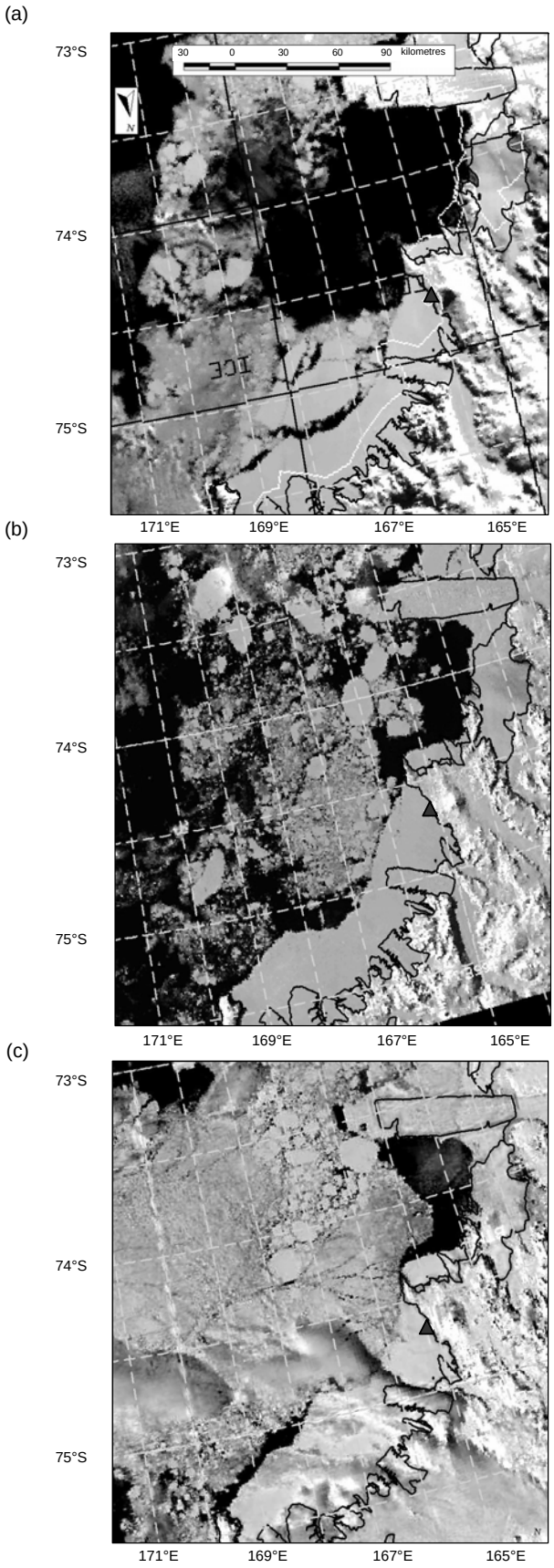

Figure 2: Sea-ice extent at Edmonson Point (▲) (Victoria Land coast) during the three study periods. Satellite images taken on (a) 29 December 1998, (b) 1 January 2001 and (c) 31 December 2002.

cycle. In 2001, fast-ice extended 20–24 km initially, but then disappeared completely by mid-January. In 2003 the fast-ice again extended about 20 km but, unlike the previous year, it did not disappear (Figure 2).

Breeding cycle

During the three breeding seasons 93.2% of the clutches were completed between 9 and 19 November. The clutch size (measured as number of eggs laid per nest with eggs) was almost identical in all three years, while the percentage of eggs hatched was lower in 2003 and 2001 (Table 1).

Breeding success varied between seasons, with 2003 values well below those recorded in 1999 and 2001 (Table 1) as well as those recorded in 1995, 1996 and 1997 (Olmastroni et al., 2000). The 2003 breeding season was in fact characterised by high chick mortality (Table 1), most of which occurred immediately after a major snow and wind storm (Figure 1).

In all three seasons the mean departure date of females for the first incubation shift (CEMP Method A2) ranged little (15–17 November), but mean trip duration varied ($F_{2,309} = 124.80$, $p < 0.001$). In 2003, trips were much longer than in 1999 and 2001 (Table 2).

As a consequence of the delayed return of females, males departed later ($F_{2,260} = 43.04$, $p < 0.001$) in 2003 (Table 2). No significant differences between years were found in the mean duration of the second incubation shift.

Hatching occurred on average between 16 and 17 December. In 1999 it occurred on 16 December (SD ± 3.9 days; $n = 98$), in 2001 on 17 December (SD ± 4.0 days; $n = 90$), and in 2003 on 17 December (SD ± 3.3 days; $n = 87$). Differences between years were not significant.

The mean crèching date, 14 January (SD ± 3.3 days; $n = 31$), appeared to be significantly delayed in 2003 ($F_{2,173} = 20.52$, $p < 0.001$). In 1999 and 2001 mean dates were 8 January (SD ± 3.1 days; $n = 74$) and 10 January (SD ± 2.6 days; $n = 71$) respectively.

Adult body mass

The body mass of adults entering the colony during the chick-rearing period varied between the three seasons (Figure 3). Differences were significant for males ($F_{2,194} = 6{,}98$, $p < 0.001$) and for females (Kruskal-Wallis, $\chi^2 = 18.58$, df = 2, $p < 0.001$), as both sexes weighed less in 2003 (Tukey HSD post-hoc comparison) (Figure 3).

Interannual differences in mass were also recorded for males ($F_{2,217} = 13.54$, $p < 0.001$) and females ($F_{2,186} = 13.69$, $p < 0.001$) leaving the colony for foraging trips. Comparisons revealed that birds were significantly lighter in the 2003 breeding season (Tukey HSD post-hoc comparison) (Figure 4).

Discussion

The breeding chronology (CEMP Method A9) of Adélie penguins at the Edmonson Point colony was similar over the study period and the dates of the main breeding events, e.g. laying, hatching and crèching, were also similar to those reported elsewhere in the Ross Sea (summarised in Ainley, 2002). Dates of the main breeding events were not significantly different from year to year, except for crèching date which was later in 2003.

Despite the consistency in timing of breeding events, breeding success (CEMP Method A6) showed a great deal of variation. Breeding success in 2003 was the lowest since monitoring commenced in 1995 (Olmastroni et al., 2000). The immediate cause of the low reproductive output was a snow and wind storm that lasted four days over the period of peak hatching.

Ultimately, however, the extensive fast-ice in that season may account for the anomalies observed. The 2002 winter season was colder than average, causing fast-ice to thicken considerably (National Ice Center, www.natice.noaa.gov/pub/outlooks/Ross_Sea/). Moreover, icebergs C16 and B15A, which had grounded in the southern Ross Sea in the previous season (Arrigo et al., 2002), had significantly altered sea-ice dynamics, and in 2003 relatively weak winds and the coastal current failed to 'flush' the sea-ice northward (National Ice Center, www.natice.noaa.gov/pub/outlooks/Ross_Sea/). At the same time, the Ross Sea Polynya was rather small. The huge iceberg C19, originally located above B15A, moved into the northwestern Ross Sea (75°10'S 172°13'E) and delayed the retreat of the northern edge of the pack-ice southward. Its northwest–southeast orientation faced southerly wind and currents. The overall effect was a delay in the break-out of the ice in the study area by approximately one month to mid-February. This event certainly had a direct effect on the colonies in the southern sector of the Ross Sea as in the previous year (Arrigo et al., 2002), including Edmonson Point.

Table 1: Clutch size, hatching, breeding success and chick mortality of Adélie penguins at Edmonson Point in 1999, 2001 and 2003.

	Breeding Season		
	1999	2001	2003
Clutch size (number of eggs laid/nests with eggs)	1.9 (216/112)	1.8 (225/123)	1.9 (249/129)
Hatched eggs (%)	176 (81.5%)	148 (65.7%)	145 (58.2%)
Breeding success (chicks reared to crèche/nests with eggs)	0.9 (100/112)	0.9 (113/123)	0.3 (44/129)
Chick mortality (%)	43.2	23.4	69.6

Table 2: Departure date and trip duration of incubation shifts of Adélie penguins at Edmonson Point in 1999, 2001 and 2003. Data are reported as mean ± SD.

	Breeding Season		
	1999	2001	2003
Female departure date	16 Nov ± 3.9 (*n* = 102)	17 Nov ± 3.5 (*n* = 105)	15 Nov ± 2.6 (*n* = 105)
First incubation trip (days)	12 ± 2.7 (*n* = 102)	13 ± 3.7 (*n* = 105)	19 ± 3.9 (*n* = 105)
Male departure date	27 Nov ± 4.2 (*n* = 101)	29 Nov ± 4.2 (*n* = 94)	5 Dec ± 4.0 (*n* = 68)
Second incubation trip (days)	12 ± 3.3 (*n* = 101)	12 ± 3.2 (*n* = 94)	13 ± 4.8 (*n* = 68)

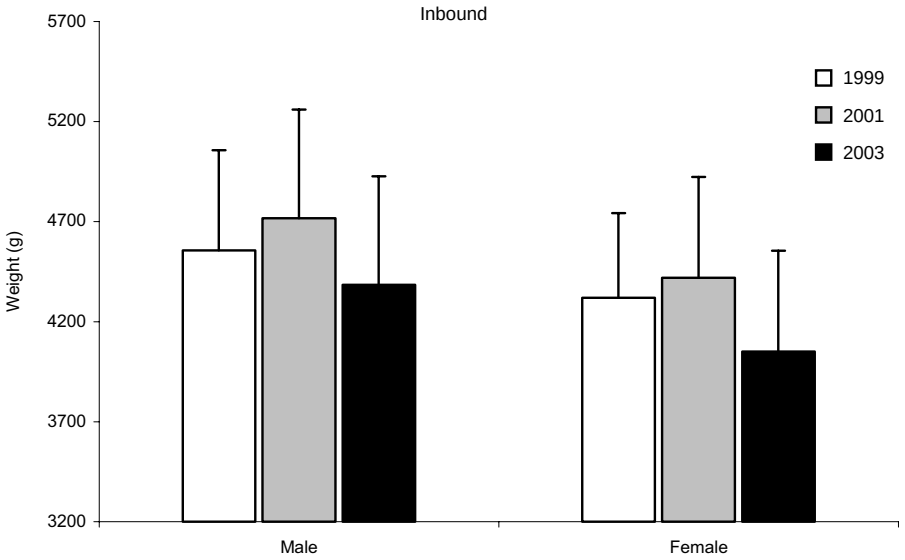

Figure 3: Average weight (±SD) of inbound Adélie penguins (calculated as the grand mean of individual means during chick rearing). Sample size: 1999 male = 88, female = 87; 2001 male = 62, female = 54; 2003 male = 47, female = 41.

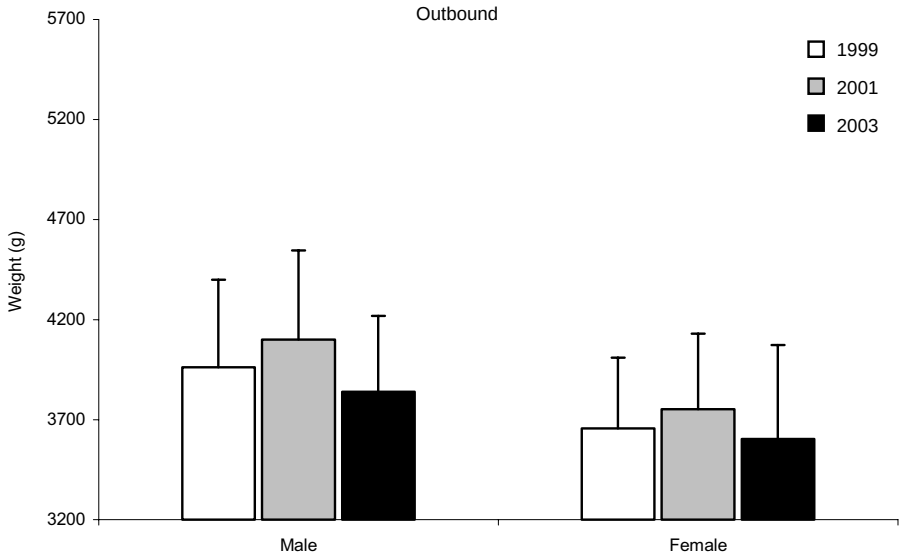

Figure 4: Average weight (±SD) of outbound Adélie penguins (calculated as the grand mean of individual means during chick rearing). Sample size: 1999 male = 100, female = 91; 2001 male = 66, female = 54; 2003 male = 54, female = 44.

The delayed female return dates during incubation in 2003 can be attributed to the extensive sea-ice. As a consequence, males were forced to depart later and hence to return later. Although eggs hatched at the normal time in 2003, chicks had to be fed for their first few days by parents in poor condition. In fact the mean body mass of adults was uniformly lower throughout the entire chick-rearing period compared with the 1999 and 2001 breeding seasons, in which sea-ice conditions and trip durations were similar. Reduced food availability or reduced feeding abilities of the adults may have caused the drop in mean adult mass, as well as the increased duration of foraging trips in 2003.

Moreover, the bad weather had such a significant effect on breeding success in 2003, causing the high chick mortality, because it occurred at a stage when the chicks were newly hatched and thus most vulnerable.

Crèche time for the chicks was also postponed in 2003. Although the cause is unknown it may be attributed to a slower growth rate due to fewer or smaller meals or both. It is not known if this resulted in lower post-fledging survival that year.

In this context it can reasonably be assumed that the capacity of penguins to cope with the severe weather conditions recorded during the hatching period in 2003 could have been reduced by the delayed return of the males. The weather conditions in 2003 were poor and sea-ice dynamics in the summer were also certainly influenced by the C15 and B15A icebergs. Although caution is required when drawing general conclusions on the effects of long-term weather and climate changes on seabird life history, these results indicate how various perturbations can coincide to negatively affect the breeding success of Adélie penguins, especially when the effects of large-scale processes are compounded by local events.

Conclusion

Significant differences in CEMP Methods A2 (duration of penguin incubation shift), A6 (penguin breeding success) and A9 (penguin breeding chronology (crèche date only)) reflected anomalies in weather and sea-ice conditions during 2003. Large-scale climatic events are likely to account for seasonal effects (e.g. sea-ice dynamics) which require adjustment in the penguins' foraging strategies in order to cope with severe short-term weather effects. In particular, it is suggested that unusual environmental conditions, both locally (weather at nest site) and at sea (sea-ice cover), play a decisive role in affecting the breeding success of Adélie penguins and may affect the way in which data under CEMP protocols are interpreted. Environmental data collected concurrently with monitoring programs are necessary for an understanding of the interrelationships between CEMP parameters and reproductive performance.

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