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Rapid increase in Adélie penguin populations in the Lützow-Holm Bay area since the mid 1990s

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Abstract: The Adélie penguin, *Pygoscelis adeliae*, an important component of the Antarctic marine ecosystem, is closely associated with sea ice. Ten breeding populations along the Sôya Coast of Lützow-Holm Bay have been monitored since the 1960s by the Japanese Antarctic Research Expedition and shown to be increasing. In most colonies, small peaks of population increase were observed in the late 1980s with a rapid increase from the mid 1990s. Frequent sea ice break-ups in Lützow-Holm Bay in the mid 1980s and since the late 1990s are thought to have induced the population increase through increased subadult survival and preferred prey availability. Population monitoring therefore needs to be continued carefully in relation to the environmental changes.

key words: Adélie penguin, population, sea ice, Lützow-Holm Bay

Introduction

Recent studies have revealed marked warming in the Antarctica, especially the Antarctic Peninsula (Vaughan *et al.*, 2001), and in such ecosystems, environmental conditions have been shown to drastically affect population dynamics of top predators such as seabirds (Croxall *et al.*, 2002). The population dynamics of Adélie penguin, *Pygoscelis adeliae*, are especially sensitive to Antarctic climate variations (Ainley, 2002) since their biology is closely associated with sea ice conditions. For example, modification of sea ice conditions has been shown to affect their foraging behaviour (Watanuki *et al.*, 1997; Rodary *et al.*, 2000), breeding success (Ainley and Le Resche, 1973; Ainley *et al.*, 1998; Irvine *et al.*, 2000) and winter survival (Wilson *et al.*, 2001; Jenouvrier *et al.*, 2006). Changes in the Antarctic climate that modify sea ice conditions over time are therefore expected to have a significant impact on Adélie penguin populations. This is clearly exemplified by the substantial concomitant atmospheric warming and reduction in sea ice in the Antarctic Peninsula region (Stammerjohn and Smith, 1997; Turner *et al.*, 2005) and accompanying decline in Adélie penguin populations in this region over the last century (Fraser and Patterson, 1997). In contrast, populations are increasing in the Ross Sea and East Antarctic areas (Jenouvrier *et al.*, 2006; Woehler *et al.*, 2001) where the extent of sea ice has been decreasing since about 1950 (Curran *et al.*, 2003). These trends can be explained using a conceptual model showing the relationship between Adélie penguin population growth and sea ice concentration (Smith *et al.*, 1999).

Despite the above, in the south Indian Ocean, air temperatures show a stable trend (Turner *et al*., 2005) and the extent of sea ice has been increasing in the past 20 years (Stammerjohn and Smith, 1997). Long-term monitoring of Adélie penguin populations has been conducted by the Japanese Antarctic Research Expeditions (JARE) in a number of localities along the Sôya Coast in Lützow-Holm Bay. Although the records date from the 1960s, regular surveys were only implemented from the 1980s. Kato *et al*. (2002) reported that most colonies of Adélie penguin increased in this area between 1961 and 2001. Here, we present recent evolution showing the population trends in this region and discuss them in relation to sea ice characteristics.

Materials and methods

Colonies of Adélie penguins breeding along Sôya Coast in Lützow-Holm Bay were monitored occasionally during the 1960s and 1970s and annually from the 1980s as part of a long-term monitoring program of Adélie penguin populations conducted by JARE. In mid November, when the number of Adélie penguins peaks in this area (Watanuki and Naito, 1992), the number of penguins on the ground or in photographs taken on the ground was counted directly three times by three people. Average values were then used for the analysis (see Kato *et al*., 2002 for details). Ten colonies were observed annually and seven other colonies with fewer penguins (range: 2–20 individuals) were observed occasionally (Fig. 1). The population data published in Kato *et al*. (2002) and from 2002 to 2004 in the above 10 colonies observed regularly were complied. The annual population increase rate (a) was calculated for each colony using the following equation:

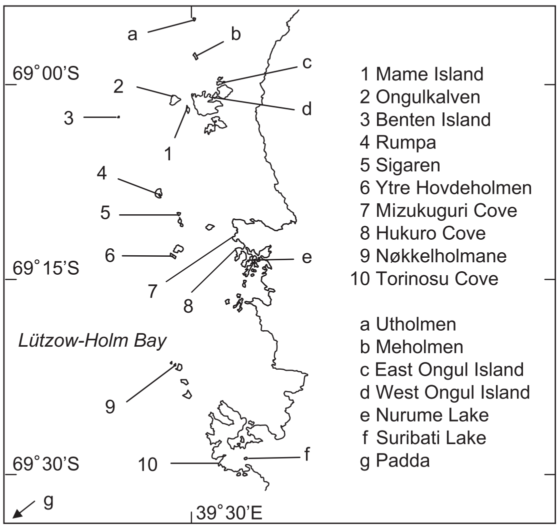

Fig. 1. Location of Adélie penguin colonies along the Sôya Coast observed annually (1–10) and occasionally (a–g).

$$\text{Log}\ (N_Y)=a\times Y+\text{Log}\ (N_0),$$

where N_Y is the number of penguins in year Y. The fit of the regression was tested by ANOVA (JMP 6.0, SAS Institute Inc.).

The severity of ice conditions in Lützow-Holm Bay was derived from the distance to Syowa Station, as well as the number of rammings performed by the icebreakers that serve Syowa Station once a year (for details see Kato *et al.*, 2002). Between 1966 and 1982, we used the minimum distance (in km) between Syowa Station and the anchor point of the icebreaker "*Fuji*", and after 1983 we used the number of rammings required by the icebreaker "*Shirase*" to complete its approach. Available breeding parameters (chick growth rate and chick survival rate) and diet data (proportion of krill in the diet) for the Hukuro Cove colony were compiled from the literature.

Results

Populations increased in five colonies (Mame Island, Ongulkalven, Rumpa, Ytre Hovdeholmen and Mizukuguri Cove), decreased in two colonies (Hukuro Cove and Torinosu Cove), and showed no significant trend in the remaining three colonies (Benten Island, Sigaren and Nøkkelholmane) throughout the monitoring period (Table 1). Note that the absence of significant trends in Sigaren and Nøkkelholmane probably resulted from the small amount of data collected in these locations. Small peaks of population increase were observed in the late 1980s in six colonies (Mame Island, Ongulkalven, Rumpa, Mi-

Table 1. Annual population growth rates of Adélie penguin colonies along the Sôya Coast from various start years and from 1995 to 2004.

Colony	Start year–2004					1995–2004			
	Start year	N	Growth rate (%)	R^2	P	N	Growth rate (%)	R^2	P
Mame Island	1972–	26	7.9	0.74	<0.0001	10	19.5	0.94	<0.0001
Ongulkalven	1962–	34	3.1	0.32	0.0005	10	22.4	0.90	<0.0001
Benten Island	1977–	15	4.1	0.16	NS	10	26.2	0.85	0.0002
Rumpa	1967–	25	2.8	0.64	<0.0001	10	9.2	0.75	0.001
Sigaren	2000–	4	16.5	0.42	NS	4	16.5	0.42	NS
Ytre Hovde-holmen	1982–	16	4.7	0.36	0.015	10	14.8	0.59	0.01
Mizukuguri Cove	1981–	22	6.7	0.80	<0.0001	10	8.9	0.79	0.0006
Hukuro Cove	1982–	20	−1.7	0.34	0.007	10	0.5	0.13	NS
Nøkkelhol-mane	1994–	10	4.6	0.24	NS	9	2.2	0.06	NS
Torinosu Cove	1981–	15	−4.2	0.54	0.002	9	−9.8	0.71	0.004

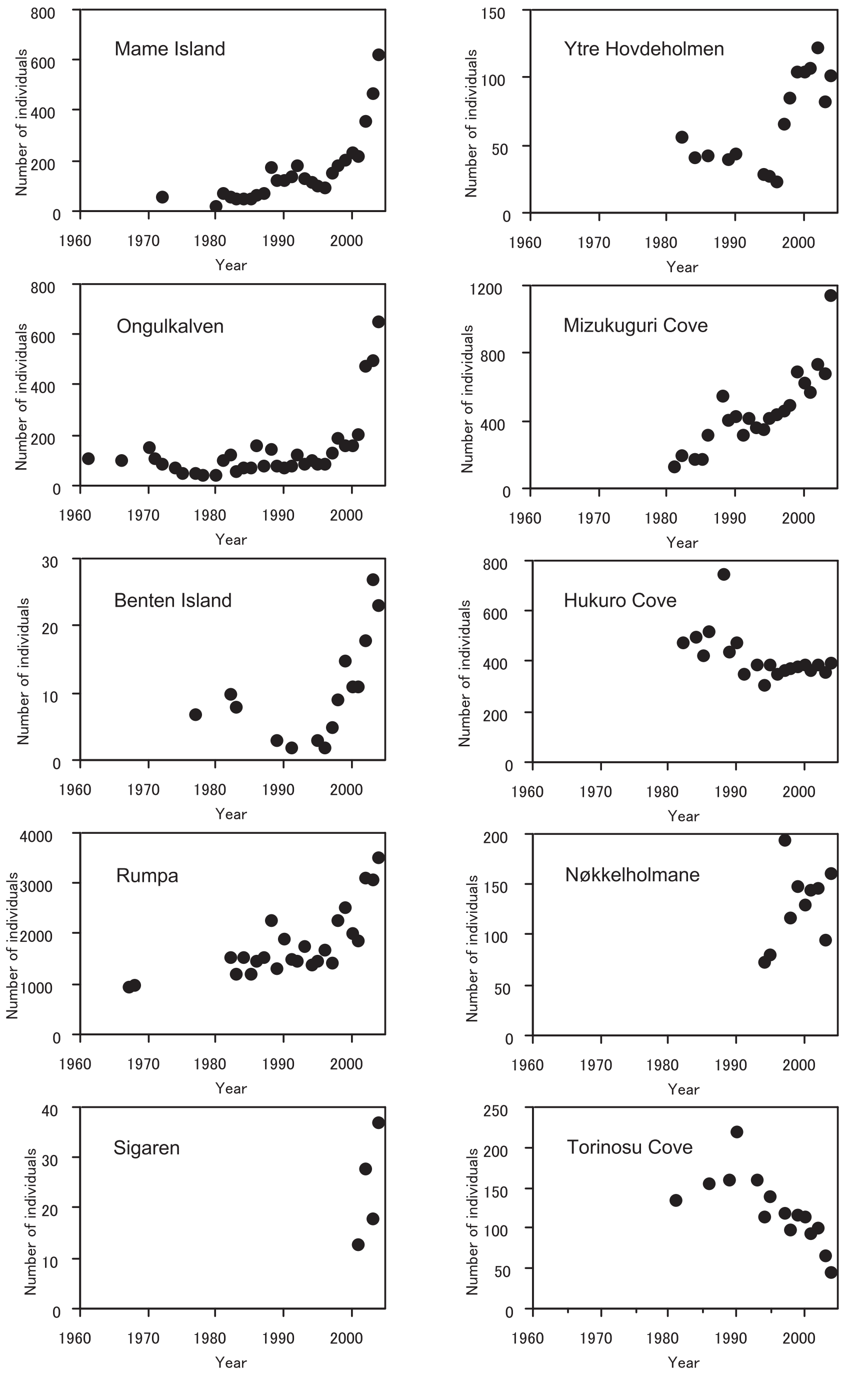

Fig. 2. Population changes in Adélie penguin colonies along the Sôya Coast.

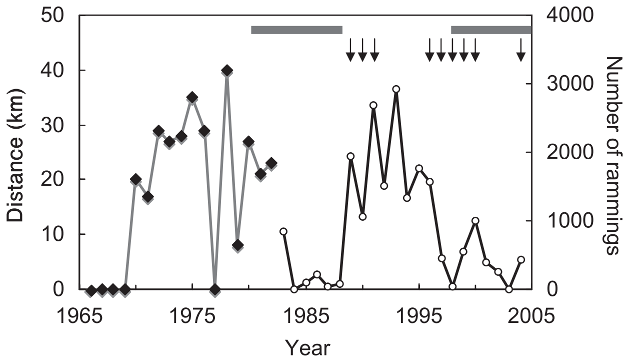

Fig. 3. Minimum distance between Syowa Station and the anchor point of the ice-breaker "*Fuji*" and the number of rammings by the icebreaker "*Shirase*" on approaching Syowa Station. Arrows show years when breeding and diet data were collected at Hukuro Cove colony. Horizontal bars show periods of sea ice break-ups in the Lützow-Holm Bay (Ushio, 2003).

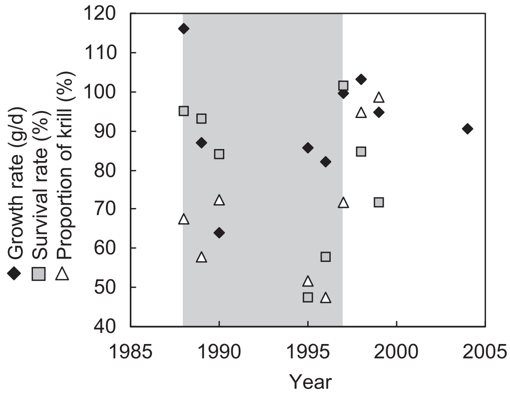

Fig. 4. Chick growth rate (closed diamonds), chick survival rate (gray squares) and proportion of krill in the diet (open triangles) of Adélie penguins breeding at Hukuro Cove colony (1989–91: Watanuki *et al*., 1992, 1993; 1995–1999: Takahashi, 2001; 2004: K. Sakamoto, unpubl. data). The hatched area represents periods without sea ice break-ups (Ushio, 2003).

zukuguri Cove, Hukuro Cove and Torinosu Cove, Fig. 2), and from the mid 1990s, populations started to increase rapidly in six colonies (Mame Island, Ongulkalven, Benten Island, Rumpa, Ytre Hovdeholmen and Mizukuguri Cove), remained stable in Hukuro Cove colony and decreased rapidly in Torinosu Cove (Table 1, Fig. 2).

Sea ice conditions in December in Lützow-Holm Bay have changed periodically since 1966 (Fig. 3). Light ice conditions were observed in the late 1960s and mid 1980s and continuously from the late 1990s to the present.

Breeding and diet data were available for 1989, 90, 91 (Watanuki *et al*., 1993), 95, 96, 97, 98, 99 (Takahashi, 2001) and 2004 (K. Sakamoto, unpublished data). Both chick survival and growth rates decreased during 1989–91 and were lower in 1995 and 96 than in 1997, 98 and 99 (Fig. 4). Penguins fed almost entirely on krill in 1998 and 99 and consumed a greater amount of fish in other years (Fig. 4). In 2004, the chick growth rate was relatively high and the main prey was krill (K. Sakamoto, unpublished data).

Discussion

Adélie penguin populations along the Sôya Coast have been increasing since the 1960s and this trend has been accelerating in the present decade. Near-surface temperatures did not show any change between 1960–2000 in Syowa Station (Turner *et al.*, 2005), while the extent of sea ice has increased in the past 20 years in the south Indian Ocean (Stammerjohn and Smith, 1997). In the 1980s and after the mid 1990s, when Adélie penguin populations increased in this area, snowfall was less and sea ice was thinner around Syowa Station than in the early and mid 1990s. Accordingly, break-ups of fast sea ice occurred frequently in the bay (Ushio, 2003; Ushio *et al.*, 2004). On the other hand, in the early and mid 1990s, snowfall was heavier, the sea ice cover was thicker and ice break-up did not occur.

Large-scale ice break-ups in the bay could be one reason for the increase in the Adélie penguin populations. Extensive sea ice during winter reduces subadult survival and population growth is very sensitive to the survival of juveniles (Wilson *et al.*, 2001). When ice break-ups occur frequently, sea ice cannot develop extensively; therefore, the subadult survival rate is expected to be higher during years with ice break-ups. Though the extent of sea ice in the Indian Ocean Sector has increased in the past 20 years (Stammerjohn and Smith, 1997), local sea ice conditions in the bay have varied, directly affecting the penguin populations.

During the period with ice break-ups occurring frequently, sea-ice conditions were not severe in the summer (Fig. 3) and both chick growth and chick survival rates of Adélie penguins breeding at Hukuro Cove colony tended to be higher than during periods without ice break-ups (Fig. 4). Sea ice conditions during the summer apparently affect the foraging behaviours and breeding success of Adélie penguins. That is, heavy sea ice during the summer increases the cost of transport when travelling from the ice edge to the breeding site (at the beginning of the breeding season) and between the breeding site and foraging site (later in the season) and it also restricts available foraging sites (Watanuki *et al.*, 1997; Ainley *et al.*, 1998). Diet composition is also affected by pack-ice distribution. In the Ross Sea area, fish are the main prey in years of little pack-ice, while krill, *Euphausia crystallorophias*, are consumed predominantly in years of heavy pack-ice cover (Ainley *et al.*, 1998). In Lützow-Holm Bay area, Adélie penguins feed both on krill (mainly *E. superba*) and fish (Watanuki *et al.*, 1994). In 1998 and 99, following ice break-ups, *E. superba* occupied >90% of the diet, while fish accounted for 30–60% of the diet in 1995, 1996 and 1997 (Takahashi, 2001). Both thick sea ice and snow layer reduce light penetration in the water (Odate *et al.*, 2004), hence restraining phytoplankton growth (Satoh *et al.*, 1986). Reversely, ice break-ups and little snow precipitation improve light penetration, thus increasing primary production in the bay. As a result, krill availability increases. On the other hand, Odate and Fukuchi (2004) suggested that high chlorophyll *a* concentration under heavy sea ice is induced by the horizontal advection of seawater. Sea ice also reduces the effect of wind on water movements. When an ice break-up occurs, the strength of the current entering into the bay increases, pushing the phytoplankton and krill into the bay.

As suggested by Smith *et al.* (1999), sea ice conditions cause Adélie penguin population increases in this area. However, the rapid population increase after the mid 1990s (9–26% annual) is unusual. Compared to the late 1980s, large-scale ice break-ups have occurred every year since the late 1990s. We therefore need to continue monitoring Adélie penguin populations in this area and investigate population trends in relation to environmental change.

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