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Distribution and reproductive behavior of penguins on Ardley Island and their environmental impact factors

Sun Weiping (孙维萍)[1,2*], Cai Minghong (蔡明红)[3], Wang Haiyan (王海燕)[4], Xing Chuang (邢闯)[5], Lu Bing (卢冰)[1], H. U. Peter[6] and A. Froehlich[6]

1 *Second Institute of Oceanography, SOA, Hangzhou 310012, China*

2 *Zhejiang University, Hangzhou 310027, China*

3 *Polar Research Institute of China, Shanghai 200129, China*

4 *Institute of Microbiology, Chinese Academy of Sciences, Beijing 100081, China*

5 *National Marine Forecasting Center, SOA, Beijing 100081, China*

6 *Institute of Ecology, Friedrich Schiller University, JENA, Germany D-07743*

* *E-mail: sunwp1998@hotmail.com*

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Abstract During the 2006/07 Antarctic summer, the species population, distribution and reproductive behavior of penguins in areas near the Great Wall Station were investigated. Five species of penguin were recorded: gentoo penguin (*Pygoscelis papua*), adelie penguin (*P. adeliae*), chinstrap penguin (*P. antarctica*), King penguin (*Aptenodytes patagonicus*) and Emperor penguin (*A. forsteri*). The first three species bred locally, while the other two species were observed occasionally. Ardley Island is one of the most important breeding areas for penguins. After the breeding season of 2006/07, there were a total of about 17 234 penguins and the breeding success rate was 0.40—1.41. Comparing with historical data, changes in penguin species populations and distribution were analyzed, and their relationships with the environment, climate change and human activity were investigated.

Key words Antarctica, Penguins, Species Distribution, Breeding Success, Environment and Climate Change.

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1 Introduction

Penguins are one of the most populous vertebrates in Antarctica and account for more than 90% of birds in Antarctica. As seabirds, they spend most of their lives in and near the ocean. Penguins take the ocean as their sole food (e.g., krill) resource and are at the top of the food chain in the Southern Ocean. Because of their particular status in the Antarctic ecosystem, including in terms of tropic level and energy transmission, the ecological investigation of penguins, especially their potential as a biological indicator of global environmental change, is an important part of research into

the life science of Antarctica. International studies on Antarctic birds have focused on (1) the long-term monitoring of dynamic changes of species, including changes in the population of dominant species, distribution of species and breeding factors[1], (2) the status of birds in mass transfer and energy transformation processes in the Antarctic ecosystem[2], and (3) effects of climate and environmental change and human activity on Antarctic birds, and effective protective measures[3-5]. The first investigation on Antarctic birds around the Great Wall Station was carried out in 1990[6]. There have since been investigations on ecology[7], population structure and breeding success[8], prey activity of dominant species[9], organochlorine pesticides in penguin blood in monitoring the environment[10] and other works. However, there is still a lack of relatively comprehensive studies on the species distribution, breeding activity and survival of penguins, especially on the relationship between the dynamic changes of species and global climate change. This paper systematically focuses on ecological studies of penguins around the Great Wall Station and determines a relation between species dynamic change and global climate change to provide scientific information to international Antarctic organizations responsible for planning environmental protection of sea areas of the Antarctica and the life-forms within.

2 Study area and methods

2.1 Study area

Areas previously studied are located at and near the Great Wall Station (62° 13′ S, 58° 58′ W), the ice-free area of Fildes Peninsula and Ardley Island; most works to date have focused on Ardley Island. Ardley Island was designated an ecological reserve by the Scientific Committee on Antarctic Research. The island is flat (with the highest elevation of 70 m) and has an area of about 2 km^2. Vegetation covers 70-80% of the island, most of which is moss and lichen. Regional annual precipitation is about 600—700 mm, most falling as snow. The average temperature in summer is above 0 ℃. The east coast of Ardley Island has the biggest penguin colony in the South Shetland Islands at present, and is also home to other seabirds, such as skuas and swallows. The wide Maxwell Bay provides plentiful food such as krill and fish for the penguins. Penguins prey on about 33 170 000 t of krill each year, which accounts for almost 90% of the total consumption by Antarctic seabirds. As one of the top predators in the Southern Ocean, penguins directly affect substance cycles in the Antarctic seas and are a sensitive biological indicator of environmental change on different scales because of the limited biodiversity in the Southern Ocean.

2.2 Methods

Separate colonies were directly observed in a biological investigation of regional penguins. Penguin species, activity type and characteristics and breeding performance were recorded during the periods of hatching and feeding and the period shortly before chicks began swimming. According to weather and tides, regular observations

were made with a zodiac supplied by Bellingshausen Station and irregular observations were made on foot. When most penguins were brooding or guarding small chicks, the breeding size was counted according to the method of nest counting[11], which involved searching for colonies, counting the nests in each colony usually two or three times to ensure accuracy, and recording the nest contents such as numbers of eggs and chicks. It was assumed that each bird attending a nest represented a breeding pair. Where colonies were divided, breeding groups were assumed to belong to the same colony unless separated by more than 50 m or by a major topographical feature[12]. The residence, breeding performance and other factors relating to breeding were also recorded. One hundred or two hundreds nests within one colony of each penguin species were selected and the breeding success after hatching was determined, where the average number of chicks in the late-crèche stage (about 8 weeks) per breeding pair was assumed as the breeding success rate.

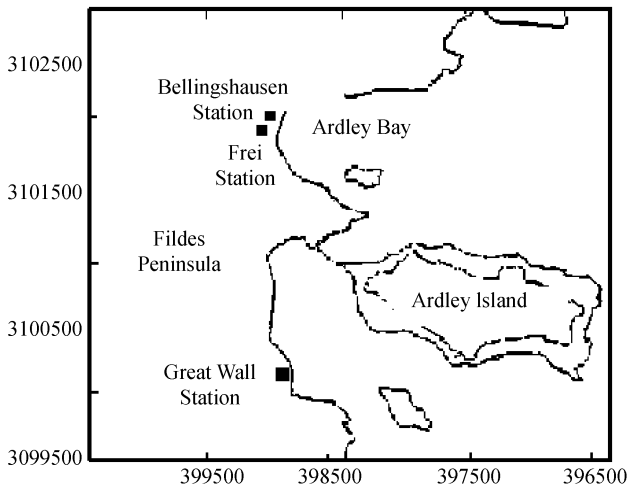

Fig. 1 Geography of Ardley Island.

3 Results and discussion

Through biological observation of the penguins around the Great Wall Station from December 2006 to February 2007, the population size, species distribution, and breeding activity and their relationships with climate, environment and human activity were analyzed.

3.1 Species and population

There were hundreds of chinstrap penguins (*Pygoscelis antarctica*) in ice-free areas of Fildes Peninsula, Shihmen Peninsula on the west coast, northwest coast, isles to the north of Huashan Peninsula and Dart Island during the investigation period. Two penguin colonies were found near the Nelson ice shelf, including five penguin families and most being chinstrap penguins (data provided by Echo Base). Breeding species on Ardley Island were mainly gentoo (*Pygoscelis papua*), adelie

(*Pygoscelis adeliae*) and chinstrap penguins. Emperor penguins (*Aptenodytes forsteri*) were mainly on the Antarctic continent, and very few appeared on Ardley Island as passing migrants; they did not partake in breeding activities on the island. In early January 2007, several King penguins were found near the Ardley sand bar, and they left three weeks later after molting in mid-January. King penguins (*Aptenodytes patagonicus*) were found in Biological Bay on the west coast, but no macaroni penguins (*Eudyptes chrysolophus*) were seen. According to previously obtained data[9], macaroni penguins once appeared on Fildes Peninsula. Table 1[8] compares the penguin species distribution and residence in the vicinity of the Great Wall Station in the 2006/07 season with historic data.

Table. 1 Distribution and residence of penguins in the vicinity of the Great Wall Station in the 2006/07 season compared with historical data

Species	1993/94			2006/07		
	Location	Residence	Breeding	Location	Residence	Breeding
Gentoo *Pygosceli papua*	Ardley island	October to February	+	Ardley Island	October to end of February	+
Adelie *Pygoscelis adeliae*	Ardley Island	October to March	+	Ardley island	October to beginning of February	+
Chinstrap *Pygosceli antarctica*	Ardley Island and its surrounds	October to March	+	Ardley Island and its surrounding	October to March	+
King penguin *Aptenodytes patagonicus*	Biological Bay	End of January to mid-February	−	Biological Bay	January to February	−
Emperor penguin *Aptenodytes forsteri*	Marsh Base	Beginning of October to mid-October	−	Ardley sand bar	January, left after 3 weeks and only one remained	−
Macaroni penguin *Eudyptes chrysolophus*	Ardley Island	End of January to mid-February	−	Not seen		

Notes: + with breeding activity, − without breeding activity

During the 2006/07 season, a total of 9 724 penguins were recorded on Ardley Island, including 4 429 pairs of gentoo penguins, 423 pairs of adelie penguins and 10 pairs of chinstrap penguins. There were a total of 17 234 penguins after the breeding season. It was clear that gentoo penguins were the absolute dominant species on Ardley Island and they accounted for more than 90% of all penguins. Adelie penguins were the second most dominant group and chinstrap penguins were the least. According to the observations of Wang[9], who recorded the numbers of gentoo, adelie and chinstrap penguins as 4 400 810, and 24 pairs on Ardley Island, respectively, the population size on the island fluctuated greatly within the short space of 5 years. The population of gentoo penguins, the dominant species, fluctuated relatively little and the results of the two investigations were similar. The populations of adelie and chin-

strap penguins decreased sharply in the 5 years, and the 2006/07 populations were only half the 2001/02 populations, or even less. There was a similar situation on Badun Peninsula opposite Ardley Island. Badun Peninsula, which is 25 km from Ardley Island, was the main habitat for chinstrap penguins. There were 5 200 chinstrap penguins on Badun Peninsula in 2001[14], but only 2 967 in 2006 (data are supported by observations made at King Sejong Station of Korea).

The results show that Ardley Island is the main breeding colony for penguins in the region. During hatching and feeding, there was a strict boundary between nests and the male and female individuals fed in turn to ensure breeding success. Two-month-old chicks had similar individual size to their parents and increased appetite. They lived together in a large group without a nest boundary under the protection of several adult penguins when both parents went hunting, similar to the situation of a kindergarten. The following are the breeding performances determined from observations on Ardley Island.

(1) Gentoo penguins usually laid two eggs from November to December, and seldom one or three eggs. An egg was bluish white with a long axis of 66.0 to 74.0 mm, short axis of 56.0 to 60.5 mm and weight of 115.0 to 160.0 g. Chicks hatched from November to late January, and molted after about 105 days. Breeding pairs would molt in February.

(2) Adelie penguins usually laid two eggs in the middle of November, and seldom only one egg. An egg was ultramarine in color with a long axis of 62.0 to 76.0 mm, short axis of 48.0 to 60.5 mm and weight of 77.0 to 150.0 g. Chicks hatched in mid-or late December, and molted after about 90 days. Breeding pairs would molt from late January to early March.

(3) Chinstrap penguins usually laid two eggs in early December, and seldom only one egg. An egg was bluish white with a long axis of 62.0 to 75.0 mm, short axis of 50.0 to 54.0 mm and weight of 80.0 to 120.0 g. Chicks hatched from late December to mid-January, and molted after about 135 days. Breeding pairs would molt from February to early March.

The observations indicate that about 7510 chicks survived to the late-crèche stage in the 2006/07 season on Ardley Island, including 7 040 gentoo chicks, 460 adelie chicks and 10 chinstrap chicks. The breeding success rates for the three kinds of penguins were 1.41, 1.10 and 0.40 chicks per pair respectively. Compared with the historic statistical data on breeding success on Ardley Island[13] (Fig. 2), the breeding success of gentoo penguins on the island was higher than that of the other two penguin species since 1993/94, and that of chinstrap penguins was lowest. The breeding success of gentoo and adelie penguins did not fluctuate so much during the statistical period and they had a similar trend before 2002/03. After the 2002/03 season, the breeding success of gentoo penguins increased, but the breeding success of adelie penguins decreased. The breeding success of chinstrap penguins changed similarly to the success rates of the other two species of penguins before 1999/2000, but it fluctuated greatly afterward. No chinstrap chicks survived in the 2003/04 season, but the breeding success in the following 2004/05 season was the highest achieved in the past

13 years. There are many factors of the breeding success of seabirds, such as species population, guarantee of food resources, climate, environment, breeding experience of breeding pairs, human disturbance[14] and the activities of the other species and predators around the colonies[15]. The high breeding success seen in our study was probably due to the large population, which has such advantages as breeding experience, resistance to abnormal climate and predators, and sourcing food. The situation for chinstrap penguins with a small population size on Ardley Island was the opposite and their breeding success was significantly affected by the climate and environment. The "zero" breeding success of chinstrap penguins in the 2003/04 season was most probably due to especially heavy snow in the winter of 2003 and the delay of the following spring. The average monthly temperatures for December, January, and February in the following breeding seasons were −1.3 ℃, 1.1 ℃, and 1.5 ℃ respectively in 2003/04, 0.3 ℃, 1.3 ℃, and 1.9 ℃ respectively in 2004/05, and 0.0 ℃, 2.7 ℃, and 2.4 ℃ respectively in 2005/06[13]. It is clear that the temperature in December 2003 was lower, and this unusual climate phenomenon probably led to the low breeding success of chinstrap penguins in that year.

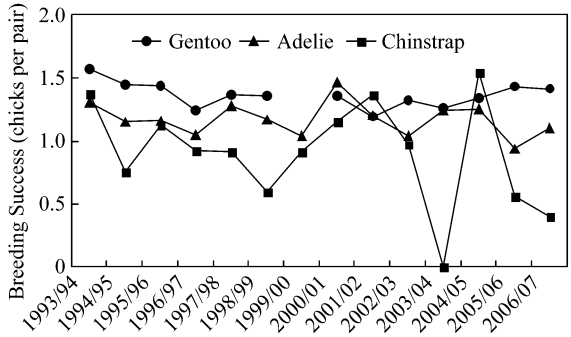

Fig. 2 Breeding success of penguins on Ardley Island[13].

3.3 Effects of climate, environment and human activity on species population

There were mainly three penguin species breeding on Ardley Island: gentoo, adelie and chinstrap penguins, with gentoo penguins being the dominant species. The different species have similar behavior in terms of foraging, using resources and selecting nest sites, and they are especially sensitive to food. The food chains in Antarctica are relatively simple because of the special geography and fragile ecosystem. The main food of penguins on Ardley Island is krill, although they also feed on fish, amphipods and cephalopods[6]. According to previous research, krill accounts for 81.79%, 86.87% and 100% of the food of adelie, gentoo and chinstrap penguins, respectively. Because the main food resource is krill for the three penguin species, there must be intense food competition among them. As relatively disadvantaged groups, adelie and chinstrap penguins are more sensitive to a change in food resources. From the middle of the 20th century, there has been an obvious climate change on the Antarctic Peninsula with global warming, and the average temperature

in winter has increased almost 6 ℃[16]. Warming has led to receding of the Antarctic ice sheet and it has reduced significantly the living areas available to penguins. It has also led to a reduction in the stocks of Antarctic krill. The populations of adelie and chinstrap penguins, which are more sensitive to food resources, has reduced since the late 1980s (Fig. 3) with a sharp decline in the krill production since the mid-1980 s[17]. However, the population of gentoo penguins on Ardley Island has been relatively stable and even increased slightly over the past 20 years, which was probably due gentoo penguins not having such strong dependence on ice habitats[16]. Robertson[12] reported that gentoo penguins were rare in colonies with great numbers of king penguins and emperor penguins. He deemed that there was probably intense competition for survival between gentoo penguins and the other two penguin species and that gentoo penguins were obviously disadvantaged. More research is needed to determine whether the phenomenon of the population of gentoo penguins remaining stable or even increasing while the populations of adelie and chinstrap penguins dramatically decreased relates to the adelie and chinstrap penguins being disadvantaged in the competition for survival.

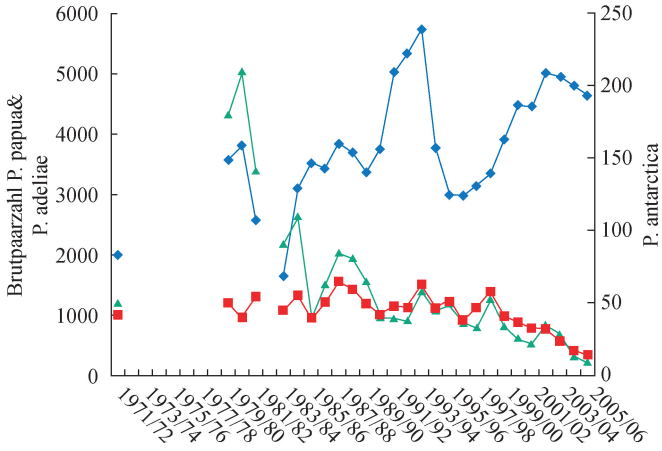

Fig. 3 Penguin breeding population on Ardley Island during the past 35 years[13].

The above discussion suggests that the fluctuation in penguin population size is closely related to climate change. Scientists have found that climate anomalies such as the El Niño/La Niña-Southern Oscillation could change the climate and environment in Antarctica to some degree, because EI Niño has a close relation with Antarctic circulation and the Antarctic sea ice[18, 19]. Vargas[20] reported that El Niño affected marine primary productivity through changing the equatorial current and further had biological effects on penguins through food chains. Figure 3 shows that the population of chinstrap penguins was much smaller in the following non-EI Niño years than in EI Niño years such as 1982/83, 1986/87, 1991/92, 1997/98 and 2005/06. The population of adelie penguins had similar tendency to that of chinstrap penguins, but not to that of gentoo penguins. Therefore, research is required to determine whether the decrease in the population of chinstrap penguins was directly related to

an Antarctic climate abnormity during the EI Niño period and why there was not a similar change for gentoo penguins.

Species fluctuations of penguins are not only related to the Antarctic climate but also closely to their living environment. Human activity could also have a direct or indirect effect on penguin survival, but the degree would be quite different for different species. When a researcher moved around adelie penguins, the level of vigilance increased, which was common behavior for the birds, and returned to its original level when the disturbance disappeared[21]. However, the "vigilance" level of gentoo penguins remained relatively high 5 minutes after the disappearance of the disturbance[15]. Such different behavior indicates that gentoo penguins were more sensitive to human disturbance. At the same time, the species population also affected the response of penguins to human disturbance. Giese's research carried out in the Vestfold Hills[14] found that research works obviously reduced hatchability and the chick survival rate in the case of small populations of penguin species (with an average number of nests in the region of 44), but had almost no influence in the case of large populations (with an average number of nests in the region of 70). Penguins are a specially protected species of Antarctic bird, and they have been protected for a long time and are more abundant than other birds in Antarctica. However, human activity disturbs penguins to some degree, especially during breeding. Our observations indicate that gentoo penguins were the most cowardly and abandoned their eggs when facing a threat during breeding season; adelie penguins would protect their nests and chinstrap penguins were most willing to protect their nests and were also much more sensitive to human disturbance. The population of chinstrap penguins has decreased rapidly since the end of the 1970s (Fig. 3), from more than 200 pairs to only 10 pairs in the 2006/07 season. Gentoo and adelie penguins mainly lived on Ardley Island, where landing was permitted only under official permission. However, chinstrap penguins preferred to take their activities to the beach in front of the Great Wall Station[6], and thus, they were much more disturbed by human activity. Since the building of Bellingshausen—the first research station built by Russia—in 1968, more and more stations have been built, including Frei Station and Escudero Station of Chile, Artigas Station of Uruguay and the Great Wall Station of China. The building of airports and stations, increased numbers of researchers and tourism, and more frequent scientific exploration activity (involving ships and helicopters) on the Fildes Peninsula have adversely affected penguins. Because of the sensitivity and vulnerability of penguins to the climate and environment, the future of these species is not optimistic when considering the growth of human expeditions on the Antarctic continent without protective measures.

4 Conclusions

Investigations carried out in the austral summer of 2006/07 indicate that Ardley Island is home to the most important breeding colonies of penguins in this region. A total of 7 510 chicks were counted to survive to the late-crèche stage of the breeding

cycle at the end of the breeding season, including 7 040 gentoo, 460 adelie and 10 chinstrap chicks, with the breeding success rates per breeding pair being 1.41, 1.10 and 0.40, respectively. The populations were slightly lower and the breeding success rates higher compared with 2005/06 records.

Climate change, food sources and human activity all affected the population sizes of penguins on Ardley Island. Chinstrap penguins were more sensitive to human disturbance than the other two species of penguin, especially during breeding season. Increased human activity (e.g., increasing tourism, disturbance from ships and helicopters) were probably one of the most important factors leading to the decrease in the chinstrap population. However, in the present study, it was difficult to establish whether the decrease in the chinstrap population was due to pressure from the climate and environment or part of the natural biological evolution of birds. More studies are required to clarify this. In any event, chinstrap penguins are a biological indicator of a crisis facing the ecological environment at present.

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