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Pygoscelid penguins breeding distribution and population trends at Lions Rump rookery, King George Island

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Abstract: Long term changes (46 years) in the abundance of pygoscelid penguins breeding populations and nests distribution in the Lions Rump (King George Island) colony were investigated in three time intervals, according to previously published two censuses and one original study conducted in 2010. At that time a detailed colony map based on the GIS system was made. Results of this study showed different trends for each investigated species. In the last three decades Adélie penguin breeding populations showed strong declining tendencies (69.61%). In contrast, the population of gentoo penguins represents the reverse trend, increasing 171.85% over the same period. Observed changes in both penguin population sizes are reflected in the different spatial and geographic distribution of their nests. The population changes observed at the Lions Rump colony are consistent with the relevant pygoscelid penguin tendencies in the western Antarctic Peninsula region. Breeding penguin population dynamics at Lions Rump area with a minimal disturbance by human activity may well illustrate a natural response of those birds to environmental changes in the Antarctic.

Key words: Antarctic, South Shetlands, *Pygoscelis*, spatial structure, population trends.

Introduction

Lions Rump is situated on King George Island in the South Shetland archipelago, West Antarctic. This ice-free area contains diverse biota and geological features representing examples of the terrestrial, freshwater, and littoral habitats of the maritime Antarctic. Lions Rump area was posted as an Antarctic Specially Protected Area No. 151 to protect its ecological values. This reference site with its diverse avian and mammalian fauna, has been subjected to minimal disturbances by human activity except for occasional monitoring of the mammal and bird populations, as well as geological, geomorphological and botanical studies. Lions Rump area is a breeding site of three penguin species, the Adélie (*Pygoscelis adeliae*), gentoo (*P. papua*) and chinstrap (*P. antarcticus*).The majority of breeding pairs at this site are Adélie and gentoo penguins. The populations of these three species in the South Shetlands have been undergoing rapid changes with significant fluctuation (Ciaputa and Sierakowski 1999; Hinke *et al.* 2007; Sander *et al.* 2007; Chwedorzewska and Korczak 2010; Korczak-Abshire 2010; Trivelpiece *et al.* 2011; Korczak-Abshire *et al.* 2012).

The earliest information about penguin populations at Lions Rump was given by Stephens in 1958 who roughly estimated their breeding population (Croxall and Kirkwood 1979; after: Stephens in 1958 unpublished). More comprehensive studies come from works by Jabłoński (1984) and Trivelpiece *et al.* (1987) who conducted censuses of all breeding penguin populations on King George Island and the later studies by Ciaputa and Sierakowski (1999) from the mid-1990s focused on the Lions Rump rookery. Due to differences in census timing and techniques applied by each of the authors, some discrepancies between the early and later results may appear. However, census results up to 1996 reveals that the most numerous species breeding in the area were Adélie penguins accompanied by a few nests of chinstraps.

King George Island is located in the Antarctic Peninsula region, a region of dynamic climate characterised by variable maritime conditions which make this region particularly susceptible to climate change. Annual temperature trends observed at King George Island show a significant temperature rise of about 0.4°C/10 years (King *et al.* 2003). This increase of air temperature is positively correlated with the increase of sea surface temperature and decrease of sea ice concentration in the Bellingshausen Sea (*e.g.* King 1994; Marshall *et al.* 2002; Vaughan *et al.* 2003). A result of climate warming during recent decades is significant glacier retreats observed on King George Island (*e.g.* Park *et al.* 1998; Braun and Goßmann 2002). Biological response of seabirds to such environmental perturbations may be manifested by changes in distribution, population sizes and densities, phenology, behavior, community interactions, morphology or physiology and migration patterns (Trathan *et al.* 2007).

The aim of this study was to compare the long term (46 years) changes in the abundance of breeding penguin pairs and nests distribution in the Lions Rump colony. In 2008, twelve years after the last penguin breeding population study on Lions Rump, the census of *Pygoscelis* penguins nests was recorded and then repeated in the next two breeding seasons. A map of this colony based on the GIS system was made. Additionally, the published data by Croxall and Kirkwood (1979), Jabłoński (1984) as well as Ciaputa and Sierakowski (1999) enabled us to analyze breeding population sizes in fifteen-year intervals from 1965. Due to local minimal environmental disturbance caused by human activity and significant climate warming in the South Shetlands region, the changes in breeding populations of penguins at Lions Rump may represent the natural response of the penguin populations to recent environmental changes in the Antarctic.

Materials and methods

The investigated penguin colony is situated in the Antarctic Specially Protected Area No. 151 (ASPA 151), formerly the Site of Special Scientific Interest No. 34 (SSSI No. 34) (Fig. 1). The study area includes approximately 1.3 km^2 at the western shore of King George Bay at King George Island (South Shetland Islands, West Antarctic) (Fig. 1).

In the three breeding seasons (2008/09, 2009/10 and 2010/11) the total number of nests in the Lions Rump penguin colony were calculated during the egg incubation period applying two different methods depending on the breeding group size. Counts of Adélie and gentoo breeding groups with ≤ 500 nests followed the CCAMLR Ecosystem Monitoring Program standards. The number of occupied nests in each breeding group was recorded one week after the peak of egg laying (e.g. Nov 4th 2008, Nov 18th 2009 and Nov 10th 2010). Three separate counts were made for each group on the same day. If one of counts differed over 5% from the others, the procedures were repeated until the criteria were fulfilled. The population size was calculated using an average of the three obtained numbers. Breeding groups with more than 500 nests (mainly Adélie) were photographed from cliffs when at 70–90% of the nests at least only one of the mates was present (e.g. Nov 6th 2008, Nov 21st 2009 and Nov 13th in 2010). These high quality and high resolution images were processed and the numbers of occupied nests were counted from the images.

To assess multidecadal trends in the population dynamics of the studied penguin species (Fig. 2) the published data from the following years: 1965, 1980, 1981 and from 1994 to 1996 were used (Croxall and Kirkwood 1979; Jabłoński 1984; Trivelpiece *et al.* 1987; Ciaputa and Sierakowski 1999). To describe the changes in breeding pair numbers over time, linear regression of log transformed data was employed. Pearson's correlation coefficient (r) was used to test statistical significance of the changes. Intrinsic annual rates of population changes were determined as follows (Caughley 1977; after van den Hoff *et al*. 2009):

$$R = (lnN_t - lnN_0)/t$$

where: lnN_t – natural logarithm of the population size at time t, lnN_0 – natural logarithm of the population at starting time, t – time interval (years) between population counts.

Data from 1965 (Croxall and Kirkwood 1979) were not included in the statistical analyses due to the roughness of the estimation. It should be noted that the cen-

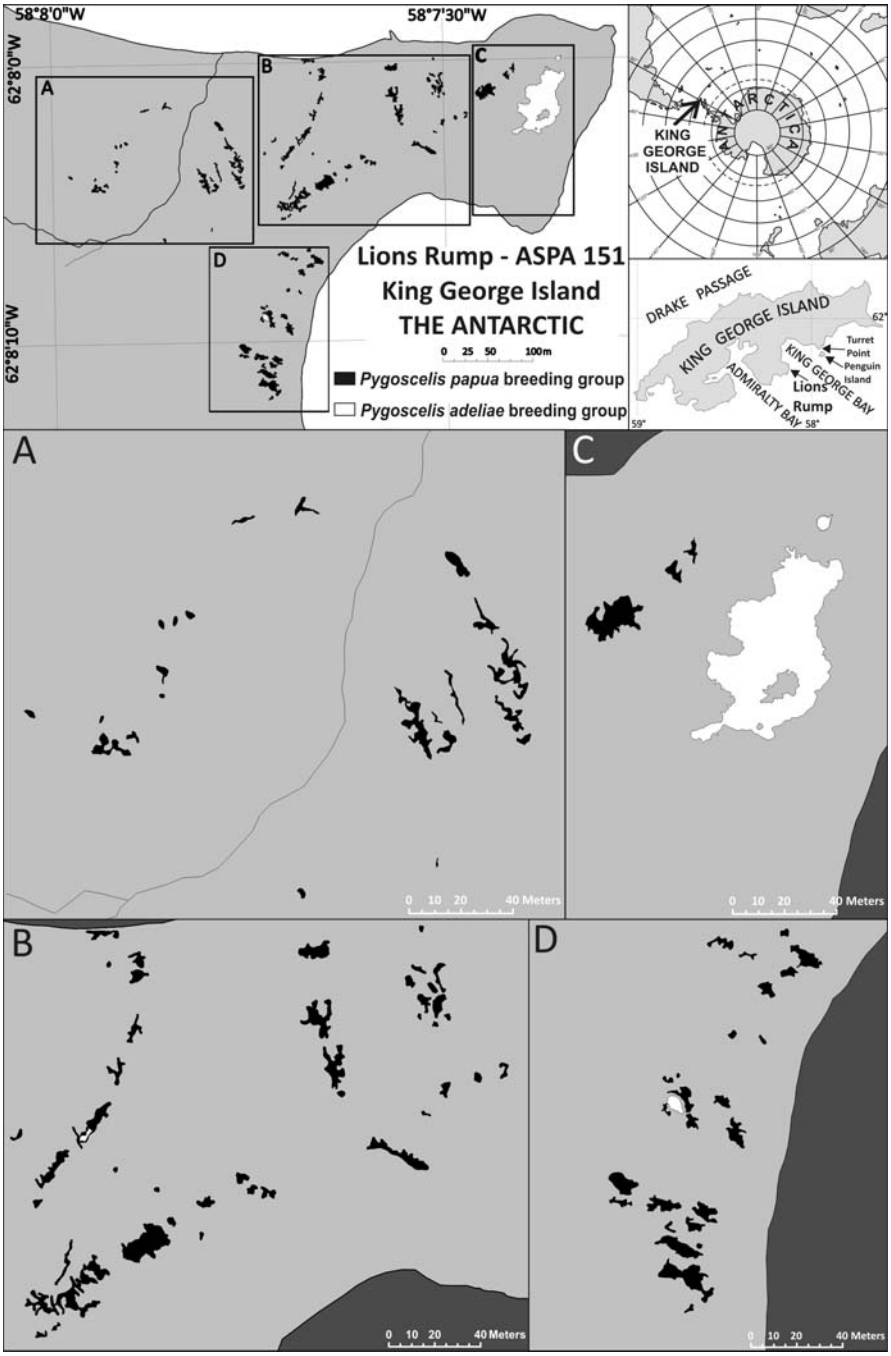

Fig. 1. Distribution of *Pygoscelis adeliae* and *Pygoscelis papua* breeding groups in Lions Rump penguin colony in 2010/2011 season, the Antarctic Specially Protected Area No. 151 (ASPA 151), King George Island, South Shetlands, Western Antarctic. A, B, C and D sub-figures present enlarged images of Lions Rump penguin colony area.

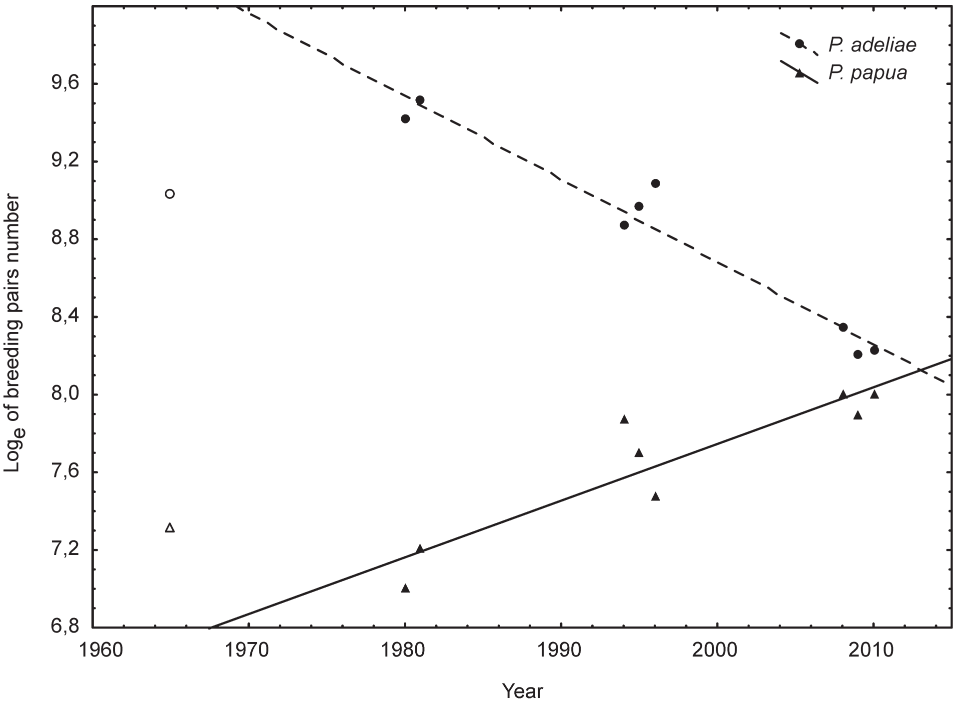

Fig 2. Natural logarithms of the numbers of Adélie and gentoo penguins breeding pairs between 1965 and 2010 at Lions Rump colony, King George Bay, King George Island, South Shetlands, the Antarctic. Historical data after: Croxall and Kirkwood (1979) – 1965 (hollow symbols, not included in the regression analyses); Jabłoński (1984) – 1980; Trivelpiece *et al.* (1987) – 1981; Ciaputa and Sierakowski (1999) – 1994 to 1996. *P. adeliae*: r = -0.9761; p = 0.00003; r^2 = 0.9528; *P. papua*: r = 0.9139; p = 0.0015; r^2 = 0.8352.

sus made by Trivelpiece *et al.* (1987) was conducted one week after the respective peaks of egg laying, whereas census by Jabłoński (1984) and Ciaputa and Sierakowski (1999) were conducted later in the season. The analyses were performed using StatSoft, Inc. (2011) and STATISTICA 10.0 software.

Additionally, a digital map of the colony arrangement was elaborated. The map was developed in two steps. During the field work the observers conducted monitoring of individual penguin breeding groups in 2008/09, 2009/10, and 2010/11 seasons. The distributional limits of an individual group were marked using a system of track-logs running on the Magellan Mobile Mapper 6 GPS (software ESRI® ArcPad 7.0). Boundaries of each breeding group were determined counterclockwise along the border, so that the extent of the group marked the set of points describing consecutive numbers. All track-logs had the projection GCS WGS 1984 Geographic Coordinate System. In the next stage, the collected track-logs were transformed into closed features (shape files) as polygons using ESRI® ArcMAP™ 10.0 application. The polygons were given a new projection Transverse Mercator Projection, WGS 84 Spheroid; Central Meridian: 57W, Reference Latitude 0. The applied method described above was used before to determine the boundaries of plant communities (Węgrzyn *et al.* 2011; Olech *et al.* 2011). The current coastline and the main proglacial river were marked on the map. Beginning from the season 2008/09 annual detailed calculation of each breeding group area was estimated by ArcGIS application.

Results

A comparison of nest census data (Table 1) and dispersion of breeding groups from different breeding seasons was conducted to follow the population dynamics of pygoscelid penguins from Lions Rump. Based on the published and the original data (see Tables 1 and 2) the number of nests in three fifteen year intervals: from1965/66 to 1980/81, from 1980/81 to 1995/96, from 1995/96 to 2010/11 were analyzed. In 1965, estimate (10–15%) of 1500 and 8400 breeding pairs of gentoo and Adelie, respectively, were noted (Table 1). In the 1980/81 1105 gentoo and 12345 Adélie nests were recorded, so the population of gentoo decreases (26.3%) while Adélie population increased (46.9%) in the first fifteen year interval (Table 1). In the second and the third intervals the tendencies in populations are reversed. The number of Adélie penguin breeding pairs decreased by 36.6% in the second interval, and further by 52.1% in the third interval (Table 2). On the contrary, the population of gentoo penguins increased by 99.7% and by 36.1% in the second and third interval, respectively (Table 1). The annual intrinsic rates of change (*R*) between 1980/81 and 2010/11 were -4% for Adélie and 3.3% for gentoo. Decrease of abundance in population of Adélie and increase in population of gentoo between 1980/81 and 2010/2011, which was based on the natural logarithm of nests numbers counted, were statistically significant, with $p < 0.001$ and $p < 0.05$, respectively, and they represented almost linear correlations, with the Pearson's coefficient values -0.9761 and 0.9139, respectively (Fig. 2).

Changes in the breeding population of chinstrap penguins on Lions Rump were significant, however, due to the small number of nests these changes were irrelevant (Tables 1 and 2). In 1965 no nests of chinstrap penguins in the rookery were observed (Croxall and Kirkwood 1979).

The range of penguin breeding groups and the number of breeding pairs within these groups were estimated in 2010/11 and was compared with data from the 1995/96 Lions Rump breeding colony (Table 2). According to the archival data from 1995/96 about 91% of Adélie penguin breeding birds were concentrated in one big nesting group on the Lions Rump rock; the remaining 5% of nests were in two middle size groups (>100 nests <1,000 nests) and 4% of nests were in six small groups (<100 nests). In 2010/11, about 96% of Adélie breeding pairs were concentrated in one big nesting group on the Lions Rump rock (Fig. 1C), while the remaining 4% of nests were in three small groups (<100 nests) shared with gentoo penguins (Table 2).

Table 1

Number of breeding pairs (submitted as nests) of *Pygoscelis adeliae, P. papua* and *P. antarcticus* in different breeding seasons at the Lions Rump colony, King George Bay, King George Island, South Shetlands, the Antarctic. Changes in the number of breeding pairs in fifteen year intervals: from1965/66 to 1980/81 (I), from 1980/81 to 1995/96 (II), from 1995/96 to 2010/11 (III) expressed as a percentage. a – Croxall and Kirkwood (1979), b – Jabłoński (1984), c – Trivelpiece *et al.* (1987), d – Ciaputa and Sierakowski (1999).

Species	Census year									Ffifteen year intervals		
	1965/66[a]	1980/81[b]	1981/82[c]	1994/95[d]	1995/96[d]	1996/97[d]	2008/09	2009/10	2010/11	I (%)	II (%)	III (%)
P. adeliae	8400	12345	13580	7113	7825	8882	4216	3661	3751	+46.9	-36.6	-52.1
P. papua	1500	1105	1348	2642	2207	1759	2996	2699	3004	-26.3	+99.7	+36.1
P. antarcticus	0	10	12	16	7	3	11	24	32		- 30.0	+357.1

Table 2

The number of breeding groups and the total number of breeding pairs (submitted as nests) of *Pygoscelis papua, P. adeliae* and *P. antarcticus* in 1995/96 and 2010/11 breeding seasons at the Lions Rump colony. Due to the different number of nests in particular breeding group the three main categories of breeding group size were distinguished: <100 nests; >100 nests and <1000 nests; >1000 nests. * Historical data 1995/96 collected by Sierakowski, archive of the Department of Antarctic Biology.

Size of breeding group	*Pygoscelis papua*				*Pygoscelis adeliae*				*Pygoscelis antarcticus*			
	1995/96*		2010/11		1995/96*		2010/11		1995/96*		2010/11	
	number of breeding groups	total number of nests	number of breeding groups	total number of nests	number of breeding groups	total number of nests	number of breeding groups	total number of nests	number of breeding groups	total number of nests	number of breeding groups	total number of nests
<100 nests	77	1676	124	2257	7	332	5	141	2	7	5	32
>100 nests and <1,000 nests	4	531	5	747	2	357	0	0	0	0	0	0
>1,000 nests	0	0	0	0	1	7136	1	3610	0	0	0	0
total	81	2207	129	3004	10	7825	6	3751	2	7	5	32

On the contrary, gentoo penguin nest sites in, both 1995/96 and 2010/11 were dispersed in many groups over a variety of landforms (Fig. 1, Table 2). In 2010/11 about 75% of gentoo penguin nests were concentrated in small size groups (<100 nests) and the remaining 25% of the nests were in middle size groups (>100 nests). In 1995/96 76% of breeding pairs were concentrated in small breeding groups (<100 nests) and the remaining 24% in more numerous middle ones (>100 nests <1,000 nests). In 1995/96 and 2010/11 most of the gentoo penguin sites (~80%) were situated on moraines of the White Eagle Glacier which retreated during the twentieth century (Angiel and Dąbski 2012) so some of the present nest sites were covered by ice in 1956. The remaining gentoo penguin nests were positioned on elevated bedrock exposures on the Lions Rump rock and on raised beaches.

Discussion

Penguin populations are good indicators of ecosystem status and therefore they are one of the best studied marine birds in the Antarctic (e.g. Croxall *et al.*2002; Forcada *et al.* 2006; Hinke *et al.* 2007; Sander *et al.* 2007; Trathan *et al.*2007; Forcada *et al.* 2008; Trivelpiece *et al.* 2011). In the last two centuries the main principal changes in the distribution and abundance of the top-marine predators of the Southern Ocean were caused by human over-exploitation of sea resources (Croxall *et al.*1992). Since a recent introduction of the directives to protect the endangered species, climate change is thought to have the main influence on bird and mammal population conditions (Wilson *et al.* 2001; Hinke *et al.* 2007; Korczak-Abshire 2010; Korczak-Abshire *et al.* 2011). Observation of bird and pinniped population dynamics on Lions Rump gives paramount reference to address the influence of pure natural climate changes on the ecosystem in contrast to the western part of King George Island with significant human impact (nine permanent and three summer stations); see Lityńska-Zając *et al.* (2012).

A comparison of the long term (46 years) changes in the abundance of two penguin species, Adélie and gentoo and their breeding populations as well as nests distribution in the Lions Rump colony showed different population trends and represent opposite dynamics (Fig. 2).

Croxall and Kirkwood (1979) reported, that in 1960 Downham described that Adélie penguins in the Lions Rump colony were divided into one large and one much smaller sub-colonies. Also the number of breeding pair counts done early in the 1965 seasons is difficult to interpret. However, even taking into account the inaccuracy of the estimation made by Croxall and Kirkwood (1979), it can be assumed that the Adélie population increased between 1965 and 1980. Trivelpiece and Volkman (1979) suggested that the decimation of marine mammals of the Southern Ocean during the latter half of the 19th and the early 20th centuries made some species of seabirds, including penguins, to increase in abundance. According to this thesis the Adélie population rise was a natural response to an increase in the food supply. This so-called "Krill Surplus" is still invoked to explain the population dynamics of some other krill predators. The less numerous gentoo population on Lions Rump in the same period decreased insignificantly (Jabłoński 1984). However, due to a small population size this decrease might be negated by accuracy error. In the second and third intervals the tendencies in populations reversed.

A decrease in the Adélie population (overall 69.61 %, annual rate of decline (*R*) -4%) was accompanied with an increase in the gentoo population (overall 171.85 %, annual rate of decline (*R*) 3.3%). In the 2010/11 season the breeding population sizes for Adélie and for gentoo were very similar.

After the absence of a breeding populations of chinstrap penguins on Lions Rump in the 1960s (Croxall and Kirkwood 1979), a small population of these birds has been observed since the 1980s. We can speculate, that the recently noted increase in the breeding pair number (32 in 2010/11) originated from penguins migrating from the nearest chinstrap penguin rookeries at Turret Point, Penguin Island or Admiralty Bay. In 1980/81 breeding season the King George Island chinstrap penguin population has been estimated to 302388 pairs (Jabłoński 1984), so the Lions Rump rookery represents only a fragment of the population inhabiting this island.

The last fifteen years of penguin population studies on Lions Rump show significant changes in the distribution and range of breeding groups (Fig. 2, Table 2), which stays congruent with population size tendencies. Reduction in the number of Adélie breeding groups is probably the result of the population decline. Gentoo penguins, whose breeding population increased over fifteen years, almost 40%, spread to adjacent areas.

After abandoning seal and whale hunting, human presence on Lions Rump was sporadic and its interference on the environment was minor. Since then, the most significant human disturbance on penguin populations on Lions Rump was reported by Stephens (1958) who noted 1000 eggs collected on Lions Rump on 1 November 1957, although it was not indicated if this practice had occurred in other seasons (Croxall and Kirkwood 1979). After the first reports by Stephens, one day censuses of breeding populations of penguins were made several times (Croxall and Kirkwood 1979; Jabłoński 1984; Ciaputa and Sierakowski 1999). In the South Shetlands intensive whaling exploitation took place in the early twentieth century (Chwedorzewska 2009). Intensive commercial fishing for fish and krill in the area began in the early 1970s (Everson and Goss 1991; Croxall and Nicol 2004) and continues up to the present day (Nicol *et al.* 2012). Over the last 50 years the area has experienced major warming with consequent reductions in seasonal sea ice (Turner *et al.* 2005). Further, variations in the timing of sea ice coverage have been linked to physical forcing driven by the El Niño-Southern Oscillation (ENSO) and Southern Annular Mode (SAM) (Yuan and Martinson 2000; Yuan 2004; Turner 2004; Stammerjohn *et al.* 2008; Dunn *et al.* 2011). The decrease in sea ice cover was followed by a period of limited krill abundance, which is the main source of food for Adélie and chinstrap penguins, and also, although to a lesser extent, for gentoo (Fraser *et al.* 1992; Hinke *et al.* 2007; Trivelpiece *et al.* 2011). In particular, strong correlations between indices of penguin and krill recruitment suggest that Adélie and chinstrap penguins in the South Shetlands may live under an increasingly krill-limited system that has disproportionate effects on the survival of juvenile birds (Hinke *et al.* 2007). In contrast to Adélie and chinstrap penguins, gentoo prey essentially opportunistically on various crustaceans, fish and cephalopods (Bost and Jouventin 1990) although significant geographical, seasonal and interannual variations are observed. Their diet is dominated by fish, squid, or amphipods at more northerly locations (Robinson and Hindell 1996; Pütz *et al.* 2001; Lescroël *et al.* 2004; Miller *et al.* 2009). So the flexibility to target variable prey, also hunting at greater depths in different habitats (benthic and pelagic), greater plasticity in breeding phenology, as well as no preference for specific nesting sites would be favorable for this species in the investigated area (Hinke *et al.* 2007; Trivelpiece *et al.* 2011; Lynch *et al.* 2012).

Ciaputa and Sierakowski (1999) interpreted changes in the Lions Rump penguin colony in terms of food availability ("Krill Surplus" and different species diet preferences), environmental warming in the Antarctic Peninsula and human-related disturbances. However, our results for the last fifteen years show that human-related disturbances probably are currently not a significant factor shaping the penguin population tendencies on Lions Rump. Firstly, the direct human disturbance on this region is minor. Secondly, the decrease of Adélie penguins was higher in the Lions Rump region than in breeding sites in Admiralty Bay where two permanent and two summer stations and two refuges are located (Chwedorzewska and Korczak 2010; Korczak-Abshire 2010). An example of disappearing penguin nesting areas due to human activity in the vicinity of research station which was recorded by Chwedorzewska and Korczak (2010) is not taking place in the Lions Rump rookery. Therefore, as climate change progresses it will be important to continue monitor these impacts on penguin populations on King George Island.

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References

ANGIEL P.J. and DĄBSKI M. 2012. Lichenometric ages of the Little Ice Age moraines on King George Island and of the last volcanic activity on Penguin Island (West Antarctica). *Geografiska Annaler, Series A: Physical Geography* 94: 395–412.

Antarctic Protected Areas Database ASPA 151: Lions Rump, King George Island, South Shetland Islands http://www.ats.aq/devPH/apa/ep_protected_detail.aspx?type=2andid=55andlang=e

BOST C.A. and JOUVENTIN P. 1990. Evolutionary ecology of the gentoo penguin *Pygoscelis papua*. *In*: L. Davis and J. Darby (eds) *Penguin biology*. Academic Press, San Diego: 85–112.

BRAUN M. and GOSSMANN H. 2002. Glacial changes in the area of Admiralty Bay and Potter Cove, King George Island, Antarctica. *In*: M. Beyer and M. Boelter (eds) *GeoEcology of Terrestrial Antarctic Oases*. Springer Verlag, Berlin-Heidelberg: 75–89.

CHWEDORZEWSKA K.J. 2009. Terrestrial Antarctic ecosystems at the changing world – An overview. *Polish Polar Research* 30: 263–273.

CHWEDORZEWSKA K.J. and KORCZAK M. 2010. Human impact upon the environment in the vicinity of *Arctowski* Station, King George Island, Antarctica. *Polish Polar Research* 31: 45–60.

CIAPUTA P. and SIERAKOWSKI K. 1999. Long-term population changes of Adélie, chinstrap, and gentoo penguins in the regions of SSSI No. 8 and SSSI No. 34, King George Island, Antarctica. *Polish Polar Research* 20: 355–365.

CROXALL J.P. and KIRKWOOD E.D. 1979. *The distribution of penguins on the Antarctic Peninsula and islands of the Scotia Sea*. Life Science Division, British Antarctic Survey, Cambridge: 186 pp.

CROXALL J.P. and NICOL S. 2004. Management of Southern Ocean Fisheries: global forces and future sustainability. *Antarctic Science* 16: 569–584.

CROXALL J.P., CALLAGHAN T., CERVELLATI R. and WALTON D.W.H. 1992. Southern Ocean Environmental Changes: Effects on Seabird, Seal and Whale Populations [and Discussion]. *Philosophical Transactions of the Royal Society B: Biological Sciences* 338: 319–328.

CROXALl J.P., TRATHAN P.N. and MURPHY E.J. 2002. Environmental change and Antarctic seabird populations. *Science* 297: 1510–1514.

DUNN M.J., SILK J.R.D. and TRATHAN P.N. 2011. Post-breeding dispersal of Adélie penguins (*Pygoscelis adeliae*) nesting at Signy Island, South Orkney Islands. *Polar Biology* 34: 205–214.

EVERSON I. and GOSS C. 1991. Krill fishing activity in the southwest Atlantic. *Antarctic Science* 3: 351–458.

FORCADA J., TRATHAN P.N. and MURPHY E.J. 2008. Life history buffering in Antarctic mammals and birds against changing patterns of climate and environmental variation. *Global Change Biology* 14: 2473–2488.

FORCADA J., TRATHAN P.N., REID K., MURPHY E.J. and CROXALL J.P. 2006. Contrasting population changes in sympatric penguin species in association with climate warming. *Global Change Biology* 12: 411–423.

FRASER W.R., TRIVELPIECE W.Z., AINLEY D.G. and TRIVELPIECE S.G. 1992. Increases in Antarctic penguin populations-reduced competition with whales or a loss of sea ice due to environmental warming. *Polar Biology* 11: 525–531.

HINKE J.T., SALWICKA K., TRIVELPIECE S.G., WATTERS G.M. and TRIVELPIECE W.Z. 2007. Divergent responses of *Pygoscelis* penguins reveal a common environmental driver. *Oecologia* 153: 845–855.

JABŁOŃSKI B. 1984. Distribution and numbers of penguins in the region of King George Island (South Shetland Islands) in the breeding season 1980/1981. *Polish Polar Research* 5: 17–30.

JABŁOŃSKI B. 1986. Distribution, abundance and biomass of a summer community of birds in the region of the Admiralty Bay (King George Islands, South Shetland Islands, Antarctica) in 1978/79. *Polish Polar Research* 7: 217–260.

KING J.C. 1994. Recent climate variability in the vicinity of the Antarctic Peninsula. *International Journal of Climatology* 14: 357–369.

KING J.C., TURNER J., MARSHALL G.J., CONNOLLEY W.M. and LACHAN-COPE T.A. 2003. Antarctic Peninsula climate variability ant its causes as revealed by analysis of instrumental records. *In*: E. Domack, A. Leventer, A. Burnett, R. Bindschadler, P. Convey and M. Kirby (eds) Antarctic Peninsula Climate Variability. *Antarctic Research Series, Amercian Geophysical Union, Washington DC* 79: 17–30.

KORCZAK-ABSHIRE M. 2010. Climate change influences on Antarctic bird populations. *Papers on Global Change* 17: 53–43.

KORCZAK-ABSHIRE M., ANGIEL P.J. and WIERZBICKI G. 2011. Records of white-rumped sandpiper (*Calidris fuscicollis*) on the South Shetland Islands. *Polar Record* 47: 262–267.

KORCZAK-ABSHIRE M., CHWEDORZEWSKA K.J., WĄSOWICZ P. and BEDNAREK P.T. 2012. Genetic structure of declining chinstrap penguin *(Pygoscelis antarcticus)* populations from South Shetland Islands (Antarctica). *Polar Biology* 35:1681–1689.

LESCROËL A., RIDOUX V. and BOST C.A. 2004. Spatial and temporal variation in the diet of the gentoo penguin (*Pygoscelis papua*) at Kerguelen Islands. *Polar Biology* 27: 206–216.

LITYŃSKA-ZAJĄC M., CHWEDORZEWSKA K.J., OLECH M., KORCZAK-ABSHIRE M. and AUGUSTYNIUK-KRAM A. 2012. Diaspores and phyto-remains accidentally transported to the Antarctic Station during three expeditions. *Biodiversity and Conservation* 21: 3411–3421.

LYNCH H.J., FAGAN W.F., NAVEEN R., TRIVELPIECE S.G., and TRIVELPIECE W.Z. 2012. Differential advancement of breeding phenology in response to climate may alter staggered breeding among sympatric pygoscelid penguins. *Marine Ecology Progress Series* 454: 135–145.

MARSHALL G.J., LAGUN V. and LACHLAN-COPE T.A. 2002. Changes in Antarctic Peninsula tropospheric temperatures from 1956–1999: A synthesis of observations and reanalysis data. *International Journal of Climatology* 22: 291–310.

MILLER A.K., KARNOVSKY N.J. and TRIVELPIECE W.Z. 2009. Flexible foraging strategies of gentoo penguins *Pygoscelis papua* over 5 years in the South Shetland Islands, Antarctica. *Marine Biology* 156: 2527–2537.

NICOL S., FOSTER J. and KAWAGUCHI S. 2012. The fishery for Antarctic krill – recent developments. *Fish and Fisheries* 13: 30–40.

OLECH M., WĘGRZYN M., LISOWSKA M., SŁABY A. and ANGIEL P. 2011. Contemporary changes in vegetation of polar regions. *Papers on Global Change* 18: 35–53.

PARK B.K., CHANG S.K. and YOON H.I. 1998. Recent retreat of ice cliffs, King George Island, South Shetland Islands, Antarctic Peninsula. *Annals of Glaciology* 27: 633–635.

PÜTZ K., INGHAM R.J., SMITH J.G. and CROXALL J.P. 2001. Population trends, breeding success, and diet composition of gentoo *Pygoscelis papua*, magellanic *Spheniscus magellanicus* and rockhopper *Eudyptes chrysocome* penguins in the Falkland Islands. *Polar Biology* 24: 793–807.

ROBINSON S.A. and HINDELL M.A. 1996. Foraging ecology of gentoo penguins *Pygoscelis papua* at Macquarie Island during the period of chick care. *Ibis* 138: 722–731.

SANDER M., BALBÃO T.C., COSTA E.S., SANTOS C.R. and PETRY M.V. 2007. Decline of the breeding population of *Pygoscelis antarctica* and *Pygoscelis adeliae* on Penguin Island, South Shetland Antarctica. *Polar Biology* 30: 651–654.

SIERAKOWSKI K. 1991. Birds and mammals in the region of SSSI No. 8 in the season 1988/89 (South Shetlands, King George Island, Admiralty Bay). *Polish Polar Research* 12: 25–54.

STAMMERJOHN S.E., MARTINSON D.G., SMITH R.C., YUAN X. and RIND D. 2008. Trends in Antarctic annual sea ice retreat and advance and their relation to El Niño-Southern Oscillation and Southern Annular Mode variability. *Journal of Geophysical Research Oceans* 113: 1–20.

TRATHAN P.N., FORCADA J. and MURPHY E.J. 2007. Environmental forcing and Southern Ocean marine predator populations: effects of climate change and variability. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362: 2351–2365.

TRIVELPIECE W.Z., TRIVELPIECE S.G. and VOLKMAN N. 1987. Ecological segregation of Adélie, gentoo, and chinstrap penguins at King George Island, Antarctica. *Ecology* 68: 351–361.

TRIVELPIECE W.Z., HINKE J.T., MILLER A.K., REISS C.S., TRIVELPIECE S.G. and WATTERS G.M. 2011. Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica. *Proceedings of the National Academy of Sciences* 108: 7625–7628.

TURNER J. 2004. The El Niño-southern oscillation and Antarctica. *International Journal of Climatology* 24: 1–31.

TURNER J., COLWELL S.R., MARSHALL G., LACHLETON A.M., CARLETON-COPE T.A., JONES P.D., LAGUN V., REID P.A. and IAGOVKINA S. 2005. Antarctic Climate Change During the Last 50 Years. *International Journal of Climatology* 25: 279–294.

Scientific Committee for the Conservation of Antarctic Marine Living Resources. 2004. *Commission for the Conservation of Antarctic Living Marine Resources Ecosystem Monitoring Program (CEMP) Standard Methods for Monitoring Studies*. Hobart, Australia (revised). http://www.ccamlr.org/pu/e/e_pubs/std-meth04.pdf

VAN DEN HOFF J., MCMAHON C.R., and FIELD I. 2009. Tipping back the balance: recolonization of the Macquarie Island isthmus by king penguins (*Aptenodytes patagonicus*) following extermination for human gain. *Antarctic Science* 21: 237–241.

VAUGHAN D.G., MARSHALL G.J., CONNOLLEY W.M., PARKINSON C., MULVANEY R., HODGSON D.A., KING J.C., PUDSEY C.J. and TURNER J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change* 60: 243–274.

WĘGRZYN M., LISOWSKA M., OLECH M. and OSYCZKA P. 2011. Methods and materials. Botanical research. *In*: W. Ziaja (ed.) *Transformation of the natural environment in Western Sørkapp Land (Spitsbergen) since the 1980s*. Jagiellonian University Press, Kraków: 23–24.

WILSON P.R., AINLEY D.G., NUR N., JACOBS S.S., BARTON K.J., BALLARD G. and COMISO J.C. 2001. Adélie penguin population change in the Pacific sector of Antarctica: relation to sea-ice extent and the Antarctic Circumpolar Current. *Marine Ecology Progress Series* 213: 301–309.

YUAN X.J. and MARTINSON D.G. 2000. Antarctic sea ice extent variability and its global connectivity. *Journal of Climate* 13: 1697–1717.

YUAN X.J. 2004. ENSO-related impacts on Antarctic sea ice: a synthesis of phenomenon and mechanisms. *Antarctic Science* 16: 415–425.

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