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ORIGINAL PAPER

Abundance estimation of Adélie penguins at the Esperanza/Hope Bay mega colony

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Abstract

The Adélie penguin (*Pygoscelis adeliae*) breeding population at Esperanza/Hope Bay, at the tip of the Antarctic Peninsula, is one of the largest Adélie penguin colonies in Antarctica. Nevertheless, the last known published field count during the egg-laying period is from 1985/1986. We counted breeding pairs within the entire colony, consisting of 274 breeding groups, during the 2012/2013 breeding season for comparison with previously published ground and satellite-derived counts. We also counted breeding pairs in 26 breeding groups that have been monitored annually since 1995/1996. We estimated the current population size to be 104,139 (95th-percentile CI 70,126–138,151) breeding pairs for the whole colony. The counts indicate population declines of 15.9% over 27 years in the whole colony and 37.5% over 18 years in the annually monitored subset of breeding groups, respectively. The observed decrease matches recent trends reported in other Adélie penguin colonies throughout the western Antarctic Peninsula and southern Scotia Sea. This population assessment contributes to the current estimates of the total predator populations in the region, which is necessary information for the management of marine living resources.

Keywords *Pygoscelis adeliae* · Breeding population size · Population decline · Antarctic Peninsula

Introduction

The Scotia Sea is one of the most productive areas in the southwest Atlantic sector, from the western Antarctic Peninsula (AP) to the Antarctic Convergence along the Scotia Arc (Steinberg et al. 2012). Roughly one-third the global population of Adélie penguins (*Pygoscelis adeliae*) breed in this region (Lynch and Larue 2014) where numerous reports indicate that Adélie breeding populations are decreasing at most sites (Forcada et al. 2006; Carlini et al. 2007, 2009; Hinke et al. 2007; Schofield et al. 2010; Trivelpiece et al. 2011; Lynch et al. 2012a; Korczak-Abshire et al. 2013; Lynch and LaRue 2014; Juáres et al. 2015). Against this backdrop of population decline, several human activities take place, including research, tourism, and fishing for Antarctic krill (*Euphausia superba*).

The fishery for Antarctic krill, hereafter krill, is mainly concentrated in a few regions of the Scotia Sea (Kawaguchi et al. 2009), and the potential impacts of krill catches on wildlife remain a research and management priority for the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). To evaluate the potential

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impacts of the krill fishery on the Antarctic ecosystem, estimates of total predator abundance and their consumption of krill, the principal prey of Adélie penguins in the Antarctic Peninsula region (e.g., Volkman et al. 1980; Lishman 1985; Coria et al. 1995), are required (Hewitt et al. 2004). Here, we seek to update estimates of total Adélie abundance with direct counts of the breeding population size of Adélie penguins at Esperanza/Hope Bay, one of the largest Adélie penguin colonies in the world (Lynch and LaRue 2014).

The Adélie penguin colony at Esperanza/Hope Bay, Antarctic Peninsula contained 123,850 breeding pairs during the 1985/1986 season (Myrcha et al. 1987). No complete ground counts of the entire colony have been completed since that time, but Lynch and LaRue (2014) used satellite images from 2011 to estimate a population size of roughly 104,182 pairs (CI 63,828–169,227). Given the large size of the Esperanza/Hope Bay colony, traditional ground counts of penguins require considerable effort and are not always possible to complete in a timely manner. While it may be useful to use alternative methods, such as remote cameras (e.g., Southwell et al. 2013, 2015), aerial surveys (e.g., Lyver et al. 2014; Goebel et al. 2015), satellite remote sensing (e.g., Lynch et al. 2012b; Lynch and LaRue 2014; Humphries et al. 2017), or opportunistic visits to penguin breeding colonies using ships of opportunity (e.g., Naveen et al. 2000), to provide more instantaneous information on breeding population size, these methods all benefit from validation with ground counts that are conducted to coincide with breeding chronology (CCAMLR 2004). Thus, we report a whole-colony estimate of the abundance of Adélie penguins at Esperanza/Hope Bay from the ground for the first time since 1985 to improve progress toward estimating overall predator abundance and krill consumption in the Antarctic Peninsula region. We also report on the 18-year change of 26 breeding groups to place the whole-colony count in the context of long-term trends observed within the colony.

Finally, we note that mega-colonies, which we define as those with > 100,000 breeding pairs, of Adélie penguins are rare (Lynch and Larue 2014), but play an important role in regulating local resource availability (Ainley et al. 2004) and in source-sink dynamics of local meta-populations (Dugger et al. 2010). Despite their important ecological and demographic role, few mega-colonies are monitored and counted regularly. Adélie penguin colonies are usually composed of multiple, distinct sub-groups of varied size and shape (Ainley 2002) that together compose the breeding colony. As nesting success can be affected by the size and shape of sub-groups (Tenaza 1971; Emslie et al. 1985), colony growth and size may be affected by the distribution of sizes of its sub-groups. To improve understanding of this mega-colony we also report on the distribution of sub-group sizes in the Esperanza/Hope Bay colony.

Materials and methods

Study area

The present study was carried out at Esperanza/Hope Bay (63°24′S, 57°01′W; Fig. 1), at the tip of the Antarctic Peninsula. The Adélie penguin colony at Esperanza/Hope Bay is a collection of numerous smaller breeding groups that served as counting units. Following Carlini et al. (2007), we defined a breeding group as an aggregation of birds nesting in a geographically continuous unit. The aggregation of all nesting groups was regarded as a colony. In this colony, systematic monitoring of 26 breeding groups, hereafter the 'subset', has been conducted since the 1995/1996 breeding season and we compare whole-colony population change to population changes observed in this subset (Fig. 1).

Census of the entire colony

During the 2012/2013 breeding season, the entire population of breeding Adélie penguins at the Esperanza/Hope Bay colony was censused. From mid-October to the first week of November, the colony was visited every 2 days to locate and map, with a handheld GARMIN GPSMAP® 60CSX receiver (accuracy of ± 4 m), all breeding groups and to monitor breeding chronology throughout the colony. The census was then conducted from November 14 to December 4. During this time, two strong storms (on the 15th and from the 21st to 24th of November) delayed the counts.

A total of 274 breeding groups were identified during the 2012/2013 season. To estimate the number of breeding pairs in each breeding group, we made three separate counts for 209 of those breeding groups according to standard CCAMLR Ecosystem Monitoring Program methods for estimating breeding population size (CCAMLR 2004). During each count, the number of nests with eggs (i.e., active nests, defined as those nests with eggs present or when birds were observed lying down in a nest) and the number of occupied nests (i.e., pairs standing in an empty nest) were recorded. The sum of the average values for active and occupied nests was considered as the total number of breeding pairs. Furthermore, the measured perimeters were used to estimate the area (m^2) of 30 of these 209 sub-groups (mean = 211.53, SD = 113.57, range 50–632 m^2) to determine a mean nest density of 1.09 ± 0.5 nests/m^2. The numbers of breeding pairs in the remaining 66 groups were estimated based on its area (range 63–10,590 m^2) and the estimated mean nest density due to their large extension.

We note that Adélie penguins exhibit strong site fidelity to nesting sites; it is unlikely that birds counted early

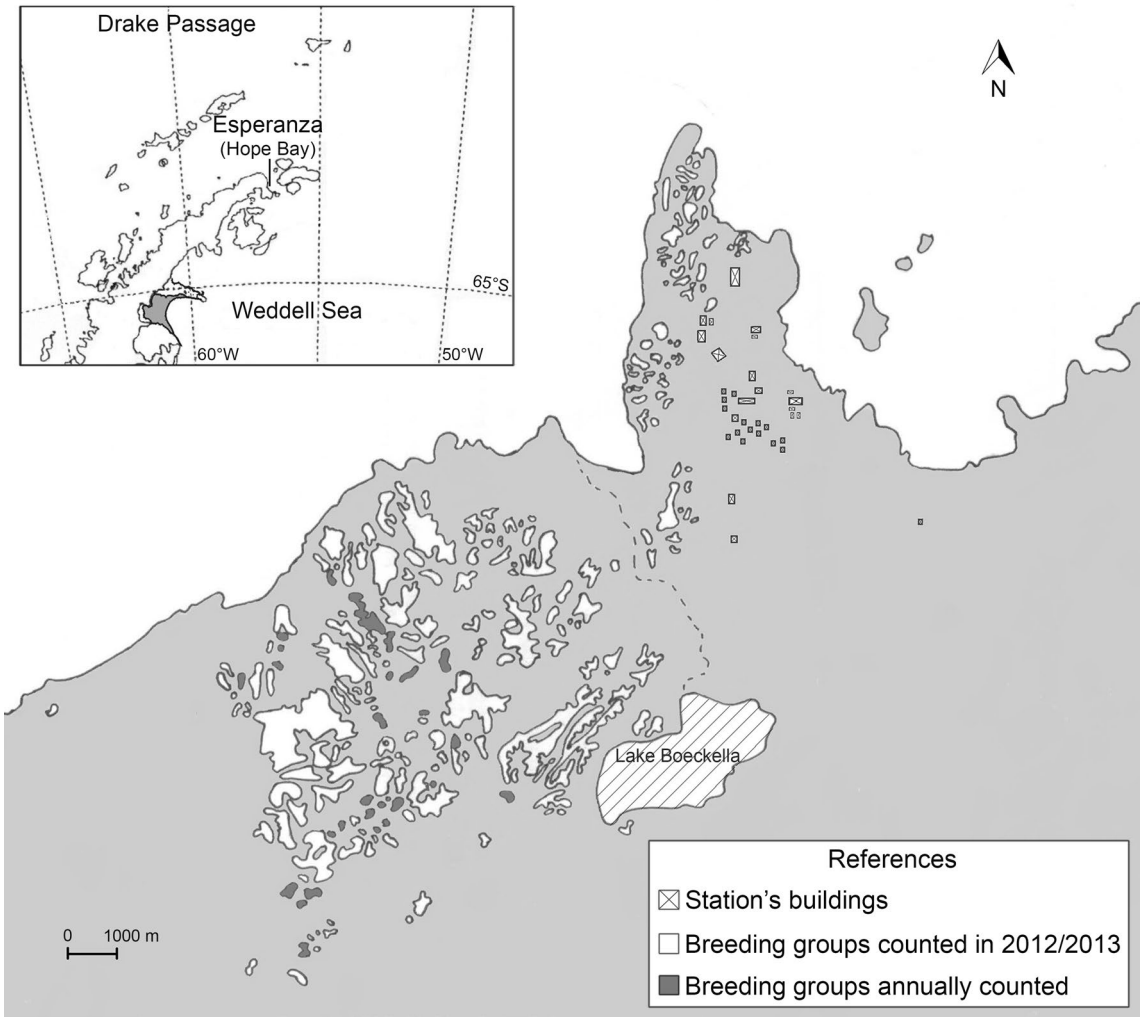

Fig. 1 Location of 274 breeding groups of Adélie penguins (*Pygoscelis adeliae*) at Esperanza/Hope Bay, at the tip of the Antarctic Peninsula, during the 2012/2013 season. The 26 selected breeding groups counted each year are shown in black

during our census period relocated to other, uncounted breeding groups during the counting period, thus minimizing any possible double-counting. The introduction of negative bias on our census due to nest failure during the census period was accounted for by daily monitoring of a sample of nests ($n = 100$ total) in the subset for abandonment. The proportion of abandoned nests in the sample was updated daily and time matched with the census to adjust counts.

Breeding population size estimated from selected breeding groups

During 1995/1996 and 2012/2013, 26 selected breeding groups (Fig. 1) were counted by eye three times 1 week after peak egg-laying (typically from November 14–20), and the mean number of breeding pairs was recorded (CCAMLR 2004).

Population growth rates

We compared population growth rates for the entire colony (274 breeding groups) and for the 26 selected groups. For each data set, we estimated annual population growth rates (λ) as:

$$\lambda = \left(\frac{N_{s2}}{N_{s1}}\right)^{T^{-1}}.$$

N represents the breeding population size in season s (e.g., $s1$: 1985/1986 and $s2$: 2012/2013) and T is the number of seasons between the two surveys (e.g., $T = 27$). Lambda (λ) indicates if the population increases ($\lambda > 1$), decreases

($\lambda < 1$), or remains stable ($\lambda = 1$) over time (Caswell 1989). Note that values of *s* and *T* differ for the two data sets.

Following Lynch and LaRue (2014), to take into account the variation around the estimation of the 26 breeding groups, we used the 95th-percentile confidence intervals (±2 SD) of the census recorded in 1995/96 and 2012/13, in order to classify the change as ''increasing'' or ''decreasing''. Unfortunately, this comparison is not feasible to perform with the entire census due to in Myrcha et al. (1987), the variability is not reported.

Results

Abundance and size structure of the colony

The total breeding population size was estimated as 104,139 (95th-percentile CI 70,126–138,151) breeding pairs in 2012/2013. A previous census conducted in this colony in 1985/1986 estimated 123,850 breeding pairs (Myrcha et al. 1987) in 280 breeding groups. This represents a decline of 15.9% ($\lambda = 0.99$) in the mean number of breeding pairs and a net loss of six breeding groups in 27 years.

During the 2012/2013 census, we found that 203 (i.e., 74.1%) of the 274 breeding groups contained between three and 300 breeding pairs (Fig. 2), but these birds only represent 21.0% of the breeding population (i.e., 21,900 pairs). Only three breeding groups (1.1%) contained more than 4000 breeding pairs (i.e., 4171; 6172 and 11,543 pairs; Fig. 2) representing a 21.0% of the total abundance. For comparison, the size distribution of breeding groups during in the Copacabana colony in Admiralty Bay, King George/25 de Mayo Island (62°10′S, 58°30′W) during 2012/2013 was generally composed of smaller groups ($n = 12$ breeding groups, median = 45 pairs, mean = 170 pairs, max = 831 pairs; Hinke, unpublished data). At Esperanza/Hope Bay, the median breeding group size was 127 pairs; the mean was 380 pairs; and the largest breeding group was composed of 11,543 breeding pairs.

Breeding population size from the subset of breeding groups

From 1995/1996 to 2012/2013, the breeding population of the subset of 26 breeding groups decreased from 5096 (95th-percentile CI 4937–5256) to 3184 (95th-percentile CI 3135–3233) breeding pairs, which represents a decrease of 37.5% over 18 years ($\lambda = 0.97$). The lack of overlap between the confidence intervals supports this result.

Discussion

The Esperanza/Hope Bay colony is, in terms of abundance, the fourth largest Adélie colony (104,139 breeding pairs) in the Peninsula region after Heroina Island (751,527 breeding pairs; Borowicz et al. 2018), Beagle Island (284,535 breeding pairs; Borowicz et al. 2018) and Paulet Island (107,000 breeding pairs; Lynch and LaRue 2014) and one of only 9 mega-colonies of Adélie penguins (Humphries et al. 2017). Esperanza/Hope Bay is the only mega-colony in the Antarctic Peninsula that is systematically monitored.

Declining Adélie penguin populations have been reported throughout the western Antarctic Peninsula, a region where rapid climate warming has been recorded (e.g., Ducklow et al. 2013) and where the commercial fishery for krill currently operates (CCAMLR Krill Fishery Report 2015). The long-term decline in the Adélie penguin population throughout the AP region is mirrored in this mega-colony at Esperanza/Hope Bay.

These estimates derive from census work standardized to occur, in general, 1 week after the peak of egg-laying. This

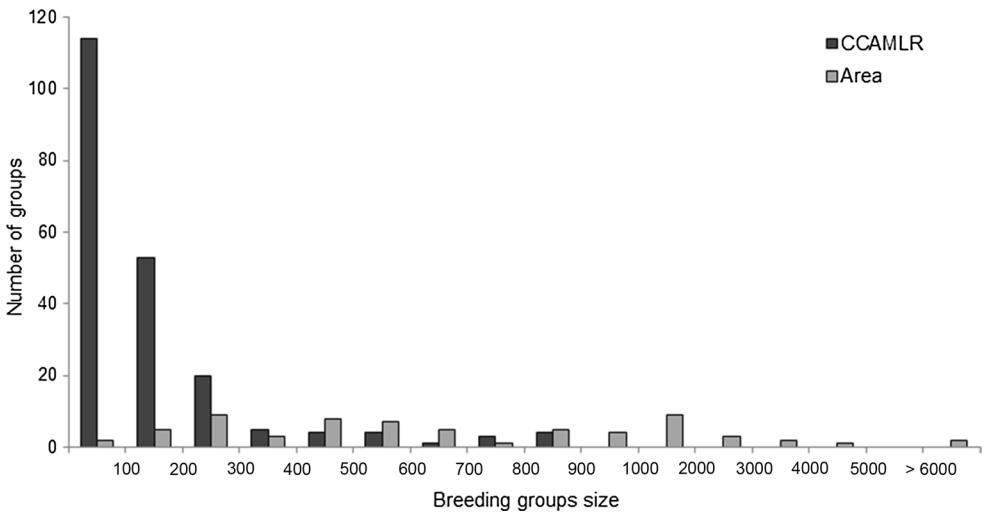

Fig. 2 Frequencies of breeding group sizes (i.e., number of breeding pairs) of Adélie penguins (*Pygoscelis adeliae*) at Esperanza/Hope Bay. We showed both the number of groups that were counted following the CCAMLR protocol (2004) and the number of groups whose size was estimated from their area

time frame is considered to provide the most representative estimate of the number of breeding pairs at a given colony (CCAMLR 2004). Properly-timed, systematic ground counts have the capacity to better detect and understand changes in local breeding populations relative to opportunistic counts, particularly given large inter- and intra-annual variability in colony attendance and nest survival (e.g., Baylis et al. 2013; Southwell et al. 2013). Thus, properly-timed ground counts provide essential information to detect and interpret changes in the physical and/or biological environment, and the response of a sentinel species such as the Adélie penguin. Such ground counts also serve to provide a baseline for comparison with estimates generated from more opportunistic census methods. Furthermore, ground counts can help us to estimate the precision and so, validate other methodologies, such as the use of satellite imagery.

Our results are similar to those reported by Lynch and LaRue (2014), who estimated the breeding population size of 104,182 pairs (CI 63,828–169,227), based on the areal extent of guano from a satellite image obtained in February of 2011. These remarkably close counts indicate the potential for satellite-based remote sensing as a means to complete time series for very large colonies; as well as the need of ground counts for validation. The satellite-based estimates and several of our estimates for large sub-groups depended on converting the nesting area to the number of breeding pairs based on an estimate of nest density. It is worth noting that minor variation in the estimation of nest density could bias census estimates when extrapolated to the larger colonies and our estimate of nest density had a CV of almost 50%. However, our mean nest density estimate is similar to those previously reported for Pygoscelid penguins (e.g., Trivelpiece and Volkman 1979: 1.13 pairs/m^2). We suggest that estimating nest density in very large breeding groups from satellite imagery, aerial photography, or direct counts will be useful to improve abundance estimates in large colonies in the future.

The combination of both the whole-colony census and the long-term monitoring in a subset of breeding groups provides a comprehensive overview of the population from Esperanza/Hope Bay. This colony represents 13.7% of the mean Adélie penguin population estimated for the AP region (specifically, Subarea 48.1; Lynch and LaRue 2014). The updated ground-count of the Esperanza/Hope Bay colony contributes towards estimates of the overall predator abundance in the Antarctic Peninsula region via ground-truthing of satellite methods in mega-colonies based on agreed census protocols for the management of Antarctic marine living resources.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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