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First direct, site-wide penguin survey at Deception Island, Antarctica, suggests significant declines in breeding chinstrap penguins

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Abstract Deception Island (62°57′S, 60°38′W) is one of the most frequently visited locations in Antarctica, prompting speculation that tourism may have a negative impact on the island's breeding chinstrap penguins (*Pygoscelis antarctica*). Discussions regarding appropriate management of Deception Island and its largest penguin colony at Baily Head have thus far operated in the absence of concrete information regarding the current size of the penguin population at Deception Island or long-term changes in abundance. In the first ever field census of individual penguin nests at Deception Island (December 2–14, 2011), we find 79,849 breeding pairs of chinstrap penguins, including 50,408 breeding pairs at Baily Head and 19,177 breeding pairs at Vapour Col. Our field census, combined with a simulation designed to capture uncertainty in an earlier population estimate by Shuford and Spear (Br Antarct Surv Bull 81:19–30, 1988), suggests a significant (>50 %) decline in the abundance of chinstraps breeding at Baily Head since 1986/1987. A comparative analysis of high-resolution satellite imagery for the 2002/2003 and the 2009/2010 seasons suggests a 39 % (95th percentile CI = 6–71 %) decline (from 85,473 ± 23,352 to 52,372 ± 14,309 breeding pairs) over that 7-year period and provides independent confirmation of population decline in the abundance of breeding chinstrap penguins at Baily Head. The decline in chinstrap penguins at Baily Head is consistent with declines in this species throughout the region, including sites that receive little or no tourism; as a consequence of regional environmental changes that currently represent the dominant influence on penguin dynamics, we cannot ascribe any direct link between chinstrap declines and tourism from this study.

Keywords Antarctic Peninsula · Chinstrap penguin · Baily Head · Vapour Col · Deception Island · Remote sensing · Tourism

Introduction

Deception Island (Fig. 1) is one of the most famous and frequently visited locations in the Antarctic. In the 2010/2011 season, 1,354 tourists visited Baily Head (IAATO 2011), a massive amphitheater of breeding chinstrap penguins on the island's eastern shore. While comprising less than 1 % of the global population, Baily Head is one of the penguin breeding sites identified in a recent analysis (Lynch et al. 2012c) as contributing most significantly to uncertainties in estimates of regional penguin abundance. Additionally, speculation suggesting chinstrap population declines at Baily Head has generated discussion at recent Antarctic Treaty Consultative Meetings as to whether Baily Head should be closed to tourists altogether or, alternatively, whether the suggested tourism landing area at Baily

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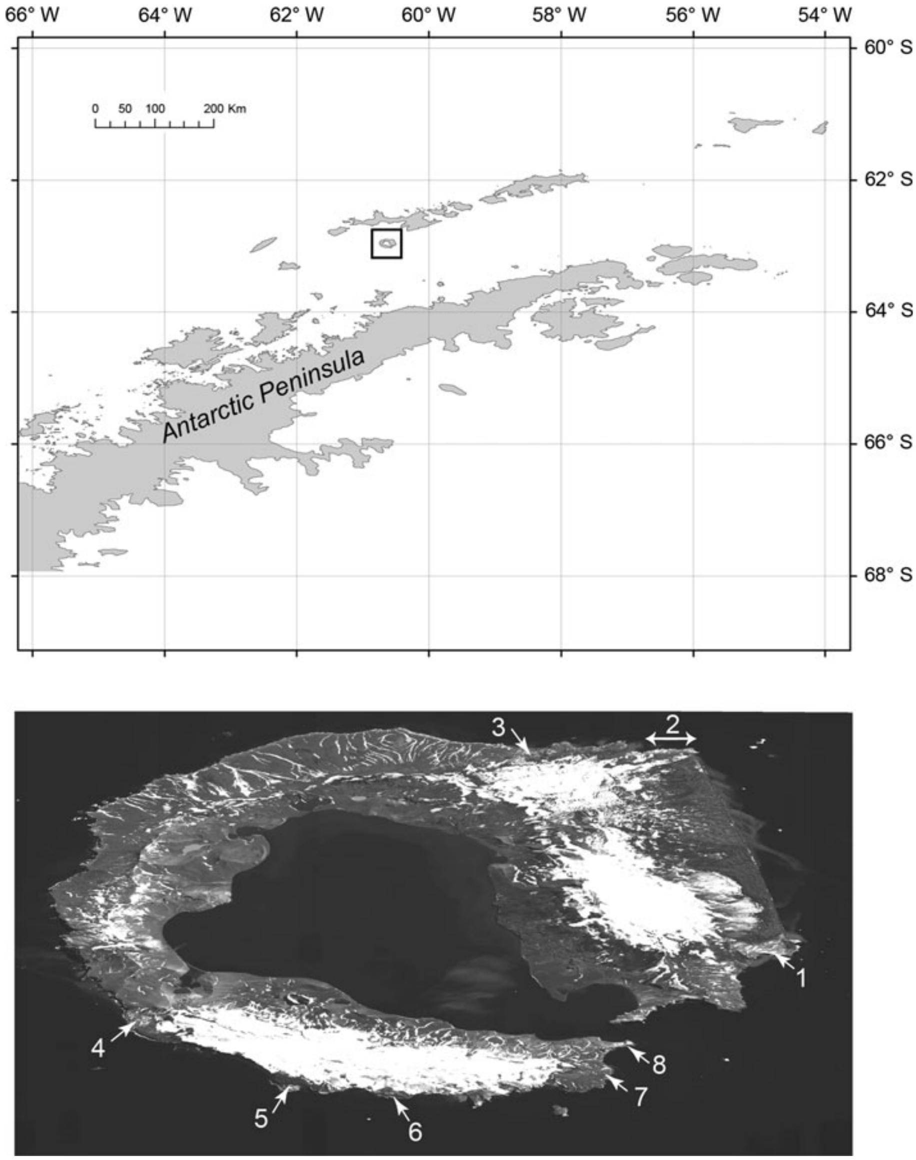

Fig. 1 Map of Deception Island and its position in the South Shetland Islands on the Antarctic Peninsula. Breeding sites are numbered in a counter-clockwise direction starting at Baily Head: (*1*) Baily Head (*2*) Macaroni Point East (*3*) Macaroni Point West (*4*) Vapour Col (*5*) South Point Northwest (*6*) South Point Bluff (*7*) Entrance Point West (*8*) Entrance Point. Satellite image (lower panel) is copyrighted 2012 by DigitalGlobe, Inc.

Head should be moved to avoid the ingress and egress of chinstraps to the site (Spain 2010; Argentina et al. 2011; R.N. Pers. Obs.). These discussions have been hampered by lack of precise and current data regarding the population dynamics at Baily Head and the other breeding sites at Deception Island. While the basic arrangement of seabird breeding areas at Deception Island has been established by Shuford and Spear (1988) and the newer survey by Downie and Smellie (2001) noted by Argentina et al. (2011), we are unaware of any previous direct census (e.g., count of individual breeding pairs) of the entire chinstrap population at Deception Island against which earlier population estimates can be compared. A comprehensive survey of all breeding sites at Deception Island, especially Baily Head, is an essential tool for effective management of both visited and non-visited sites in the ongoing discussions regarding the Deception Island Management Plan (Argentina et al. 2011).

All efforts to assess long-term rates of population change inevitably rely to some extent on early abundance estimates that, in many cases, suffer from low precision. Despite their limitations, these early census data are essential and unavoidable benchmarks against which to compare updated, high-precision, abundance estimates and have been used by a number of researchers to infer change even when older counts involving adults or chicks must be compared against newer counts of nests (or, equivalently, breeding pairs) (e.g., Croxall and Kirkwood 1979; Woehler 1993; Lynch et al. 2010b, 2012b; Trathan et al. 2012). To ensure the most robust inference possible, we estimated long-term changes in abundance using two independent methods: (1) a comparison of our own direct nest counts against an estimate of breeding pairs derived from Shuford and Spear's (1988) count of adults using a simulation explicitly accounting for various sources of potential error and (2) a comparative analysis of high-resolution satellite imagery from 2003 and 2010 for the chinstrap population breeding at Baily Head.

While a direct correlation of chinstrap abundance and levels of tourism would seem the most direct approach to addressing concerns over tourism-related population declines, significant changes in regional climate have occurred over the same period that Antarctic tourism has increased (compare Clarke et al. 2007 with Lynch et al. 2010a). As a result, it is difficult to distinguish between these two hypotheses considering any one breeding location in isolation. Therefore, our approach is to compare rates of population decline across neighboring breeding sites that have experienced similar kinds of climatic changes but have been subject to varying levels of tourism.

Methods

Field survey

We surveyed penguins at Deception Island from December 2 to 14, 2011, using the yacht *Pelagic* as base of operations. Our unit for assessing penguin abundance was the breeding "site," which we define as being all those penguins accessible from a single landing point. In this context, our definition of "site" is equivalent to Penney's (1968) "rookery," but we prefer the term "site" because it can also include similar geographic areas in which penguins are not breeding and is therefore more robust to local population extinction and colonization. Breeding sites are typically composed of multiple "colonies," defined as a contiguously nesting group of penguins. The sites known as Baily Head, Entrance Point, Vapour Col, and Macaroni Point West (see Fig. 1) were censused by counts of individual nests. In most cases, individual colonies could be counted in their entirety or could be unambiguously divided into smaller groups (<c. 500 nests) based on natural features of the landscape. When this was not possible, we divided large colonies into smaller discrete sections using brightly colored climbing rope placed on the ground. Each group was counted three times. If these three counts were within 5 % of their mean, we used the mean of these counts as the nest count for that group. If the spread in counts was larger, the group was divided into progressively smaller groups until three counts of each group were within 5 % of their mean. The sites known as Entrance Point West, South Point, South Point West, and Macaroni Point East (see Fig. 1) were inaccessible during our visit because of timing limitations, topography, or difficult sea and weather conditions and were censused by post-facto counting of digital photographs taken from offshore. Photographs were counted using Photoshop's Count tool by two different penguin biologists familiar with the location (R.N. and H.L.); reported values represent the average of these two counts.

For consistency with previous penguin census reports, we report census precision using the following five-point scale (Croxall and Kirkwood 1979; Woehler 1993):

N1: Nests individually counted, accurate to better than ±5 %
N2: Nests counted in known area then extrapolated over total site area, accurate to 5–10 %
N3: Accurate estimate of nests, accurate to 10–15 %
N4: Rough estimate of nests, accurate to 25–50 %
N5: Estimate of nests to nearest order of magnitude

Note that because counts of individual penguin groups (small colonies or equivalent portions of larger colonies) were achieved with high precision (<±5 %) and error in the counts of different groups are uncorrelated, our total "site" population estimates are actually significantly more precise than the ±5 % implied by the N1 category we assign them (see Taylor 1982).

Changes at Baily Head: comparison with Shuford and Spear (1988)

The best available abundance data to establish long-term rates of change at Deception Island come from censuses completed by Shuford and Spear in early 1987. However, direct comparison is difficult because Shuford and Spear estimated the population of adults in early February and we counted the number of occupied nests (breeding pairs) in early December. Not only does the ratio of adults to occupied nests change over the course of the breeding season, but the number of occupied nests declines over time after the peak of clutch initiation due to nest loss (Lynch et al. 2009). To address both of these factors, we developed a stochastic simulation to construct a probability distribution for population change that accounted for each of these sources of uncertainty.

To make inference regarding population change at Baily Head in a manner that directly and transparently accounted for census precision in both population estimates being compared, we used a simulation in which the true breeding population associated with each census is drawn from a distribution that includes the various sources of uncertainty. The simulation procedure includes six steps:

1. Shuford and Spear (1988) estimated that the population of adults at Baily Head was 100,000–150,000. Therefore, we draw an estimated population $E_{86/87}$ from a uniform (flat) distribution reflecting this range

$E_{86/87} \sim \text{Uniform}\,(100000,\ 150000)$.

2. The uncertainty associated with this estimate was given by Shuford and Spear (1988) as ±50–100 %. Therefore, we draw an estimated uncertainty $U_{86/87}$ from a uniform distribution reflecting this range

$$U_{86/87} \sim \text{Uniform}\,(0.50,\ 1.0)$$

and define this uncertainty $U_{86/87}$ as two standard deviations; the implied range then represents the 95th percentile confidence interval.

3. Using the values of $E_{86/87}$ and $U_{86/87}$ drawn above, the true number of adults present $A_{86/87}$ at Baily Head when Shuford and Spear estimated the population (February 8, 1987) is drawn from a normal distribution

$$A_{86/87} \sim N\left(\text{mean} = E_{86/87},\ \text{SD} = E_{86/87} \times \left(U_{86/87}/2\right)\right)$$

To extrapolate from the true number of adults present on February 8, 1987, to the number of breeding pairs at the peak of clutch initiation, we need two pieces of information. First, we need to estimate the number of days that passed between peak clutch initiation and the census. Second, we need to know how adult occupancy changes over the course of the season. We use the model for clutch initiation presented in Lynch et al. (2009, 2012a) to estimate that Shuford and Spear's (1988) population estimate on February 8, 1987, occurred 73 ± 1 days (mean ± 2SE) after mean clutch initiation, which is the best estimate of peak adult occupancy at the colony. To translate this lag into a correction factor for abundance, we use the occupancy curves provided by Ainley (2002), which are to our knowledge the best available data for pygoscelid colony occupancy as a function of date. While Ainley's occupancy curves relate to Adélie penguin colonies and not chinstrap penguin colonies, the two species have the same incubation period of c. 36 days (Williams 1995; Ainley 2002), and therefore, we use the colony occupancy curves in Ainley as the best available guide to the evolution of adult penguin abundance as a function of the number of breeding pairs. Assuming that (1) peak occupancy is associated with mean clutch initiation (consistent with CEMP Standard methods [Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR) 2004]), and (2) there are 2 adults/nest at peak occupancy (this is somewhat tautological, since courtship and copulation involve both adults), these data suggest that the number of adults present at the colony 73 days after peak occupancy is between 24 and 90 % of the number of breeding pairs at peak occupancy. Note that while this interval is large, reflecting significant variability among breeding sites in Ainley's (2002) study, the number of adults present at the colony this far into the season is always smaller (a maximum of 90 %) than the true number of breeding pairs. Similarly, because the Shuford and Spear's census (c. 73 days after mean clutch initiation) likely occurred just after mean chick crèche (at Deception Island, 65–71 days after clutch initiation [Williams 1995]), chicks would have been attended by either a single parent or neither parent. Therefore, as in Ainley's (2002) study, the number of adults present at the colony during Shuford and Spear's (1988) census on February 8, 1987, would similarly be smaller than the true number of breeding pairs active in that year. This conversion factor is reflected in Step 4 of the simulation.

4. We draw the number of breeding pairs $P_{86/87}$ in the 1986/1987 season from a uniform distribution on the interval suggested by the Ainley (2002) data:

$$P_{86/87} \sim \frac{A_{86/87}}{\text{Uniform}\,(0.24, 0.90)}$$

While our December 2011 census was significantly more precise than the Shuford and Spear's census, we need to account for the remaining census uncertainty and nest attrition occurring between peak clutch initiation and our census. This is the focus of Steps 5–6.

5. The uncertainty associated with our count of occupied nests is ±5 %. Therefore, we draw the true number of nests present at the time of census $N^{\text{true}}_{11/12}$ from a normal distribution centered on the number counted in the field $N^{\text{counted}}_{11/12}$ and a standard deviation reflecting this uncertainty

$$N^{\text{true}}_{11/12} \sim N\left(\text{mean} = N^{\text{counted}}_{11/12}, \text{SD} = 0.05/2\right)$$

where we again take the 5 % uncertainty to reflect two standard deviations.

6. Using the model for clutch initiation presented in Lynch et al. (2009, 2012a), we estimate that our census (centered on 8 December) occurred 18 days after the peak of clutch initiation. The chinstrap nest attrition rate estimated by Lynch et al. (2009) was 1.0 ± 0.6 % (mean ± 2 SE) per day, so we draw a value for the rate of nest attrition R from this distribution

$$R \sim N(\text{mean} = 0.01, \text{SD} = 0.006/2)$$

and use this to calculate the fraction of the population F remaining at the time of the census

$$F = 1 - 18R$$

from which we estimate the number of breeding pairs at Baily Head in the 2011/2012 season $P_{11/12}$ as

$$P_{11/12} \sim \frac{N^{\text{true}}_{11/12}}{F}.$$

The conversion of the original data to stochastic draws for the number of breeding pairs at the peak of clutch initiation

($P_{86/87}$ and $P_{11/12}$) allows us to compare equivalent quantities and to generate a statistical distribution (based on 10,000 draws) reflecting the size and direction of population change supported by the data.

Satellite imagery interpretation

The images used for population abundance estimation were a 0.60-m-resolution Quickbird-2 panchromatic image from January 21, 2003, and a 0.50-m-resolution Worldview-1 panchromatic image from January 3, 2010 (images copyright 2012 by DigitalGlobe, Inc.). Both images were orthorectified using the Radarsat Antarctic Mapping Project's Digital Elevation Model and projected into a South Polar Lambert Azimuthal Equal Area projection. To construct images that were directly comparable, we resampled the 0.60-m-resolution 2003 image to match the 0.50-m-resolution of the 2010 image and georegistered the 2003 image to the 2010 image using boulders and other geological features visible in both images. We visually identified guano staining on the satellite imagery as in Lynch et al. (2012d) and then conducted a supervised maximum likelihood classification using ArcGIS 10 (ESRI 2010) to differentiate between active and non-active breeding areas. We masked the resulting classification image using manually constructed polygons that included only areas of potential breeding; this eliminated areas clearly misclassified as representing penguin breeding (e.g., snow). Our classification methods were restricted to Baily Head where we have both the most personal experience and recent nesting density estimates.

To convert the number of "active breeding" pixels to an estimate of breeding pairs, we needed to estimate the density of nests. We used population data on seven colonies that were clearly identified in the 2010 satellite image and were counted by the Antarctic Site Inventory on December 11, 2010, to estimate nesting density in the 2009/2010 breeding season. We used population data on six colonies that were clearly identified in the 2003 satellite image and were counted by the Antarctic Site Inventory on either December 30, 2002, or December 19, 2003, to estimate nesting density in the 2002/2003 breeding season. A linear regression of abundance on the number of pixels classified as active breeding allowed us to estimate average nesting density and extrapolate from the classified maps to estimates of breeding pairs.

Results

Field survey

The total raw count of chinstrap penguins at Deception Island in December of 2011 was 79,849 breeding pairs, including 50,408 breeding pairs at Baily Head and 19,177 breeding pairs at Vapour Col (Table 1; all counts ±5 %). As the most direct, precise, and assumption-free assessment of population size, we consider these raw counts as the most appropriate for future compilations and attendant analyses. However, our phenology-corrected simulation-based estimates for the true number of breeding pairs in 2011/2012 derived for comparison with Shuford and Spear (1988) were 61,823 ± 8,219 for Baily Head (mean ± 2 SD; Fig. 2) and 22,348 ± 2,218 (mean ± 2 SD) for Vapour Col, where the increased error in the phenology-corrected estimates reflects uncertainty in the rate of nest attrition in the days between our census counts and the estimated date of peak clutch initiation. While macaroni penguins have bred intermittently at Deception Island (Croxall and Kirkwood 1979), we found no breeding macaroni penguins on Deception Island. Observation on flying birds are reported in "Appendix."

Comparison with Shuford and Spear (1988)

Our analysis finds that the true number of breeding pairs in 1986/1987 was between 127,398 and 502,321 (95th percentile interval; Fig. 2). While this range is large and a precise estimate of the true abundance in 1986/1987 is not possible, these results demonstrate strong support for a significant decline in the number of breeding chinstrap penguins at Baily Head between 1986/1987 and 2011/2012, with over 97 % of the simulated draws suggesting a decline of at least 50 % (mean = 71 %; range = 34 % to 91 %).

Satellite image analysis

We found no difference in average nesting density between the 2002/2003 season and the 2009/2010 season (Welch's two-sample t test: $t_{9.6} = 0.29$, $P = 0.78$), although our sample size for making such inference was small ($n = 6$ and $n = 7$, respectively). Using the aggregated density data available (Fig. 3), we estimate a nesting density of 1.5 ± 0.4 nests/m^2 (mean ± 2 SE). This estimate is slightly lower but generally consistent with the 1.54 nests/m^2 and 2.34 nests/m^2 estimates derived from inter-nest distance data presented in Stonehouse (1975) and Carrascal et al. (1995), respectively, assuming hexagonal packing of nests. Using this nest density and the classified satellite images obtained for January 2003 (Fig. 4a) and January 2010 (Fig. 4b), we estimate 85,473 ± 23,352 (mean ± 2 SE) breeding pairs at Baily Head for the 2002/2003 season and 52,372 ± 14,309 (mean ± 2 SE) breeding pairs for the 2009/2010, based on the reduction in areal extent of active breeding. The net change in abundance for these two time periods, 33,101 ± 27,387 (mean ± 2 SE) breeding pairs, is significantly different from zero despite the population

Table 1 Raw data on the abundance of breeding chinstrap penguins at Deception Island (for location of sites, refer to Fig. 1)

Location/survey date(s)	Abundance (breeding pairs)	Precision, method[b]	Location in Shuford and Spear (1988)	Abundance in Shuford and Spear (1988) (adults)
Baily Head 62°57′50″S, 60°30′17″W December 7–9, 2011	50,408	N1, ground	72	100–150 k ("guesstimate")
Macaroni Point East 62°53′56″S, 60°32′05″W December 9, 2011	885	N2, photo	73	>1,000 ("casual observations")
Macaroni Point West 62°53′59″S, 60°35′20″W December 6, 2011	2,448	N1, ground	74	400 ("detailed counts")
Vapour Col 62°59′31″S, 60°43′15″W December 4, 2011	19,177	N1, ground	75	15 k ("rough estimate")
South Point Northwest 63°01′08″S, 60°39′39″W December 9–11, 2011	5,352	N2, photo	76	15 k ("rough estimate")
South Point Bluff 63°00′57″S, 60°38′05″W December 9–11, 2011	217	N3, photo	77	4–5 k ("rough estimate")
Entrance Point West[a] 63°00′28″S, 60°33′43″W December 8, 2011	852	N3, photo	78	4 k ("rough estimate")
Entrance Point[a] 62°59′56″S, 60°33′25″W December 8, 2011	551	N1, ground	78	Included in above
Total	79,849 nests	N1[b]		140–191 k adults

Breeding sites are listed in a counter-clockwise direction starting at Baily Head

[a] We believe that location "78" ("Entrance Point") in Shuford and Spear (1988) represents a combination of both Entrance Point West and Entrance Point. We did not find penguins breeding at the site Shuford and Spear (1988) refer to as location "79" ("Pt northwest of Entrance Point")

[b] The error on the total count (see Taylor 1982) is ≤3.5 %

estimate uncertainties. The 2009/2010 Baily Head population estimate obtained by satellite image interpretation is statistically indistinguishable from the abundance estimate for the 2011/2012 season obtained by direct counting. This comparative analysis of the satellite imagery suggests a 39 % decline in the chinstrap penguin population between 2002/2003 and 2009/2010 (Fig. 4c). We have not corrected the satellite imagery–derived abundance estimates for phenology because guano persists after a nest has been abandoned and we do not yet know how the area of guano staining changes over time. We estimate that penguin phenology was 12 days more advanced on January 21, 2003, than January 3, 2010, so the abundance estimate for the former is, if anything, underestimated relative to the latter and our estimate of 39 % decline is correspondingly conservative.

We found that individual breeding colonies within Baily Head varied significantly in the magnitude of population change between 2003 and 2010, which ranged between 4.8 % (population growth) and −28.8 % (population decline). We found no correlation between colony-scale population change and initial colony population size, and we found no consistent

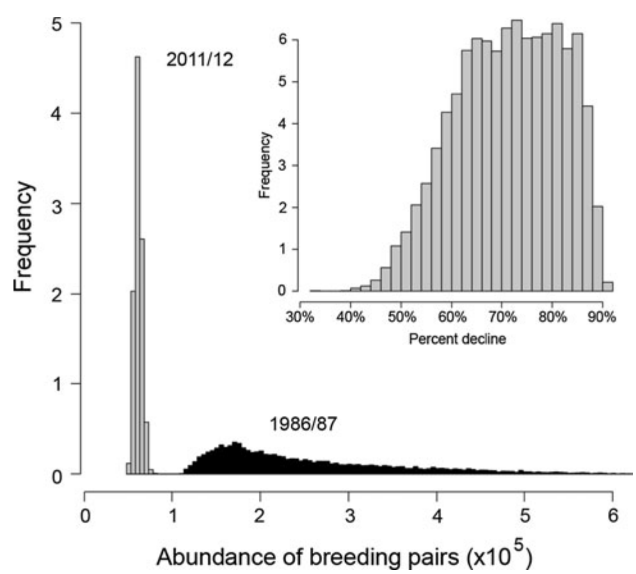

Fig. 2 Histograms showing the distribution of phenology-corrected estimates for the number of breeding pairs in 1986/1987 and 2011/2012 associated with Shuford and Spear (1988) and our field survey, respectively. The distribution reflects 10,000 draws from the simulation described in "Methods". *Inset* Distribution of the percent decline associated with the phenology-corrected estimates shown in the main figure

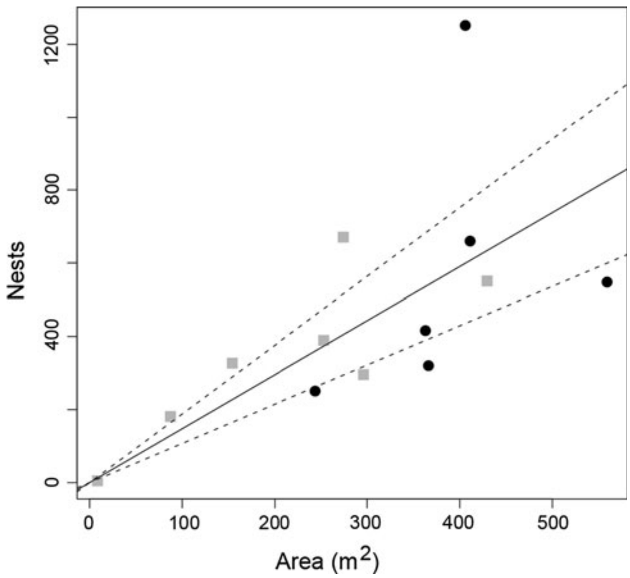

Fig. 3 Nests versus area for seven colonies counted in December 2010 (*black circles*) and six colonies counted in December 2002 and December 2003 (*gray squares*). The best-fit line (intercept set to zero) is shown ($r^2 = 0.80$), the slope of which yields a density estimate of 1.5 nests/m^2. The 95th percentile confidence intervals for the best-fit line are shown as *dashed lines*

spatial gradient in population change suggesting a relationship between population change at the colony scale and nesting elevation.

Discussion

The chinstrap census here reported, in combination with the comparative satellite imagery analysis and the simulation-facilitated comparison to Shuford and Spear's (1988) population estimate, provides compelling evidence for significant (>50 %) declines in the chinstrap penguin populations at Baily Head over the last 25 years (Table 2). We estimate at least a 50 % decline in chinstrap abundance at Baily Head since 1986/1987 and a 39 % decline since 2003/2004. While estimates of loss since 1987 are sensitive to uncertainties in the baseline count reported by Shuford and Spear (1988), uncertainties in the conversion between their estimate of adults and our count of nests (or, equivalently, breeding pairs), and potential phenological differences that might affect population estimates (see Lynch et al. 2009, 2012a), the statistical distribution for percent decline does not include zero. In fact, the smallest percentage decline supported by the data is 34 %. Moreover, these results are consistent with declines independently assessed for Baily Head between 2002/2003 and 2009/2010 using the high-resolution satellite imagery. Over longer time scales (Table 3), the Baily Head population appears to have fluctuated widely, leading to a range of hypotheses [e.g., glacial retreat (Shuford and Spear 1988), volcanic activity (Croxall and Kirkwood 1979)] involving neither of the two drivers (climate change and tourism) currently being debated. From this perspective, it is clear why trends at individual breeding locations must be placed in a regional context for inference on causal drivers of change.

With regard to tourism, there has been considerable discussion about potential visitor impacts at recent Antarctic Treaty Consultative Meetings (ATCMs). In 2005, the Treaty Parties began to adopt Site Guidelines for frequently visited locations, recognizing a concern about the potential for visitor-related pressures at these sites (Antarctic Treaty Consultative Parties [ATCP] 2005). As of ATCM XXXIV

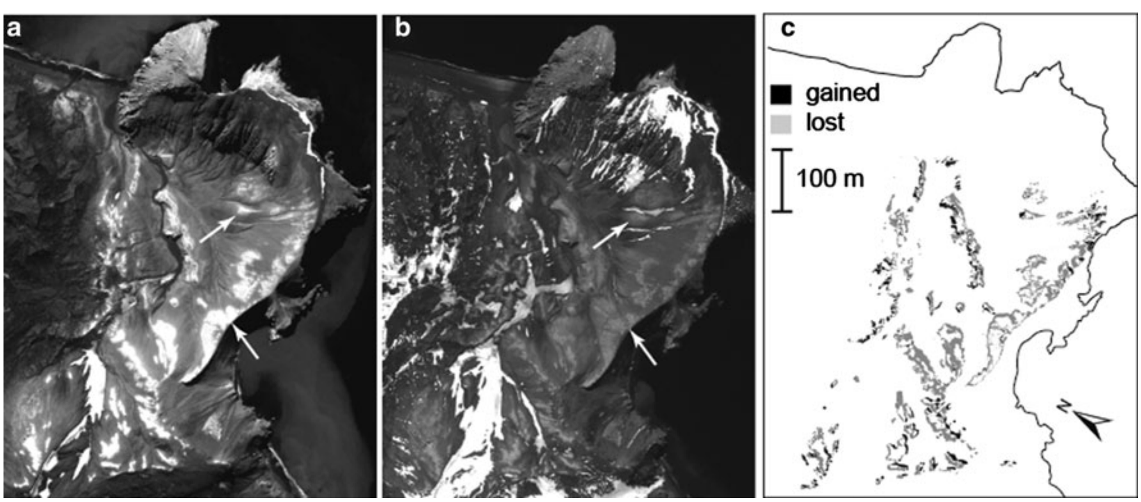

Fig. 4 Sub-meter resolution satellite imagery of Baily Head used for analysis: **a** 0.60-m-resolution Quickbird-2 panchromatic image from January 21, 2003, and **b** 0.50-m-resolution Worldview-1 panchromatic image from January 3, 2010 (images copyrighted 2012 by DigitalGlobe, Inc.). Two representative penguin colonies are indicated by *white arrows* for orientation. **c** Changes in colony area between 2003 and 2010 as derived from maximum likelihood classification of images in **a** and **b**

Table 2 Chinstrap colonies within 100 km of Baily Head, Deception Island, listed in order of population size

Site	Trend estimate (95th CI)	Current abundance (year of census)	Average number (and range) of landed passengers (1998/1999–2008/2009)
Baily Head 62°58′S, 60°30′W	−4.6 % (N/A[a])	50,408 nests (2010/2011)	1,912 (1,091–3,040)
Vapour Col 62°59′S, 60°43′W	1.6 % (N/A[a])	19,177 nests (2010/2011)	0 (0–0)
Barrientos Island 62°24′S, 59°45′W	2.0 % (1.4 %, 2.5 %)	~5,500 nests (2008/2009)	4,218 (2,396–6,560)
Cape Shirreff 62°28′S, 58°28′W	−3.9 % (−4.3 %, −3.4 %)	4,339 nests (2009/2010)	0 (0–0)
Half Moon Island 62°35′S, 59°55′W	−1.6 % (−1.9 %, −1.4 %)	~2000 nests (2008/2009)	8,285 (1,454–16,280)
Fort Point 62°32′S, 59°34′W	−2.8 % (−6.8 %, 1.3 %)	853 nests (1999/2000)	45 (0–185)
Hannah Point 62°39′S, 60°36′W	−1.6 % (−2.4 %, −0.8 %)	759 nests (2004/2005)	3,371 (94–5,485)
President Head 62°43′S, 61°12′W	−28.0 % (−29.9 %, −26.0 %)	0 nests (2011/2012)	17 (0–90)

Population trends reflect the average annual percent change in abundance between 1979/1980 and 2010/2011 reported in Lynch et al. (2012b), and current population estimates are from Naveen and Lynch (2011) and Van Cise (2011). Tourism data provided by the International Association of Antarctica Tour Operators

[a] Due to the difficulty in quantifying uncertainty in Shuford and Spear's (1988) estimates, we do not include confidence intervals

Table 3 Historical data prior to Shuford and Spear (1988) on the abundance of chinstrap penguins at Baily Head. Data and source details from Croxall and Kirkwood (1979) except as noted

Date	Count	Precision	Original source
July 12, 1909	50,000 adults	4 (±25–50 %)	Gain, 1914
1926/1927	40,000 nests	4 (±25–50 %)	Bennet in Roberts
January 1937	72,660 nests	2 (area extrapolation, approx. ±5–10 %)	B. B. Roberts
December 1957	37,500 adults	4 (±25–50 %)	White 1957
January 1967	50,000–75,000 adults	4 (±25–50 %)	Barlow 1966
1989	100,000 nests	4/5 (±25–100 %)	S. & J. Poncet, pers. comm. in Woehler (1993)

(2011), 32 Site Guidelines have been adopted, and, presently, there are Site Guidelines for three Deception Island visitor sites: Whalers Bay (ATCP 2008), Telefon Bay (ATCP 2009), and Baily Head (ATCP 2009). Baily Head is the only chinstrap penguin site at Deception Island that is visited by tourists. In the 2010/2011 season, 1,354 tourists visited Baily Head, making it the 26th most heavily visited site in the Antarctic Peninsula region (IAATO 2011). At ATCM XXXIV (2011), the report of the Deception Island Management Group noted concern that changes in the abundance of the Baily Head chinstrap penguin population "may require some changes to, or strengthening of, the protection and management of this zone" and "that it would be necessary to significantly reduce the number of visitors," and recognized "that any such proposals will require further discussion" (Argentina et al. 2011).

The population declines we report here for Deception Island are consistent with declines at other neighboring chinstrap penguin breeding sites. These include locations that are off-limits to tourists (Cape Shirreff), locations no longer visited by tourists (President Head [IAATO 2011]), locations infrequently visited by tourists (Fort Point, ranked #103 in Peninsula tourist visits in the 2010/2011 season [IAATO 2011]), and locations regularly or frequently visited by tourists (Half Moon Island, Barrientos Island, and Hannah Point, respectively ranked #7, #11, and #21 in Peninsula tourism visits in the 2010/2011 season [IAATO 2011]; Table 2).

As a result, we find no evidence to support a link between chinstrap declines and levels of tourism at the Baily Head penguin site or at chinstrap penguin breeding sites in proximity to Deception Island. This finding is further supported by a recent analysis of individual chinstrap penguin breeding colonies at Vapour Col (Barbosa et al. 2012), though we are cautious about interpreting changes at scales smaller than the entire site. Irrespective of the levels of tourism received, most of the chinstrap penguin populations in the vicinity of Deception Island are declining. Our findings provide additional support for the significant regional-scale declines in chinstrap penguin abundance reported recently (Forcada et al. 2006; Forcada and Trathan 2009; Trivelpiece et al. 2011; Lynch et al. 2012b) that are ascribed to regional climate change and associated changes in sea ice coverage and biological productivity. Importantly, our results confirm that breeding sites with large populations such as Baily Head are declining as rapidly as the many smaller populations more frequently censused (e.g., Naveen et al. 2000; Lynch et al. 2008), consistent with a larger study showing no relationship between rates of population change and breeding population size (Lynch et al. 2012b). We nonetheless continue to recognize that tourism or associated activities may affect penguin behavior (Holmes 2007), with stress on or habituation of, breeding penguins (Nimon et al. 1995; Culik and Wilson 1995; Holmes et al. 2006; Walker et al. 2006) and that attendant effects on breeding abundance may be simply undetectable in the context of climate-driven regional population changes.

Importantly, we found that the rate of population change varied considerably between colonies at the same breeding site. While some colonies have suggested a population increase over the last 31 years (Lynch et al. 2012b), our site-wide census reveals substantial population declines. We do not yet understand why some colonies decline more rapidly than others and as yet have no way to predict which colonies will be representative of the entire site. Future analyses of chinstrap population change should limit consideration to those sites for which time series data are available at the scale of the entire breeding site. Repeat measurements at smaller scales (i.e., at “control” or “study” groups that contain only a portion of the breeding birds at a location; e.g., Barbosa et al. 2012) may be unreliable indicators of change, a conclusion with important implications for the design of future population monitoring studies.

While our 2011/2012 census of Deception Island represents a key benchmark for population monitoring of the Deception Island penguin colonies, such census efforts are time consuming and expensive. It is unlikely that censuses of that quality will be possible at the intervals required for effective site management. High-resolution commercial satellite imagery represents a clear alternative to direct nest counting and has been shown, at least in our trial study of Baily Head, to produce abundance estimates that are nearly identical to those achieved in the field. Our satellite-derived abundance estimates, however, have large uncertainties due to variability in nesting density and the relatively small number of groups that were both counted in the field and clearly identifiable in the imagery. More sophisticated models of nesting density, including covariates such as slope, aspect, and terrain, will be required to narrow the confidence intervals on future abundance estimates derived from satellite imagery.

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Appendix: Flying birds at Deception Island

Our finding on the detection (presence) or non-detection (presumed absence) of flying birds are consistent with results described in Downie and Smellie (2001), with these additional observations:

1. Skuas (*Catharacta* spp.): An individual south polar skua was observed flying near Collins Point on December 8, 2011, but breeding was not observed. The melt pond south of the remains of the Hektor whaling station, which was observed on December 3, 7, 9, and 14, 2011, at all times hosted an assemblage of brown Skuas as well as apparent, hybrid *Catharacta* skuas.
2. Blue-eyed shag (*Phalacrocorax atriceps*): Since 2004, the Antarctic Site Inventory has recorded and observed nesting blue-eyed shags breeding on cliffs at the southern end of Whalers Bay. The number of nesting blue-eyed shags varies between 8 and 18.
3. Antarctic tern (*Sterna vittata*): Antarctic terns were frequently observed in the vicinity of our yacht anchorage in Stancombe Cove, and nesting in this vicinity is suspected.

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