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RESEARCH ARTICLE

First global census of the Adélie Penguin

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ABSTRACT
We report on the first global census of the Adélie Penguin (*Pygoscelis adeliae*), achieved using a combination of ground counts and satellite imagery, and find a breeding population 53% larger (3.79 million breeding pairs) than the last estimate in 1993. We provide the first abundance estimates for 41 previously unsurveyed colonies, which collectively contain 420,000 breeding pairs, and report on 17 previously unknown colonies, 11 of which may be recent colonizations. These recent colonizations represent ~5% of the increase in known breeding population and provide insight into the ability of these highly philopatric seabirds to colonize new breeding territories. Additionally, we report on 13 colonies not found in the survey, including 8 that we conclude have gone extinct. We find that Adélie Penguin declines on the Antarctic Peninsula are more than offset by increases in East Antarctica. Our global population assessment provides a robust baseline for understanding future changes in abundance and distribution. These results are a critically needed contribution to ongoing negotiations regarding the design and implementation of Marine Protected Areas for the Southern Ocean.

Keywords: Antarctica, high-resolution satellite imagery, Marine Protected Area, population estimate, Ross Sea, South Shetland Islands

Primer censo global de *Pigoscelys adeliae*

RESUMEN
Reportamos el primer censo global de *Pigoscelys adeliae*, logrado usando una combinación de conteos en tierra e imágenes satelitales, con el que encontramos una población reproductiva 53% más grande (3.79 millones de parejas reproductivas) que el último estimado en 1993. Proveemos el primer estimado de abundancia para 41 colonias que no habían sido previamente censadas que en conjunto tienen 420 000 parejas reproductivas, y reportamos 17 colonias anteriormente desconocidas. Pensamos que 11 de estas colonias antes desconocidas podrían ser producto de colonizaciones recientes. Estas colonizaciones recientes representan aproximadamente un 5% del incremento en la población reproductiva conocida y provee información sobre la habilidad de estas aves marinas altamente filopátricas para colonizar nuevos territorios de reproducción. Adicionalmente reportamos 13 colonias que no se encontraron en el censo, incluyendo 8 que se extinguieron. Nuestra evaluación global de la población de estos pingüinos provee una línea base robusta para entender los cambios futuros en su abundancia y distribución, y encuentra que la disminución de *P. adeliae* en la península Antártica es compensada de sobra por su incremento en Antártica del este. Estos resultados representan una muy necesaria contribución a las negociaciones sobre el diseño y la implementación de áreas protegidas marinas en el Océano del Sur.

Palabras clave: Antártica, Área marina protegida, estimación poblacional, imágenes satelitales de alta resolución, Islas Shetland del Sur, Mar de Ross

INTRODUCTION

With its circumpolar high-latitude distribution, the Adélie Penguin (*Pygoscelis adeliae*) is both an Antarctic icon and the subject of considerable study as a "canary in the coal mine" for environmental change in the Southern Ocean. As a key predator of krill (*Euphasia* spp.) and fish (*Pleuragramma* spp.), the Adélie Penguin has long been considered an indicator species of the Antarctic environment (Taylor and Wilson 1990) and, as such, is monitored by an international agency responsible for sustainable fisheries management, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). In an effort to maintain an ecosystem-based approach to fisheries management, an Ecosystem Monitoring Program was initiated by CCAMLR to, among other things, track Adélie Penguin population abundance as an indicator of ecosystem health (e.g., Taylor et al. 1990, Emmerson and

Southwell 2011, Trivelpiece et al. 2011). Available data on abundance and distribution are far from complete, however, because the Adélie Penguin's breeding range includes vast stretches of remote habitat that are expensive and logistically challenging to survey.

Several studies have recently demonstrated the utility of remote-sensing imagery to identify and estimate the abundance of Antarctic penguin colonies (Fretwell et al. 2012, Lynch et al. 2012a, Mustafa et al. 2012). Here, we report on the first global census of the Adélie Penguin using recent field counts and high-resolution ($\sim$0.6 m) satellite imagery. We use this continental-scale, high-resolution census to assess how the Adélie population is changing at spatial scales from individual colonies to the entire breeding range and to estimate abundances in regions of particular interest for management of Southern Ocean fisheries. Our use of satellite imagery also allows us to document several instances of colonization and local extinction, two processes that, because of their rarity, are difficult to study.

METHODS

To differentiate aggregations of breeding penguins from the physical location where they are found, we refer to groups of contiguously nesting penguins as a "colony" (Ainley 2002) and the physical locations of terrain free of snow and ice in the austral summer as (actual or potential) breeding "sites." We prefer to make this distinction explicit, because sites are permanent and exist before colonization by breeding penguins as well as after extirpation. In the Antarctic, potential breeding sites for Adélie Penguins (snow free during the breeding period) are relatively well-defined and host a breeding population that is, by virtue of natal philopatry, a separate breeding population from colonies at adjacent sites (Ainley 2002). In some cases, however, there is ambiguity about whether an area should be considered one large site or multiple smaller sites (Ainley 2002); in these cases, we have deferred to historical precedent to facilitate comparison of census data across time (Hatherton et al. 1965, Taylor et al. 1990, Whitehead and Johnstone 1990, Woehler et al. 1991, Norman 2000). Note that we use the word "census," as opposed to "survey," in describing both the field counts and the satellite-based population estimates because our estimates reflect (as far as we are able to determine) a complete enumeration of the population at each breeding site and, taken in aggregate, of the entire global Adélie population.

Search Strategy

We used a three-pronged approach to survey the global population of Adélie Penguins. (1) Direct field counts of breeding pairs during incubation (December–January) were used when recent ($\leq$4-yr-old) field data were available or when satellite imagery was either unavailable or insufficient to distinguish Adélie Penguins from other breeding pygoscelid penguins (n = 38 sites). (2) High-resolution satellite imagery (0.6-m resolution; DigitalGlobe, Longmont, Colorado, USA) was used for all other locations with known or suspected Adélie Penguin colonies ($n = 199$ sites). (3) Poorly or infrequently surveyed coastline was visually searched in the available high-resolution satellite imagery for new or previously unreported Adélie Penguin colonies. Among the 37 sites where we had neither recent field counts nor imagery with which to estimate abundance, 30 had been previously censused. We used those older census estimates (representing 3% of the total) in calculating regional and global abundance. Adélie Penguins at the remaining 7 locations (Continental Rock, Gibson Bay, Ivanhoff Head, Low Tongue, "Unnamed 2," "Unnamed Island PE 1," and Young Island) have never been completely censused, although the existence of Ivanoff Head and Low Tongue were confirmed by both aerial surveys (Wilson et al. 2009, Southwell and Emmerson 2013) and the recent Landsat survey reported in Schwaller et al. (2013).

Adélie Penguin colonies were identified by the spectral and spatial characteristics of their guano (Lynch et al. 2012b); boundaries were either delineated by hand or identified by supervised classification and a subsequent maximum likelihood classification (Naveen et al. 2012, LaRue et al. 2014). Although different species of penguins can sometimes be distinguished in high-resolution imagery (Lynch et al. 2012b), identification of Adélie colonies at mixed-species sites required either prior knowledge of the site or multiple images where species could be differentiated on the basis of breeding phenology. Although rates of omission are estimated to be very low in continental areas where Adélie Penguins are the only *Pygoscelis* species present (see Appendix A), it is possible that newly formed colonies of Adélie Penguins on the Antarctic Peninsula and associated islands were not captured by our survey, either because they exist within an established colony of another *Pygoscelis* species or because it was not possible to identify the species associated with a new colony.

Estimations of Abundance from Satellite Imagery

Except where constrained by topography, Adélie Penguins nest in a close-packed nesting formation with a relatively homogeneous nest density that allows us to convert an area of nesting (as identified by the area of guano staining) to an estimate of the number of pairs breeding within. We used a Poisson regression model for abundance (each colony indexed by i) developed in a previous study (LaRue et al. 2014) to convert the area of guano stain (in the most recent year available) to a statistical distribution representing the predicted number of breeding pairs at each site:

$$\text{Abundance}_i \sim \text{Pois}(\lambda_i)$$
$$\log(\lambda_i) = \beta_0 + \beta_1 * \text{Slope}_i + \text{Colony}_i + \log(\text{Area}_i) \quad (1)$$

where, as in LaRue et al. (2014), we used a model for abundance that included an intercept ($\widehat{\beta_0} = -0.44$, SE = 0.07), the fixed effect of site slope (Slope_i) as calculated using the Radarsat Antarctic Mapping Project (RAMP) digital elevation model ($\widehat{\beta_1} = 0.0062$, SE = 0.0005), and a random effect (Colony_i) incorporating variation in nesting density among colonies unrelated to slope. Because the RAMP dataset does not extend to the South Sandwich Islands, we used a model that does not include slope as a covariate for these colonies. Regionally and globally aggregated population estimates were calculated by repeated sampling from the abundance distribution for each breeding site to construct a regional or global abundance distribution. This approach allowed us to propagate uncertainties associated with individual abundance estimates to aggregate measures of abundance at larger spatial scales. All reported point estimates, including the site-specific abundance estimates in Supplemental Material Appendix A, reflect the median of the associated abundance distribution.

Population Change

For each site location, we compared our estimate of abundance with previous data to assess whether the population had increased or decreased in abundance. In most cases, the "historical" census data used for comparison came from the last available census of the population, but where multiple prior population estimates were available, we focused on those ≥10 yr previous to the current period. The mean time span over which we estimated population change was 24 yr (range: 2–58 yr). If the 95th-percentile confidence intervals (± 2 SE) of the 2 censuses did not overlap, we classified the change as "increasing" or "decreasing." If the 95th-percentile confidence intervals overlapped but the 68th-percentile confidence intervals (± 1 SE) did not, we classified this as "likely increasing" or "likely decreasing." If the 68th-percentile confidence intervals (±1 SE) of the 2 counts overlapped, we designated this as "no change." Populations may be denoted as having "no change" either because they are genuinely unchanging in size or because large uncertainties in one or both of the abundance estimates made it impossible to assess any change in abundance.

RESULTS

We estimate the total global population of Adélie Penguins to be 3.79 million (95th-percentile CI: 3.52–4.10 million) breeding pairs in 251 breeding populations (Appendix B and Supplemental Material Appendix A). This global estimate does not include penguins breeding at 7 sites that have been noted, but not censused, in previous reports and that we were not able to census given the imagery available. Approximately 21% of the population breeds on the Antarctic Peninsula, ~33% in the Ross Sea, and ~30% in East Antarctica (CCAMLR subareas 58.4.1 and 58.4.2). Information on site location, total breeding area at each site, current estimated abundance and associated confidence interval, and the date of census (date of direct census or date of imagery used for abundance estimation) are included in Supplemental Material Appendix A. Where satellite imagery was used to estimate abundance, Supplemental Material Appendix A also includes the most recent field census counts (and attendant metadata) for comparison. Abundance estimates aggregated to spatial units relevant for management of Southern Ocean resources are included as Tables 2 and 3 in Appendix B.

We found 420,000 breeding pairs within 41 colonies that, to our knowledge, have not been previously censused, including 17 colonies not previously known to exist. We consider it likely that 11 of these new colonies are recent colonizations, given that they are in close proximity to previous surveys but were not reported. The remaining 6 colonies are far enough from previous field-survey efforts that they could have been extant but undiscovered, and so we cannot necessarily infer recent colonization (see Figure 1).

There were 18 locations with a total of 384 Landsat pixels (~346,000 m^2) identified as containing penguin guano in Schwaller et al. (2013) for which imagery sufficient for confirmation was unavailable (Appendix A). Confirmed penguins at these locations would increase the total known breeding population, particularly along the coast from the Amery Ice Shelf to Ranvik Glacier (75–80°E), where the majority of these unconfirmed breeding sites occur.

We did not combine trends to estimate rates of change across large regions of Antarctica because of patchy temporal coverage in historical estimates. Nevertheless, focusing on the number of sites in each region that have apparently increased or decreased in abundance over the past several decades, some patterns emerge. We found that Adélie populations along the western Antarctic Peninsula have declined, as have colonies between 75°E and 95°E, while populations in Victoria Land and Terre Adélie have increased. Population change was uncorrelated with population size, although the 2 largest Adélie Penguin populations at Cape Adare and Cape Crozier appear to be increasing (also see Ainley et al. 2004, LaRue et al. 2013, Lyver et al. 2014). Of the 13 colonies previously reported that we did not find, 8 are clustered in Lützow-Holm Bay and adjacent Prince Olav Coast (38–41°E) and were

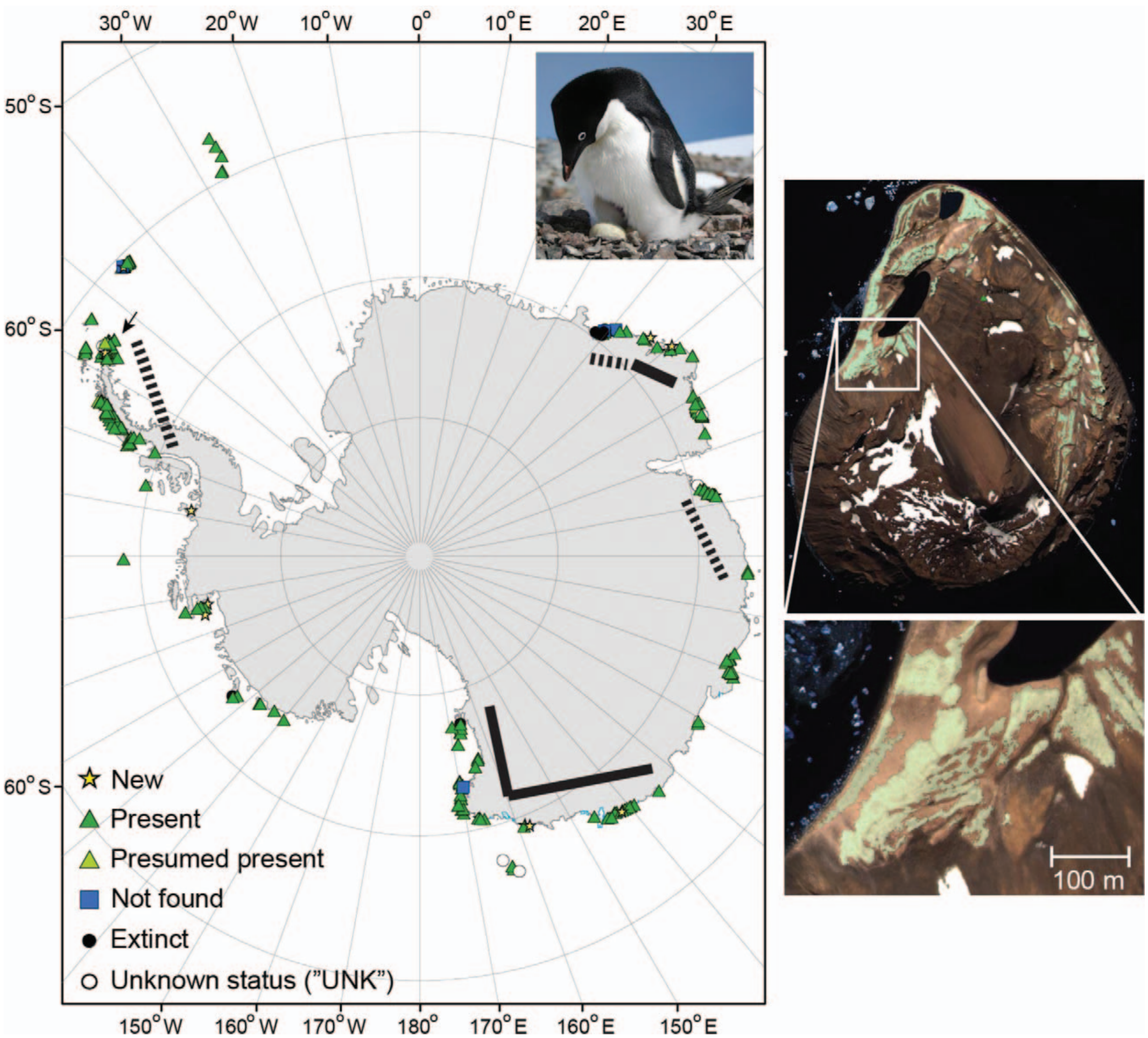

FIGURE 1. Map of extant Adélie Penguin colonies, as well as penguin colonies not found in imagery and presumed extinct. Solid bars represent sections of coastline in which populations are generally increasing in abundance, and dashed lines those in which populations are generally decreasing. Areas with no bar are either a mix of increasing and decreasing populations, are not changing in abundance, or do not have sufficient data to assess population change (see Supplemental Material Appendix A). Right: example of high-resolution imagery from Devil Island (–63.797°, –57.290°; location indicated by black arrow). Areas identified in the analysis as guano are shaded in light green. Imagery © 2014 by DigitalGlobe, Inc.

relatively small (≤1,500 breeding pairs). Other than this grouping and their small sizes, we found no other patterns to explain these potential extinctions. New colonizations were widely distributed around the continent and displayed no clear pattern with respect to geography or changes in population at adjacent sites. Finally, we did not find the colony reported by Horne (1983) and re-reported by Woehler (1993) and Ainley (2002) to be at Gaussberg (–66.799°S, 89.184°W). We believe, after consultation with the original source (Korotkevich 1964), that the supposed Adélie Penguin colony at Gaussberg reflects a misinterpretation of Korotkevich's map. It is not included in our dataset (Supplemental Material Appendix A) and should be stricken from future compilations.

DISCUSSION

Our global total abundance of 3.79 million breeding pairs is 53% larger than the most recent estimate of 2.47 million breeding pairs 20 yr ago (Woehler 1993). This difference of

~1.3 million breeding pairs can be explained largely by increasing abundance at known colonies (27% of the difference) and abundance estimates of colonies that had not been previously surveyed (explaining 32% of the difference). Adélie Penguins are generally increasing in abundance from Victoria Land to Terre Adélie, and increases in these areas are partially responsible for the apparent increase in global abundance. Importantly, several of the colonies responsible for this increase are already among the largest in the world and lie in the Ross Sea, where sea-ice extent and duration have increased substantially over the past 40 yr (Stammerjohn et al. 2012). Increasing sea-ice trends in East Antarctica, including the Ross Sea, are in stark contrast with the western Antarctic Peninsula, where drastically decreasing sea ice has had a detrimental impact on Adélie Penguin populations (Ducklow et al. 2007, Trivelpiece et al. 2011, Lynch et al. 2012a). Our results provide further support to the hypothesis that sea ice plays a critical role in Adélie Penguin abundance and distribution.

LaRue et al. (2013) found that a colony on Beaufort Island, in the southern Ross Sea, grew by 84% in response to glacial retreat and increased habitat availability. We hypothesize that some colonies may be experiencing habitat release where climate changes have caused glacial retreat (LaRue et al. 2013). Increases in the Ross Sea may also reflect competitive release for Adélie Penguins following an exploratory fishery for Antarctic toothfish (*Dissostichus mawsoni*) implemented in the late 1990s. Antarctic toothfish prey on Antarctic silverfish (*Pleuragramma antarctica*; Ainley et al. 2012), and their removal may benefit other predators of *Pleuragramma* spp., such as the Adélie Penguin (Ainley et al. 2012). Regional-scale changes in the Adélie Penguin population likely reflect both biotic and abiotic factors that deserve further study; our global census provides a baseline against which to assess future changes.

In addition to a genuine increase in the size of known colonies, the increase reflected in our census is, in part, an artifact of estimating abundance at colonies that had never been surveyed before. In fact, mapping abundance and distribution for the largest and most remote Adélie Penguin colonies is one of the major advantages of using high-resolution satellite imagery. Indeed, our finding is similar to the recent global estimate of Emperor Penguins (*Aptenodytes forsteri*) using satellite imagery (Fretwell et al. 2012) that found nearly double the number of Emperor Penguins expected on the basis of previous estimates, as well as breeding populations previously unknown to science.

Extinctions and Colonizations

Adélie Penguin populations are inherently patchy, both because they are colonial breeders and because available habitat is itself patchily distributed along the coastline. Several authors have addressed the metapopulation dynamics of Adélie Penguins breeding in the southern Ross Sea (e.g., Ainley et al. 2004, Dugger et al. 2010, LaRue et al. 2013), and as a defining characteristic of metapopulations, patterns of local extinction and colonization are of particular interest (Hanski and Gilpin 1991). Although local extinctions of small Adélie Penguin populations can be inferred from the literature (e.g., comparing Croxall and Kirkwood [1979] to Woehler [1993] and other compilations), colonization events are particularly difficult to study via field surveys because of logistical difficulties associated with surveying all ice-free coastal habitat. The ability to detect both colonization and extinction events is one of the most important advances offered by high-resolution satellite imagery, and here we report on 11 likely colonizations and at least 8 (and up to 13) possible extinctions requiring confirmation by future field surveys. We cannot be completely certain whether an apparent colonization represents a recent colonization or a new finding of an established colony; discrepancies in names and locations in the historical record compound the challenge. Nevertheless, we carefully considered the historical record and the available imagery when categorizing 8 sites as having gone extinct. All of the apparent extinctions were reportedly small colonies ($\leq$1,500 breeding pairs) that had been last censused prior to 1990. Cape Barne, which is just 3.5 km from Cape Royds, was briefly colonized in the mid-1980s and was never recorded as having >5 breeding pairs (Woehler 1993); its disappearance proves that some small colonies can blink in and out of existence, although the drivers for "satellite" colony formation are not well understood.

Implications for Marine Spatial Planning

Although the idea that penguin colonies can be identified in satellite imagery is several decades old (Schwaller et al. 1984, 1986, 1989, Olson et al. 1987, Williams and Dowdeswell 1988), increased pressure to monitor Southern Ocean "sentinel" species, combined with increased access to polar geospatial imagery, is driving a renaissance in the tracking of penguin populations using satellite imagery (Fretwell et al. 2012, Lynch et al. 2012b, Mustafa et al. 2012, Schwaller et al. 2013). In contrast to the recent Landsat survey reported by Schwaller et al. (2013), our survey relied on manual identification and interpretation of Adélie Penguin colonies, an effort that was time consuming and required the extensive experience of two interpreters (H.J.L. and M.A.L.). Nevertheless, we have demonstrated that global-scale remote-sensing surveys of Adélie Penguin abundance and distribution are feasible, and automated methods already in development will permit regular monitoring of Adélie Penguins across their entire breeding range. Monitoring abundance is critical to understanding predation rates of krill during the austral summer, a topic of considerable interest for designing a sustainable krill fishery for the Southern Ocean (Croxall and Nicol 2004, Hewitt et al. 2004).

Over the past several years, CCAMLR has discussed the implementation of a series of Marine Protected Areas (MPAs) surrounding Antarctica and the sub-Antarctic islands (Grant 2005, Ballard et al. 2012). Adélie Penguins are not only themselves a species of conservation concern, but their distribution and abundance also reflect the distribution of their marine prey. Accordingly, our survey provides a critical piece of information for ongoing discussions regarding the need for, and optimal design of, MPAs in the Southern Ocean. Our site-specific abundance estimates and associated errors will allow policymakers to generate Adélie Penguin population estimates at any scale, including within the boundaries of proposed MPAs. Our results, specifically the 53% increase in Adélie Penguin breeding abundance, suggest that estimates of krill consumption by Adélie Penguins may be seriously underestimated.

Priorities for Future Work

While global in scope and nearly complete with respect to the 251 known extant Adélie Penguin breeding sites, our survey highlights 2 priorities for future work. Distinguishing the 3 *Pygoscelis* spp. in mixed colonies is possible under certain conditions (e.g., Lynch et al. 2012b), but in most cases this requires multispectral imagery and considerable a priori knowledge of the site. While Adélie Penguins and Chinstrap Penguins (*P. antarcticus*) can often be distinguished by their different phenology and spectral characteristics, Gentoo Penguins (*P. papua*) are particularly difficult to distinguish from Adélies; until these technical challenges have been overcome, field surveys at mixed Adélie–Gentoo sites are perhaps the only way to keep track of Adélie abundance and distribution at sites on the Antarctic Peninsula, where they breed sympatrically. A second priority is the set of 7 sites that have never been censused (Continental Rock, Gibson Bay, Ivanhoff Head, Low Tongue, "Unnamed 2," "Unnamed Island PE 1," and Young Island). Cloud-free imagery in these areas will be required to confirm breeding Adélie Penguins and estimate abundance.

These results, and the underlying technique of using high-resolution commercial satellites to map Adélie Penguins at a global scale, provide a case study for understanding the biogeography of colonial seabirds. There has been a long-standing interest in the geographic structuring of seabird colonies (Furness and Birkhead 1984) and of Adélie Penguin colonies in particular (Ainley et al. 1995, 2004). Global surveys of Adélie Penguin abundance and distribution that include both presence and true absence, as demonstrated here, will greatly facilitate our understanding of how resources are divided among colonies with overlapping foraging ranges. Such occupancy maps are particularly valuable when combined with tracking data, information that is becoming increasingly available as the size and cost of satellite tags decrease.

Because the Southern Ocean provides direct and indirect ecosystem services to humanity (Grant et al. 2013), it is important that all available data are considered when setting management goals. High-resolution satellite imagery has the potential to be a "disruptive technology" that radically expands the spatial scale over which we can reliably monitor the abundance and distribution of major krill predators such as the Adélie Penguin. These data provide a natural complement to more detailed studies of Adélie Penguin diet, reproduction, phenology, and foraging at existing long-term study sites and provide a spatial context in which to understand how changes in these parameters are reflected in patterns of occupancy and abundance. In many ways, the ability to make high-resolution, large-extent occupancy maps makes the Adélie Penguin (and, by extension, the Emperor Penguin; see Fretwell et al. 2012) a model system for understanding colonial seabirds, their metapopulation dynamics, and their responses to climate change. While further development of these new techniques will continue to improve our ability to monitor Adélie Penguins remotely, our results already provide critical and timely information of direct relevance to the debate surrounding ecosystem management of the Southern Ocean.

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APPENDIX A

Sites from Schwaller et al. (2013) That We Were Unable to Survey

There were 18 locations indicated as containing breeding Adélie Penguins by Schwaller et al.'s (2013) survey that we were not able to assess (Table 1).

Rates of Omission

Our initial survey was completed with no information from the concurrently conducted medium-resolution survey of continental Antarctica by Schwaller et al. (2013). However, to ensure that our survey was as complete as possible, and to estimate rates of omission when doing a broad-extent survey by high-resolution satellite imagery, we compared our survey results to those reported by Schwaller et al. (2013). Differences between the 2 surveys in areas of common coverage fell into 3 categories: (1) locations where we do not have sufficient imagery to make a determination (see text), (2) locations where we can see the spectral signature identified but disagree with its interpretation as a penguin colony, and (3) locations that we genuinely missed as part of our survey but could confirm on reexamination as containing breeding penguins. There were 3 locations in this last category, which have been included in our survey for completeness, out of 151 breeding locations in the areas of overlapping coverage. From this, we estimated a rate of omission of $\sim$2% as measured by the number of breeding locations, or $<$0.5% as measured by the number of breeding pairs.

TABLE 1. Unsurveyed sites identified as penguin colonies in Schwaller et al. (2013).

Latitude	Longitude	Notes
−73.6623°	−101.528°	Near Edwards Island. No imagery.
−73.8221°	−102.941°	Near Edwards Island. No imagery.
−73.9686°	−104.137°	No imagery.
−68.6653°	77.8308°	Near Vestfold South. No imagery.
−68.6645°	77.8702°	Near Vestfold South. No imagery.
−68.5052°	77.9524°	Near Vestfold South. No imagery.
−68.7674°	77.8929°	Near Rauer Islands. Possibly a colony but imagery is cut off.
−68.8685°	77.525°	Near Rauer Islands. No imagery.
−68.8667°	77.5641°	Near Rauer Islands. No imagery.
−68.8801°	77.5953°	Near Rauer Islands. No imagery.
−69.1494°	77.2666°	Near Brattstrand Bluff. Poor imagery, wrong time of year.
−69.2728°	76.8328°	Near Brattstrand Bluff. Poor imagery.
−69.4722°	75.5559°	Part of Bølingen Islands–Lichen Island? No imagery.
−69.4699°	75.5734°	Part of Bølingen Islands–Lichen Island? No imagery.
−69.4374°	75.6726°	Part of Bølingen Islands–Lichen Island? Poor imagery.
−69.3641°	75.6685°	Part of Bølingen Islands–Lichen Island? Poor imagery.
−67.4557°	60.8821°	No imagery.
−67.4102°	59.3749°	Ambiguous. If this colony exists, the guano stain is very faint and located on light granite-colored rocks.

APPENDIX B

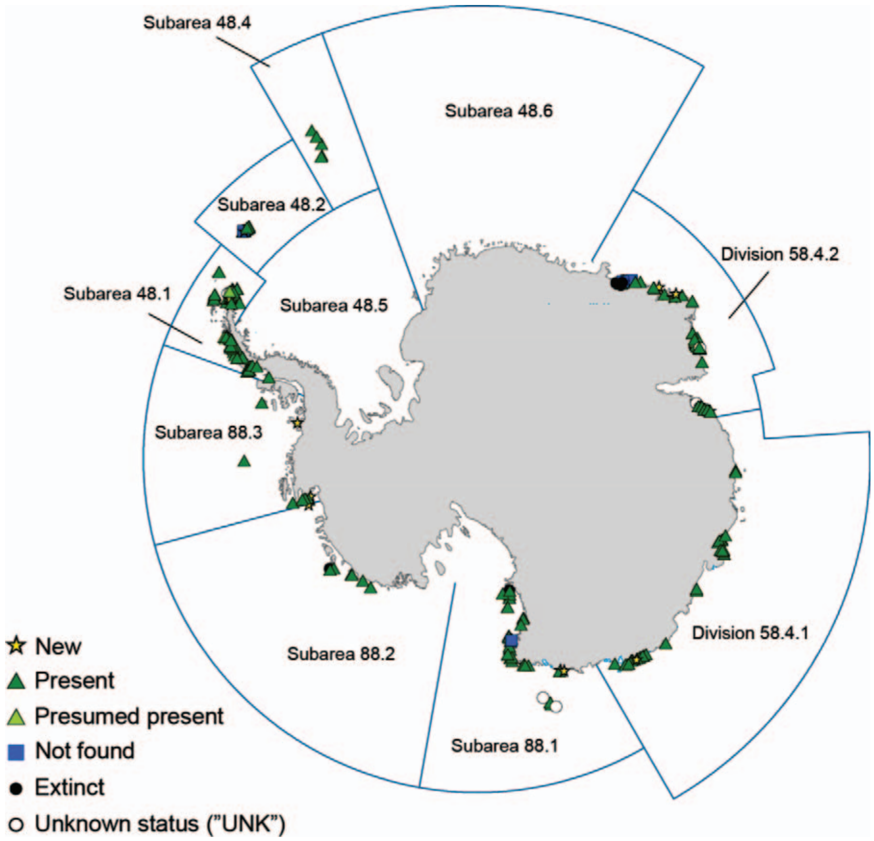

FIGURE 2. Map of CCAMLR areas from Table 2.

TABLE 2. Estimated abundance (in breeding pairs) for each of the CCAMLR areas (Figure 2).

Spatial unit	Abundance (95th-percentile CI)
Subarea 48.1	805,257 (714,474–919,997)
Subarea 48.2	191,624 (162,177–223,107)
Subarea 48.4	56,932 (13,908–98,330)
Division 58.4.1	516,038 (450,596–597,722)
Division 58.4.2	625,446 (542,635–732,127)
Subarea 88.1	1,233,816 (1,064,451–1,487,609)
Subarea 88.2	53,694 (40,447–73,127)
Subarea 88.3	172,891 (128,719–231,385)

TABLE 3. Estimated abundance (in breeding pairs) for each of the small-scale management units defined for area 48 (Figure 3).

Small-scale management unit	Abundance (95th percentile CI)
South Orkney Islands Southeast	103,142 (84,283–123,523)
South Orkney Islands Northeast	87,381 (65,961–114,060)
Antarctic Peninsula Elephant Island	2,217 (1,288–3,721)
Antarctic Peninsula Bransfield Strait East	35,437 (31,821–40,053)
Antarctic Peninsula East	641,407 (550,947–755,013)
Antarctic Peninsula West	11,782 (10,325–13,510)

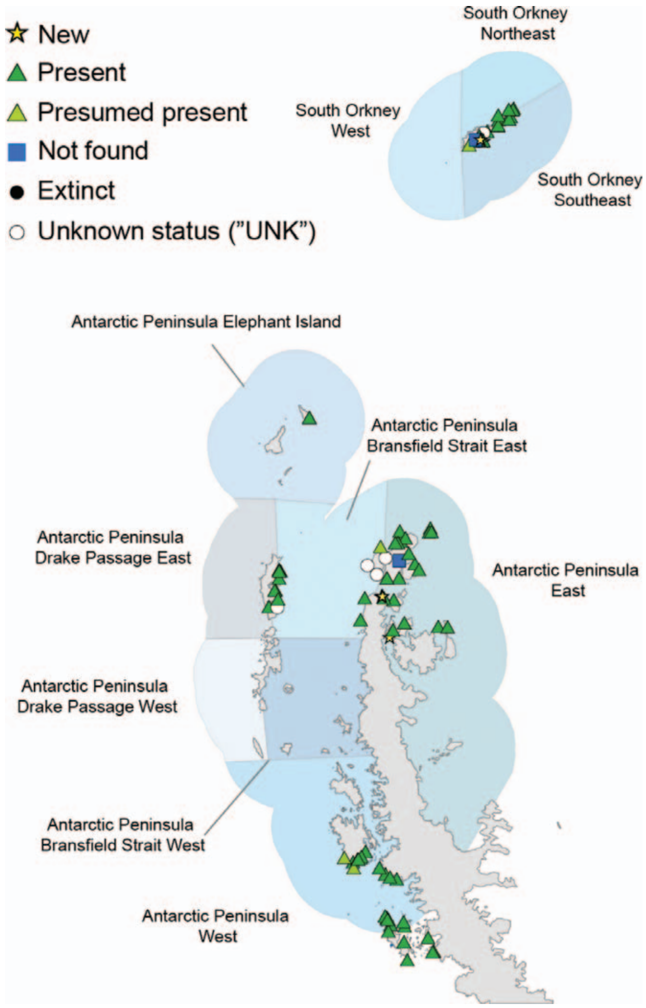

FIGURE 3. Map of small-scale management units within subareas 48.1, 48.2, and 48.4 from Table 3.

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CORRECTION

Erratum: First global census of the Adélie Penguin

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ABSTRACT
In Figure 1 of our article (Lynch and LaRue 2014), we accidentally misidentified the island on the right-hand side (panel B) as Devil Island. The island should have been identified as Paulet Island.

Keywords: Adélie Penguin, Antarctica, Devil Island, Paulet Island

Errata: Primer censo global del Pingüino de Adelia

RESUMEN
En la Figura 1 de nuestro artículo (Lynch y LaRue 2014), accidentalmente identificamos erróneamente la isla del lado derecho (Panel B) como Isla Diablo. La isla debió haber sido identificada como Isla Paulet.

Palabras clave: Antártida, Isla Diablo, Isla Paulet, Pingüino de Adelia

In Figure 1 of our article (Lynch and LaRue 2014), we accidentally misidentified the island on the right-hand side (panel B) as Devil Island. The island should have been identified as Paulet Island. The corrected caption should read

> **FIGURE 1.** Map of extant Adélie Penguin colonies, as well as colonies not found in imagery and presumed extinct. Solid (or dashed) bars represent sections of coastline in which populations are generally increasing (or decreasing) in abundance. Areas with no bar are either a mix of increasing and decreasing populations, are not changing in abundance, or do not have sufficient data to assess population change (see Appendix A). Right: Example of high-resolution imagery from Paulet Island (–63.5801°, –55.7881°; location indicated by black arrow). Areas identified in the analysis as guano are shaded in light green.

Note that, given the proximity of Devil Island and Paulet Island in relation to the scale of the map in Figure 1, the location of the arrow in the map is still correct.

LITERATURE CITED

Lynch, H. J., and M. A. LaRue (2014). First global census of the Adélie Penguin. The Auk: Ornithological Advances 131:457–466.