Population trends of light-mantled sooty albatross (Phoebetria palpebrata): At Adams Island and trials of ground, boat, and aerial methods for population estimates

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ABSTRACT: Population sizes of light-mantled sooty albatross (*Phoebetria palpebrata*, LMSA) at the three New Zealand breeding sites (Auckland, Antipodes, and Campbell Islands) are poorly known. Annual counts since 1999 of a small number of LMSA nests show a long-term population decline on Adams Island, Auckland Islands. Mean nest numbers in 2016-17 were 10% down on counts in 1999–2000, with an annual rate of decrease, lambda, of 0.44 in the period 1999–2019. Three methods to estimate the breeding population size were trialled: ground counts of nests (Adams); aerial photography of LMSA with ground-truthing (Adams); and boat-based counts of LMSA on coastal cliffs (Campbell). Ground counts in a clearly delimited area were repeatable (42 and 40 active nests in 2017 and 2018, respectively), thus useful for monitoring, but ground counts are too limited for a whole-island population estimate. Aerial photography overestimated the number of active nests by 12.5% compared with ground counts. Ground-truthing showed that most apparently occupied nests contained an egg, and so nests occupied by birds with no egg are a smaller error source when interpreting aerial photographs than for other albatrosses. Boat-based LMSA counts proved inaccurate due to vessel movement. Considering that the terrain favoured by LMSA is very difficult to access, population size estimates based on aerial photography with ground calibration for apparent breeders appear the most effective of the techniques trialled. Ongoing counts at vantage-point and ground-count sites enable continued monitoring of LMSA trends at Adams Island.

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Introduction

Light-mantled sooty albatross (*Phoebetria palpebrata*) (LMSA) is a circumpolar species that breeds on nine subantarctic island groups around the Southern Ocean (Figs 1, 2). The species is classified as Near Threatened by the IUCN and as At Risk – Declining in the New Zealand Threat Classification System (Robertson *et al.* 2017; BirdLife International 2018).

Globally, introduced mammals are linked to breeding failure in light-mantled sooty albatross via direct and indirect effects (ACAP 2010). Nest disturbance by browsing animals such as sheep (*Ovis aries*) and cattle (*Bos taurus*) can make LMSA vulnerable to predators, and feral cats (*Felis catus*), rats (*Rattus* spp.), and mice (*Mus musculus*) prey on the chicks of seabirds like LMSA (Moore 1997; Taylor 2000; Cuthbert *et al.* 2013; Dilley *et al.* 2016). In the Auckland Islands (Figs 2, 3), introduced mammals are limited to the main Auckland Island, where pigs (*Sus scrofa*) and cats prey on eggs and chicks of any seabirds except those protected on all sides by sheer cliffs (Russell *et al.* 2020 – Chapter 6 in this book). Mice are also present on the main Auckland Island, although their impact on albatrosses there remains unknown.

Unlike many species of albatross, LMSAs do not commonly follow vessels, including fishing vessels. In New Zealand, only six LMSAs were recorded as being caught in observed fisheries during 2002–17 (Abraham & Thompson 2015), and globally, records of the incidental capture of LMSA in commercial fisheries are rare compared with other albatross species (BirdLife International 2018). Nonetheless, higher LMSA mortality rates are sometimes detected in observed fisheries (Brothers 1991; Bartle 2000; Taylor 2000). LMSA

FIGURE 1. Light-mantled sooty albatross, Adams Island, Auckland Islands, February 2017. *Image: Graham Parker.*

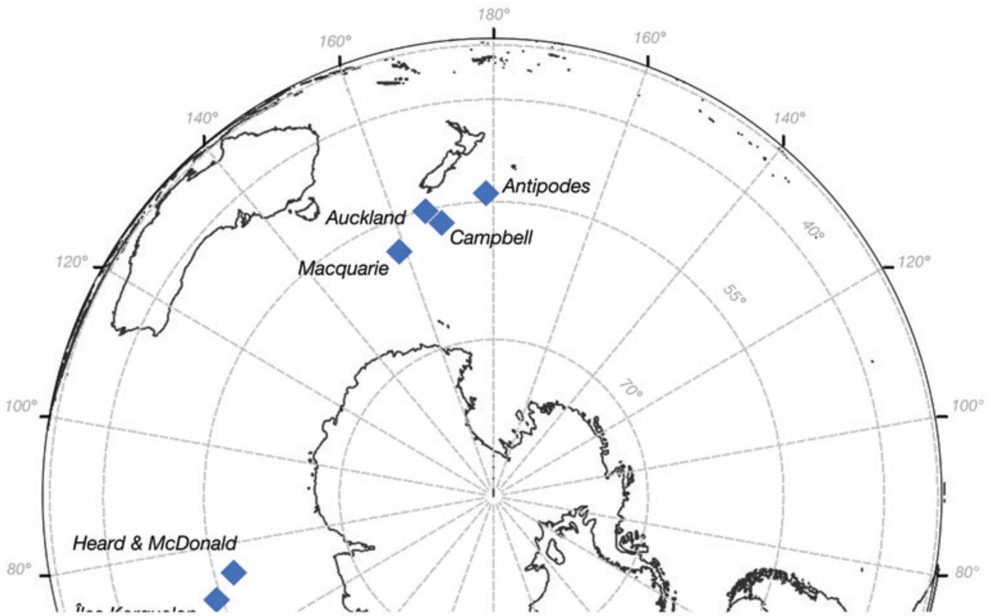

FIGURE 2. Light-mantled sooty albatross breeding sites.

represented 6% of the total seabird by-catch from tuna longliners during 1988–97 (Baird *et al*. 1998 *in* Taylor 2000). Numbers of individuals killed can be masked by clustered capture events: for example, 30 and nine LMSAs, respectively, were caught by tuna longliners in just two capture events (Oct 1996–Dec 1997; Bartle 2000). Similarly, three LMSA were caught during one 17-day voyage in Tasmanian waters (Jun 1988; Brothers 1991). Given that such examples of LMSA mortality were recorded in observed fisheries, it is of concern that high-seas fisheries (outside national jurisdictions) conditions are mostly not observed.

Basic demographic and distribution data for LMSA are needed to inform conservation status assessments and management actions, particularly estimates of population size and trends, and tracking to follow at-sea distribution (BirdLife International 2018). The global LMSA population size is thought to be 19,000–23,000 breeding pairs, but only three of the nine breeding populations have had robust estimates: Île de la Possession in the Îles Crozet; Macquarie Island; and Marion Island in the Prince Edward Islands (Fig. 2), with latest estimates being 746, 2,136, and 318 nesting pairs, respectively, at these islands (ACAP 2010, 2019). Robust estimates here are of moderate to high accuracy based on reliable methods (see

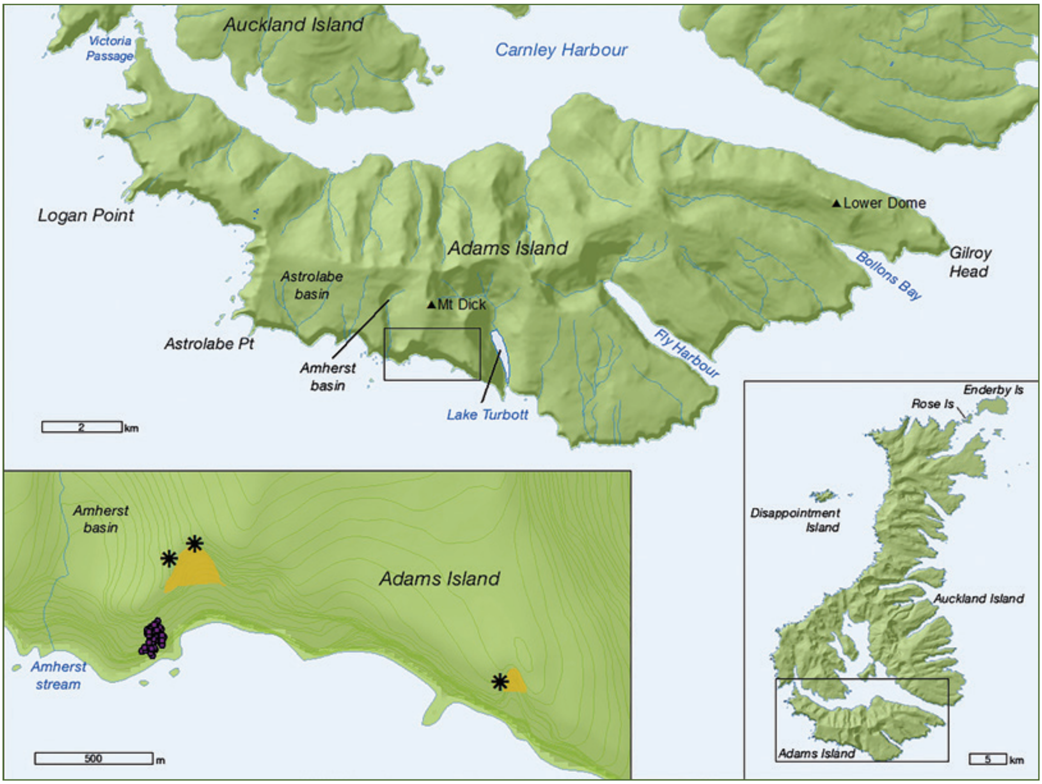

FIGURE 3. Adams Island overview (top) and light-mantled sooty albatross count areas on Adams (inset, lower left). Vantage-point count areas are shown as orange polygons, with marked vantage points starred. The study area photographed from helicopter and ground-truthed is indicated in purple. Lower right: overview of the Auckland Island group.

criteria of the Agreement on the Conservation of Albatrosses and Petrels; ACAP 2010). For these island groups where there have been robust population estimates, trends showed broadly similar patterns: decreases followed by stable or increasing populations in the early 2000s, which have then declined again since the mid-2000s (Weimerskirch & Jouventin 1997; Ryan *et al.* 2003, 2009; Delord *et al.* 2008; ACAP 2010, 2019; Schoombie *et al.* 2016).

The lack of robust population size and trend estimates from the majority of the LMSA breeding range reflects that LMSAs are difficult to count and monitor (Schoombie *et al.* 2016). Nests are located on coastal and inland cliff shelves and on steep terrain, in sites that are often difficult or impossible to reach safely without rope access equipment. The species can be sensitive to disturbance during courtship (Taylor 2000) and some birds may abandon nests if handled during early incubation (Moore 1996), which further complicates studies. LMSAs breed biennially, and so surveys for population size estimates need to be conducted over at least two consecutive years to overcome some of the variation caused by breeding patterns (Taylor 2000; Delord *et al.* 2008).

In the New Zealand region, population trends remain unknown as there have been no robust estimates of LMSA population size. In the mid-1990s a pilot study at Campbell Island (Fig. 2) suggested that around 1,600 LMSA pairs nested there (Moore 1996), but this was later thought to be an under-estimate (P. Moore, *pers. comm. in* Taylor 2000). On the smaller Antipodes Islands, approximately 200–300 pairs were recorded breeding in 1995 (Taylor 2000). In the mid-1970s, the LMSA population at the Auckland Islands was thought to be the world's largest, with roughly 5,000 pairs

(Bell 1975). Adams Island likely supports most of the Auckland Islands' LMSA population. The LMSA distribution on Adams Island is relatively well known: small breeding colonies were seen on nearly every suitable cliff along the south coast in a survey in Nov 1989 (Buckingham *et al.* 1991). The biggest colony was on a cliff shelf just east of Amherst Stream mouth (Fig. 3), with 100–150 birds seen, of which 40–50 were thought to be on eggs (Buckingham *et al.* 1991). A second large colony of about 100 birds was seen at Logan Point, with several hundred more nesting singly or in small groups scattered along the cliffs and ledges of the southern coast from Astrolabe Point to Gilroy Head, and on ledges in the inland cirque basins of Mt Dick–Lake Turbott, Fly Harbour, and Bollons Bay–Lower Dome (Elliott *et al.* 2020 – Chapter 3 in this book) (Fig. 3).

Taylor (2000) concluded that to accurately assess the conservation status of LMSA in the New Zealand region, and globally, a baseline census of populations on the Auckland Islands was needed. Taylor (2000) also recommended Adams Island as a priority site, followed by estimates from across the Auckland Islands group. Importantly, population size estimates must be based on methods that are reliable (ACAP 2010) and repeatable, to enable eventual analysis of population trends.

This study aimed to compare approaches to estimate and monitor LMSA numbers on New Zealand breeding islands. The four specific objectives of this work were to: (1) estimate LMSA trends using data from a small annual vantage-point count study (Adams Island); (2) conduct ground counts of breeding LMSAs (Adams Island); (3) test the feasibility of detecting breeding LMSAs in aerial images taken from a helicopter, corrected with ground-truthing data (Adams Island); and (4) trial the feasibility of boat-based surveys of breeding LMSAs (Campbell Island).

Methods

Light-mantled sooty albatross biology

Known breeding sites for LMSA in the Auckland Islands are Adams, Disappointment, Auckland, Enderby, and Rose Islands (Fig. 3; Taylor 2000; Miskelly *et al.* 2020 – Chapter 2 in this book). LMSAs are first observed around the breeding colonies in early-Oct, both in the Auckland Islands (Turbott 2002; Miskelly *et al.* 2020 – Chapter 2) and at Campbell Island (Bailey & Sorenson 1962). Eggs are laid late-Oct to early-Nov at Campbell Island (Bailey & Sorenson 1962). Laying dates appear to be similar at the Auckland Islands as birds were on eggs on 26 Oct 1942 and 14 Nov 1989 (Buckingham *et al.* 1991; McEwen 2006). LMSA eggs hatch late-Dec to early-Jan, and chicks are brooded for 19–21 days by both parents. LMSA chicks fledge after 140–157 days (data from other regions; ACAP 2010). Observations from the 1940s recorded that all chicks in the Auckland Islands had fledged by the first week of June (Turbott 2002).

Vantage-point counts, Adams Island

Vantage-point counts of a small number of active LMSA nests at two colonies on the southern cliffs of Adams Island were conducted annually during 1999–2019 (for 20 out of 21 years; Fig. 3). Yearly vantage-point counts involved two observers scanning the areas with high-quality binoculars and recording the total number of LMSA breeding attempts, with the position and status of each incubating adult or chick verified by a second observer. One count site comprises the upper portion of the large Amherst shelf colony where 150+ birds were noted in 1989 (Figs 3, 4), while the second, much smaller, site was identified in 1995 (Notch site, Fig. 3). The vantage points were marked with poles in Feb 1998, viewing nests that are at most 340 m away, and GPS coordinates recorded so that repeat counts with binoculars could use the same vantage points in subsequent years (Fig. 3). Vantage-point counts took place around the beginning of February, varying from 13 Jan to 12 Feb. At this time, counts were mostly of unguarded chicks. One count that took place 2–4 weeks early (31 Dec 2017) was excluded from analyses. The significance of count trends was examined via generalised linear models in program R (R Core Team 2019), using quasi-likelihood Poisson regression models. There was no effect of vantage-point site on trends in count data, and so we pooled counts from both sites to assess whether the timing of counts each year affected count trends. An exponential trend was fitted to the time series for the whole survey period. The annual breeding population growth rate (λ or lambda) was estimated using

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

where N represents the number of nests, s the seasons (s1 = 1999 and s2 = 2019), and t the number of years in the time series. Lambda indicates when populations are in decline (λ < 1), stable (λ = 1), or increasing (λ > 1) (Caswell 1989).

Ground counts, Adams Island

In a lower-elevation part of the same large Amherst shelf LMSA colony viewed during Adams Island scan counts (Figs 3, 4), a small,

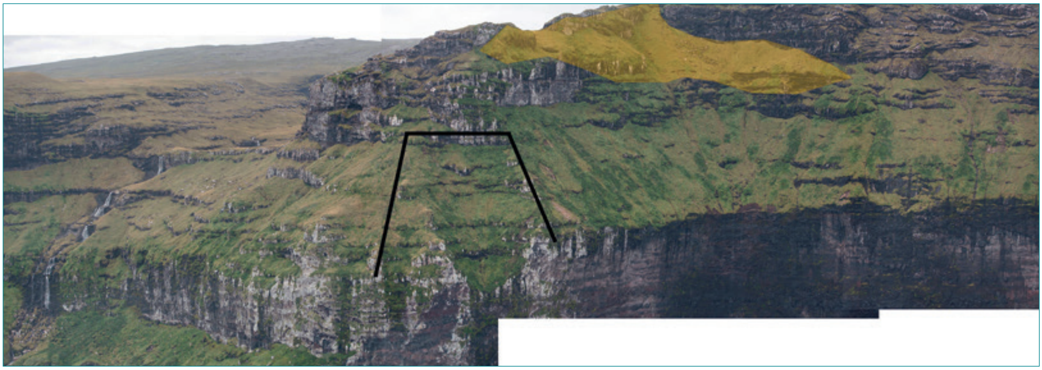

FIGURE 4. Assembled photographs of Amherst shelf count area for light-mantled sooty albatrosses, Adams Island, January 2017. Bold, dark lines indicate the area where albatrosses were counted on the ground and from helicopter. The Amherst vantage-point area counted is shaded yellow. Amherst Stream is at left. *Image: Barry Baker.*

FIGURE 5. Sample montage of overlapping aerial photographs and counts from within the light-mantled sooty albatross study area on Amherst shelf, Adams Island, in January 2017. Ellipses are coloured according to inferred status: yellow = apparently occupied nest, blue = unattended chick. *Image: Barry Baker.*

clearly defined study area was identified that could be accessed on foot without need for abseil equipment. Ground counts were conducted in this study area in the 2017 and 2018 breeding seasons (13 Jan and 27 Dec, respectively). In 2017, all nests in a 50 m buffer zone around the study area were also counted. During ground counts, two workers exhaustively searched the area via parallel transects *c*. 10 m apart across the slope. Adults on nests were approached, the position recorded by GPS, and breeding status (incubating an egg, brooding a chick, not actively breeding) was recorded when birds stood up. Clear cases of nest failure (large eggshell fragments, dead chick) were also recorded.

The aims of these ground counts were (1) to test the feasibility of adding ground counts to the two vantage-point areas, which would enable more nests to be followed annually in an area accessible by foot, and thereby allow things like breeding failure to be quantified, and (2) to ground-truth aerial images (see section below). Ground-truthing involved determining whether any nests were missed and estimating the error associated with 'loafing' birds (birds that look like they are not nesting, including non-breeding and failed breeders) when interpreting aerial images. Loafing birds can sit on empty nests, appearing from a distance to be incubating or brooding. Since loafing birds can substantially skew estimates of numbers of breeding pairs in other albatrosses (e.g. Parker *et al*. 2017), these individuals need to be accounted for.

Aerial images, Adams Island

Aerial photography was conducted on 18 Jan 2017 from an AS350-B3 Squirrel helicopter. The LMSA study area described above was overflown and photographed using high-definition DSLR (digital single-lens reflex) cameras. All photographs were taken through the open port door with standard 35 mm photographic gear (Nikon D800 cameras, 70–200 mm f2.8 zoom lens) recording high-resolution image files of minimum 20 MB, using shutter speeds >1/1,000 s to minimise effects of helicopter vibration on image quality. Photographs were generally taken *c*. 150 m to the seaward side of nesting sites. Since the high cliffs of Adams Island have LMSAs on upper and mid-elevation terraces (Fig. 4), photographing both terraces from one elevation point could compromise image quality, impairing detection and reducing count precision. To test whether counts would differ, we took photographs at two heights (213 m a.s.l. and 305 m a.s.l.). In other albatrosses there tend to be fewer non-breeding birds at breeding sites between 1000 h and 1700 h (e.g. Baker & Jensz 2016), and so all LMSA photos were taken in a brief period around 1430 h. Weather conditions on the 18 Jan flight day (overcast, low wind, cloud base 1,500 m) permitted clear photographs of the site (bold lines, Fig. 4).

Counting protocols followed those for aerial censuses of albatross colonies (Arata *et al*. 2003; Baker *et al*. 2018). In brief, photographic montages of the LMSA colony were constructed from overlapping photographs using Adobe Photoshop (http://www.adobe.com). Montages were magnified to view individuals and their nests, and all birds were counted, attempting to distinguish apparently occupied nests (adult or unattended chick on a nest) and loafing birds (e.g. Fig. 5). Each apparently occupied nest was assumed to represent a breeding pair. While most birds in photographs were alone at nest sites, instances when two birds were sitting close together (i.e. within pecking distance) were counted as a single breeding pair. Independent ground-truthing (above) was used to check the contents of apparently occupied nests.

Yacht-based counts, Campbell Island

On Campbell Island (Figs 2 & 8), boat-based counts of LMSA nesting on coastal cliffs were trialled on 19–29 Jan 2015. Three observers with high-quality binoculars scanned cliff areas from the vessel (SV *Tiama*, 14 m length and 3 m draught with keel down), motoring at approximately 5 knots (9.3 kph) about 500 m offshore and parallel with the coastline. Wind conditions were light (Beaufort 1) and sea state 3–4 with a moderate, long-period swell. Counts were timed to occur under favourable sea conditions (minimal swell) and light angles (no sun, or sun behind observers). All vessel tracks were recorded on GPS. Each observer separately estimated the number of chicks. The position of each chick was verified by a second observer, and only chicks detectable by two or more observers were included in the count. Approximate chick locations were recorded directly onto maps.

TABLE 1. Light-mantled sooty albatross chick counts, Adams Island. Analysis of deviance of Poisson regression (using quasi-likelihood) of counts of nests against year and the timing of counts.

	df	Deviance	Residual *df*	Residual deviance	F	*P* (>F)
Year	1	30.86	17	63.36	9.668	0.007
Timing of count	1	10.18	16	53.18	3.189	0.093

df = degrees of freedom.

TABLE 2. Boat-based counts of light-mantled sooty albatross chicks on coastal cliffs, Campbell Island, New Zealand, January 2015.

Coastal area	Survey date	Duration hours	Distance km / nm	Chick count
Ramp Point to Monowai Island	19 Jan	2.5	17.2 / 9.3	20
Monowai I. to Perseverance Hbr	19 Jan	2.5	25.5 / 13.8	59
Perseverance Hbr to Northeast Hbr	23 Jan	1.5	22.7 / 12.3	18
Northeast Harbour to Dent Island	28 Jan	3.0	25.0 / 13.5	21
Gomez Island to Ramp Point	29 Jan	4.0	9.0 / 4.9	41
Total		**13.5**	**99.4 / 53.8**	**159**

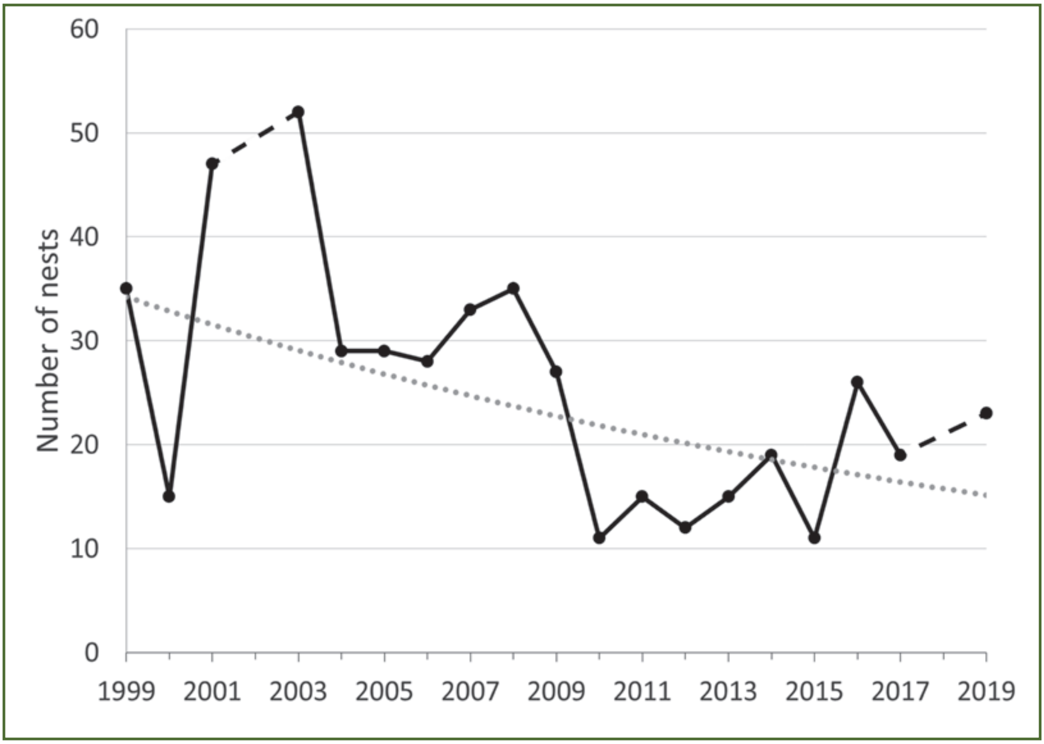

FIGURE 6. Vantage-point counts of light-mantled sooty albatross chicks in two southern cliff areas on Adams Island, Auckland Islands, 1999–2019. The dotted line is the overall trend for the time series (calculated rate of exponential decline, family Poisson), and the solid line is the fitted trend (data lacking for 2002 and 2018 are indicated by dashed lines).

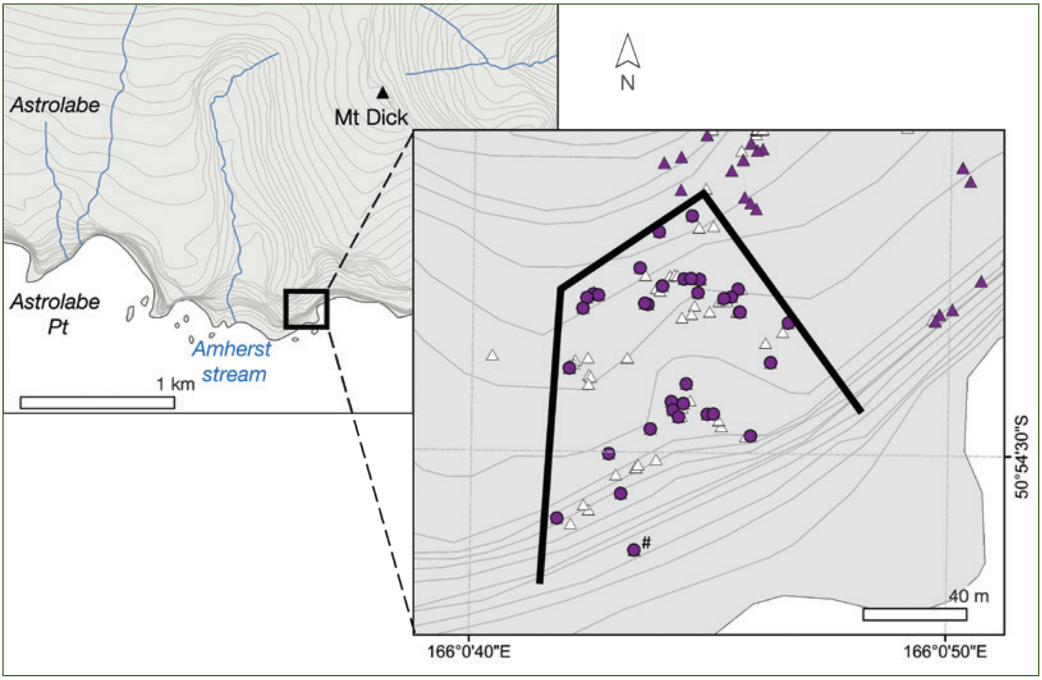

FIGURE 7. Light-mantled sooty albatross nest ground counts at Amherst shelf, Adams Island, in January 2017. Filled symbols are active nests (adult incubating egg or brooding chick) counted on the ground; circles are active nests within the aerially photographed study area indicated by bold lines) and filled triangles show other active nests in the colony. White triangles show inactive nests (empty nests and nests occupied by loafers). # indicates seven active nests present at this site.

Results

Vantage-point counts, Adams Island

Annual counts revealed a significant annual decline in the number of LMSAs breeding at the two localities on Adams Island (Table 1; Fig. 6). The nest count in 2017 and 2018, averaged to account for biennial breeding, was down 10% on the 1999–2000 average. Between 1999 and 2019 the annual rate of population decline was $\lambda = 0.44$. There was no significant effect of the timing of the counts (Table 1), despite dates ranging from 13 Jan to 12 Feb.

Ground counts, Adams Island

In a small, well-defined area within the large Amherst shelf colony, 42 and 40 active nests were counted in mid-Jan 2017 and late-Dec 2017, respectively (Fig. 7). Nests in the Amherst shelf colony were abundant, with 84 active nests within 50 m of the study area in 2017. Ground counts in 2017 and 2018 revealed that 5% and 2% of apparently occupied nests did not contain an egg but were loafing adult LMSAs sitting on nest pedestals (i.e. 84 nests with egg out of 88 apparently occupied nests in 2017, and 40 eggs out of 41 apparently occupied nests in 2018).

Aerial images, Adams Island

Counts from the aerial photographs taken on 18 Jan identified 48 apparently occupied nests, each assumed to represent a breeding pair (e.g. Fig. 5). There was no difference between the counts from photos taken at 213 m a.s.l. and 305 m a.s.l.

Ground-truthing 5 days earlier (13 Jan) showed a total of 42 active nests in the photographed section of the study area (Fig. 7). Eight (16.7%) of the 48 apparently occupied nests identified in aerial photos were not active nests (i.e. did not contain an egg or chick), but were nests occupied by loafers. Two active nests were not visible in the photos. Based on these data, aerial counts over-estimated the number of annual breeding pairs by 12.5%.

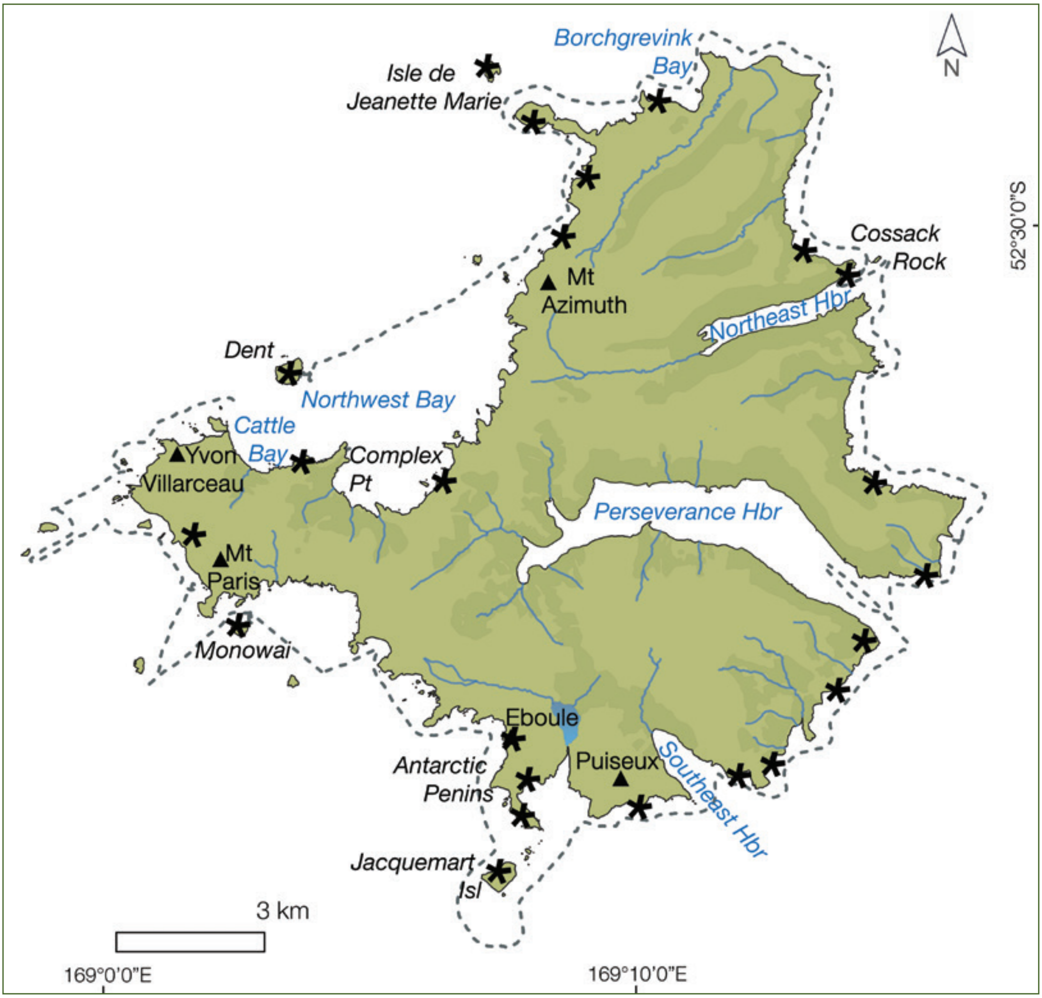

FIGURE 8. Light-mantled sooty albatross survey of Campbell Island coastline 19–29 January 2015. Dashed lines represent survey transects and stars show locations where chicks were sighted.

Yacht-based counts, Campbell Island

A total of 53.8 nautical miles (99.4 km) of boat-based LMSA surveys and counts were conducted (Table 2; Fig. 8) during a complete circumnavigation of Campbell Island. Offshore islands and rock-stacks were surveyed and counted whenever possible, but some areas could not be approached closely (i.e. close enough to detect LMSAs) as Campbell Island has poor bathymetry charting. The coastline with LMSA breeding populations was divided into five areas, and these were counted on four separate days between 19 and 29 Jan 2015 (Table 2).

A minimum of 159 LMSA chicks were counted along the coastal cliffs (Table 2; Fig. 8). Detectability of LMSAs could not be quantified with concurrent ground counts to determine whether some nests were missed. However, we believe that detectability will have been poor because (1) the angle of view from a boat does not allow inspection into all ledges of cliffs up to 300 m high, and opportunistic checks from clifftop vantage points showed some LMSAs nesting on ledges that would not have been visible from the sea; (2) boat-based counts of LMSAs were hindered by vessel movement despite calm sea conditions for surveys, making searching more difficult and likely less accurate; and (3) light conditions occasionally impeded surveys despite best efforts (sun in front or to the side of observers, haze). Ground-truthing data to estimate the magnitude of these detection-related errors are not readily obtained for Campbell Island's coastal LMSA sites.

Discussion

Vantage-point counts, Adams Island

Annual counts of two LMSA areas on Adams Island from vantage-point sites showed that the population declined at an annual rate of 0.44% over the period 1999–2019. Although count dates ranged from mid-Jan to early-Feb, the timing did not significantly influence the overall decrease in chick numbers over 21 years. Breeding LMSAs also appear to be less common on inland ridges on Adams Island than they were in the 1990s (authors, *pers. obs*). Trends at Adams Island fit roughly with trends from other island groups, where LMSA numbers were stable or increased in the 2000s and then declined from 2007–08 (Île de la Possession, Prince Edward Islands, Macquarie Island) (Ryan *et al.* 2003, 2009; Delord *et al.* 2008; ACAP 2010, 2019; Schoombie *et al.* 2016). Another biennially breeding albatross on Adams Island, the Gibson's wandering albatross (*Diomedea antipodensis gibsoni*), has also seen steep declines from the mid-2000s followed by a slow, gradual recovery since *c.* 2010 (Elliott *et al.* 2018), which appears to have been echoed by Adams Island LMSAs. However, the vantage-point counts underpinning these LMSA trends at Adams Island are limited by scale – a relatively small number of pairs breed in the two vantage-point count areas each year – and timing, with an unknown rate of breeding failure occurring each year before counts take place. Since the date of vantage counts cannot be easily optimised due to logistic constraints, we assessed the potential to increase scale via a new ground-count area where more birds could be followed.

Ground counts, Adams Island

The ground-count location on Adams Island was selected as it can be safely accessed on foot, and so the number of sites and number of pairs that are monitored annually can be increased. Over 2 years, 42 and 40 active nests were counted in the small, well-defined study area. Expanding the count area by 50 m easily doubled the number of nests that could be monitored. We suggest that an expanded ground-count area is necessary given the trends seen on Adams Island over the past two decades. With suitable timing of colony visits and mark-recapture effort, a ground-count site could enable nest failure rates and adult and juvenile survival to be estimated, and tracking devices could document the currently unknown at-sea distribution of LMSAs from the Auckland Islands region.

Aerial images, Adams Island

High-quality photographs enabled LMSA counts that showed good correspondence with nest detection on the ground. Comparison of breeding status assessed from photographs with ground-truthing showed a relatively small error rate at this stage of the breeding cycle (late incubation/brood-guard period). Of apparently occupied nests identified in photographs, 17% did not contain an egg, and ground surveys suggest this can be as low as 2–5% during late incubation. These rates are much less than than the 36% of apparently occupied white-capped mollymawk (*Thalassarche cauta steadi*) nests that lacked eggs at late incubation (Parker *et al.* 2017). The LMSA breeding status error rate was fairly consistent across two breeding seasons (2017 and 2018) but should be checked at other sites. If the error rate remains consistent and is similar over several sites, it could provide a useful correction factor for aerial-photography counts of LMSAs from other areas in the future.

The timing of the survey (late incubation/brood-guard period) meant that some birds that bred may have failed, and so counts at this stage of the breeding cycle are conservative. As for ground counts, aerial counts would benefit from data on nest failure rates.

Considering that the terrain favoured by LMSAs for nesting sites ranges from difficult to inaccessible for humans, counts derived from aerial photography – with ground-truthing where possible – probably represents the most effective technique for rapid assessment of LMSA population size in the Auckland Islands. Satellite imagery or higher-altitude photos taken from a fixed-wing aircraft are not likely to be useful for these cliff habitats, which require sideways-looking photographs such as those from helicopters. We showed that the optimal helicopter elevation for photography had an acceptable tolerance of ±100 m within which nest counts were not affected. Study design for future surveys should include the optimal elevation range for each group of cliff terraces (Baker & Jensz 2014).

Other areas suitable for aerial image counts could include northern breeding sites like Enderby, Rose, and Disappointment Islands. Few birds breed on these islands, although we note that aerial photographs taken to count white-capped mollymawks at Disappointment Island (Baker *et al.* 2014) were also suitable for counting breeding LMSAs; 79 LMSAs were detected in white-capped mollymawk survey photos there (Baker & Jensz 2014). However, Adams Island should be the priority since it appears to have the largest LMSA population, particularly focusing on the southern cliffs and inland bluffs (Taylor 2000). The main Auckland Island appears less of a priority since there has been little evidence of extensive LMSA nesting here, neither from island-wide helicopter surveys (G.B. Baker, M. Holdsworth, & L. Chilvers, *unpubl. data*) nor from groundwork at the Falla Peninsula and around the northern bluffs and headlands (Cox *et al.* 2019). Small nest numbers may be linked to the mammalian predators present on main Auckland, which are not found on other islands in the group. However, the main Auckland Island is the largest island in the archipelago and so should not be excluded from efforts to compile an Auckland Islands LMSA population estimate.

Another avenue to explore is aerial photography via unmanned aerial vehicles (UAVs or drones), which have been used to count albatrosses in other regions where access is difficult (e.g. Inaccessible Island; McClelland *et al.* 2016). Use of drones at cliff sites like those on Adams Island will be considerably more challenging than for the gentler slopes of Inaccessible Island. However, we note that drones have been used successfully in the Auckland Islands for monitoring birds nesting on smaller cliffs and in dense vegetation, and for whale research (Dawson *et al.* 2017; Muller *et al.* 2019; Cox *et al.* 2019). At tiny Bollons Island in the Antipodes group, LMSAs were successfully counted using a drone (G. Elliott, *unpubl. data*). Drone-based methods for monitoring albatrosses are being explored further in the New Zealand subantarctic, as the technology advances.

Yacht-based counts, Campbell Island

Boat-based counts of Campbell Island LMSAs proved challenging due to vessel movement, despite targeting good light and sea conditions. Most of the Campbell Island coastline is fully exposed to open-ocean swell, and so it is unlikely that better conditions will be encountered. Importantly, ground-truthing data to assess detection rates are not readily obtained for Campbell Island's coastal LMSA sites, nor are data to assess the rate that apparently occupied nests (counted from the boat) involve birds loafing on a nest with no egg or chick. Loafers may not be a major error source considering the relatively small proportion of apparently occupied LMSA nests that were actually occupied by loafers on Adams Island, although this assumes that LMSA behaviours on Campbell Island are similar to those on Adams Island.

Overall, boat-based counts of LMSAs on the coastal cliffs of Campbell Island remain a minimum count with poor confidence in accuracy, with the method as tested primarily useful for assessing presence versus absence and of little use for accurately estimating breeding numbers. Boat-based counts could be aided by gimbal mounts to help stabilise optics, and potentially by thermal imagery. Campbell Island is too far from mainland New Zealand for a helicopter-based population size estimate to be practical, but drone-based technologies could provide a platform for aerial surveys in future. Since the island is much smaller than the Auckland Islands, drones may potentially enable a full survey to assess Campbell Island's LMSA population size.

There are no obvious areas along the Campbell Island coastline where ground counts like those on Adams Island cliff shelves might be possible. The landward face of Folly Island is accessible but supports too few nests to be a useful sample. However, counts from land-based vantage points have been explored on Campbell Island before (Moore 1996), and may be the best option for ongoing monitoring of population trends. Vantage-point counts in that study were challenged by light and viewing-angle factors similar to those that hindered boat-based counts, and suitable vantage points are not available for all areas of the Campbell Island coastline. However, we show here that repeatable counts from the same vantage points over time can provide useful data for monitoring, even when obtained from a very small sub-set of breeding sites (Adams Island). Replicating counts from vantage points used by Moore (1996) would provide comparable data to assess trends of LMSAs at Campbell Island since 1995, and enable monitoring over time.

Conclusions

Counts of small numbers of LMSA chicks in two areas on Adams Island suggest that the population is declining, following the general trend at other LMSA islands. Globally, there is a recognised need for population estimates and population trends for LMSA (BirdLife International 2018), and the Auckland Island group has been highlighted as a regional priority (Taylor 2000). We show that the number of breeding birds monitored annually by vantage-point counts can be increased at Adams Island via a combination of aerial and ground counts. Counts over larger areas including more individuals provide better resolution for detecting trends.

A full count of LMSAs is needed for the Auckland Islands, and for New Zealand as a whole. Our study did not collect the kind of data needed to underpin such a population estimate, as the surveys were designed to test and identify methods suitable for assessing population size. A robust population size estimate would require such methods to be expanded to cover all LMSA habitat, either in full or using a randomised sample of representative habitat. An approach combining aerial survey and ground counts could be extended to produce counts for the whole Auckland Island group, corrected with nest failure rates from an Adams Island study area. At islands too far from mainland New Zealand for helicopter-based work to be practical (Campbell and Antipodes Islands), population size estimates could potentially use drones as the platform for aerial surveys in future, particularly since LMSAs there use less rugged terrain than the cliff shelves of the Auckland Islands. For now, we suggest that a mix of ground counts and vantage-point counts is the most feasible way to continue monitoring LMSA trends, but to obtain population size estimates, ground-truthed aerial count effort must be expanded.

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A pair of light-mantled sooty albatrosses in courtship flight, Enderby Island, January 2016. *Image: Tony Whitehead.*