Unmanned aerial vehicle (UAV) survey of the Antarctic shag (*Leucocarbo bransfieldensis*) breeding colony at Harmony Point, Nelson Island, South Shetland Islands

W. Chris Oosthuizen[1*], Lucas Krüger[2], William Jouanneau[3], Andrew D. Lowther[4]

[1] Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

[2] INACH Instituto Antártico Chileno, Plaza Muñoz Gamero 1055, Punta Arenas, Chile

[3] Centre d'Etudes Biologiques de Chizé, UMR 7372 du CNRS-Université de La Rochelle, Villiers-en-Bois, France

[4] Norwegian Polar Institute, Framsenteret, Tromsø, Norway

[*]Corresponding author

wcoosthuizen@zoology.up.ac.za

ORCID

W. Chris Oosthuizen 0000-0003-2905-6297

Abstract

Monitored seabird populations - useful sentinels of marine ecosystem health - have been declining worldwide at a rapid pace. Yet, lack of reliable long-term monitoring data constrains assessment of the conservation status of many seabird populations. Unmanned aerial vehicles (UAVs) have the potential to increase survey efficiency and count precision of seabird populations, especially where time constraints or inaccessible terrain, such as sea stacks, limit meaningful ground-based surveys. Furthermore, tremendous potential exists to combine fine scale spatially-integrated habitat mapping obtained from UAV images with occupancy to unravel how abiotic factors such as topography affect animal populations. In late December 2018, we used an UAV to create a georeferenced orthomosaic image and digital elevation model (DEM) from which we determined the size of the Antarctic shag (*Leucocarbo bransfieldensis*) breeding colony at Harmony Point, Nelson Island, South Shetland Islands. Our population estimate of 69 breeding pairs is approximately double that reported for the early 2000s and the highest count since the late 1980s. Most nests were located 10 to 20 meters above sea level, on relatively shallow gradients that predominantly faced southeast. While it is difficult to compare historical ground-based counts with the UAV-derived estimates presented here, our new data provide robust baseline information for future monitoring of the colony population size using comparable survey methods. Our basic mapping of the topography of the breeding colony also highlights how UAV-derived habitat information can facilitate our understanding of the influence of landscape structure on animal population dynamics.

Keywords

drone, monitoring, population count, population size, seabird, spatial ecology

Introduction

Unmanned aerial vehicles (UAVs) – also called unmanned aircraft systems (UAS) or drones – represent a new frontier in ecological research and ecosystem monitoring (Anderson and Gaston 2013; Linchant et al. 2015). UAVs are increasingly being used by ecologists and managers to obtain fine spatial resolution remote-sensing data (Borowicz et al. 2018) and as a monitoring tool for estimating population parameters such as abundance and distribution (Goebel et al. 2015; Mulero-Pázmány et al. 2015) or individual attributes such as body condition (Allan et al. 2019). UAV-facilitated population monitoring is particularly relevant to bird species that aggregate, including surface nesting seabirds, colony breeding waterbirds, and the staging flocks of migratory birds. UAV-based counts of seabirds are more accurate than ground-based observer counts (Hodgson et al. 2018) and may be semi-automated to reduce time investment by researchers (Chabot and Francis 2016). UAVs can also provide reliable counts of seabirds breeding on inaccessible terrain, such as sea stacks, or at sites where time constraints limit meaningful ground-based surveys (McClelland et al. 2016). Finally, tremendous potential exists to combine fine scale spatially-integrated habitat mapping obtained from UAV images with occupancy to unravel habitat selection (e.g., nest site selection by breeding birds) (Sardà-Palomera et al. 2012, 2017). Mapping occupancy in UAV-derived high-resolution topographic images can thus improve our understanding of habitat suitability, and the relationship between habitat, fine scale microclimate effects and demographics (e.g., breeding success variation in relation to landscape structure; Sardà-Palomera et al. 2017).

In this study, we used an UAV to accurately determine the size of the Antarctic shag (*Leucocarbo bransfieldensis*) breeding colony at Harmony Point, Nelson Island, South Shetland Islands (Fig. 1a). We compare our count to ground-based counts made between 1988 and 2010, and map individual nest locations in relation to topography to demonstrate the feasibility of UAVs to investigate nest-site selection in relation to fine scale habitat within a seabird breeding colony.

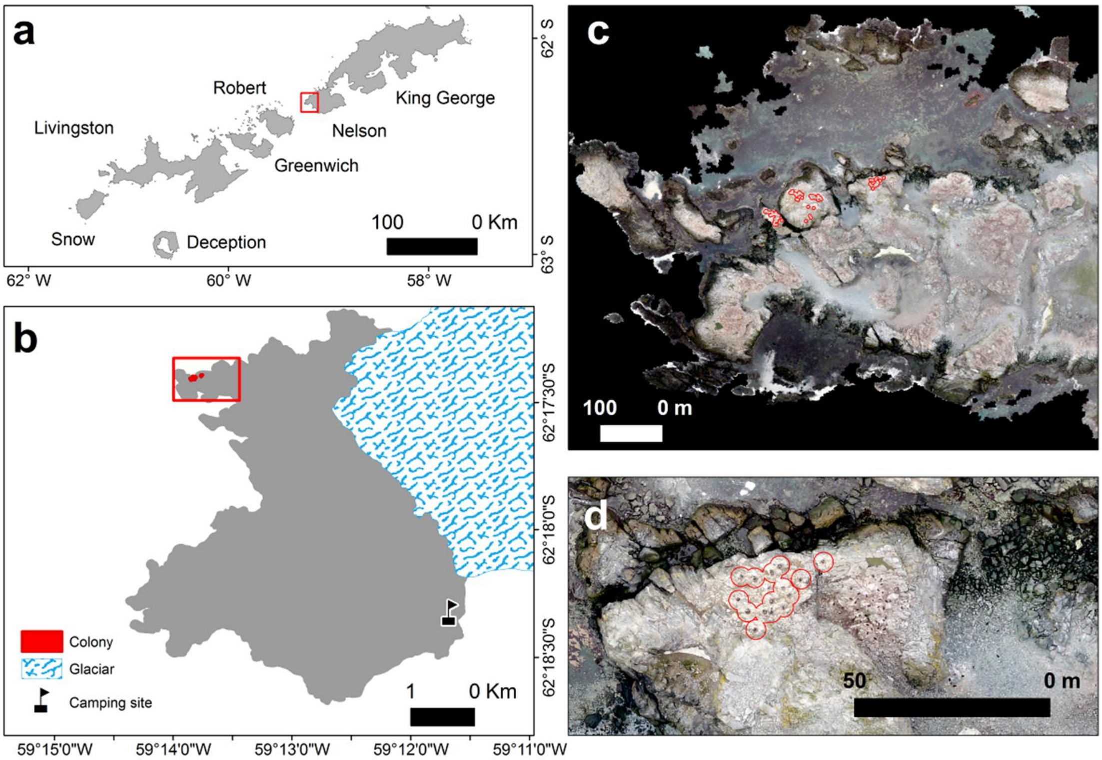

Fig. 1 **a** Harmony Point, Nelson Island, South Shetland Islands. **b** The location of the Antarctic shag colony at Harmony Point. **c** Orthomosaic image of the Antarctic shag colony. **d** Antarctic shag nests (delimited by red lines; a colour version of this figure is available online) are clearly distinguished from breeding chinstrap penguins (to the right of the shag colony).

Monitored seabird populations are useful sentinels of marine ecosystem health. However, interrupted monitoring makes assessment of the global conservation status of Antarctic shags, the southernmost cormorants in the world, rather challenging. Many shag populations around the Antarctic Peninsula appear to have decreased in recent decades, mirroring global seabird population declines (Paleczny et al. 2015). Trends are variable, however, with population increases reported in southern and eastern range edges (Schrimpf et al. 2018; Phillips et al. 2019). At Nelson Island, both the Duthoit Point and Harmony Point Antarctic shag colonies exhibited clear population declines between the late 1980s and 2010 (Casaux and Barrera-Oro 2016; Schrimpf et al. 2018).

Materials and methods

Antarctic shag taxonomy

Morphological similarities have led to much taxonomic ambiguity within the blue-eyed shag complex. There remains disagreement about the genus name *Leucocarbo* or *Phalacrocorax*, and the Antarctic shag is often considered a subspecies of the blue-eyed (or imperial) shag *L.* or *P. atriceps bransfieldensis* (e.g., Schrimpf et al. 2018). We consider Antarctic shags a separate species (*L. bransfieldensis*) based on the results of extensive phylogenetic analysis (Kennedy and Spencer 2014). Antarctic shags inhabit the Antarctic Peninsula, the South Shetland Islands and Elephant Island (Schrimpf et al. 2018).

Unmanned aerial vehicle survey

Antarctic shags breed in a single but spatially segregated colony on the northern coastline of Harmony Point, an Antarctic Specially Protected Area (ASPA No. 133) (Fig. 1b, 1c) (Silva et al. 1998). Most nests are located on three promontories near the ocean, with steep slopes leading up to the top impeding easy access on foot (Fig. 1c). The breeding colony was surveyed on 27 December 2018 as part of concurrent mapping of chinstrap (*Pygoscelis antarctica*) and gentoo (*P. papua*) penguin colonies around Harmony Point. This period corresponds to the late incubation breeding phase of Antarctic shags.

Surveys were conducted using a DJI Phantom 4 Advanced (SZ DJI Technology Co. Ltd, Shenzhen, Guangdong, China) drone with an in-built camera (effective pixels: 20M). Flight transects were pre-programmed using the autonomous flight planning software Map Pilot (Drones Made Easy, San Diego, California, USA) and was set to record images with a 70 % overlap while flying 90 meters above the terrain. This target altitude was chosen to keep flight missions as short as possible while recording images with sufficient resolution to easily identify individual birds. The drone was launched and landed away from all bird colonies, and drone approaches did not have any noticeable impact on animal behavior (e.g., Weimerskirch et al. 2018).

UAV-captured images with overlapping fields of view were processed in Agisoft PhotoScan Professional (version 1.2.6; Agisoft LLC, St Petersburg, Russia) using structure-from-motion processing (e.g., McDowall and Lynch 2017). Structure-from-motion processing generated a high-resolution georeferenced orthomosaic of the study site. Antarctic shag nest locations were marked and counted on the orthomosaic image. Only active nests were marked, and no corrections were made for nest failures. Breeding shags could easily be distinguished from nesting penguins (Fig. 1d).

ArcGIS 10.4 (Environmental Systems Research Institute Inc., Redlands, CA, USA) was used to analyze the georeferenced orthomosaic. We generated a digital elevation model (DEM) from which elevation, slope and aspect was calculated to describe the topography of the breeding colony, and the location of nests within this landscape. In ArcGIS, slope is the maximum change in elevation over a specific distance (i.e., it identifies the steepest gradients), while aspect identifies the direction of downslopes. Imagery and processed data are available from the authors.

Results

In late December 2018, the Harmony Point Antarctic shag colony comprised three sub-units, totaling 69 breeding pairs (Fig. 2a). Most nests were positioned 10 to 20 meters above sea level (Fig. 2b), on relatively shallow gradients (gentle slopes) (Fig. 2c) that predominantly faced southeast (aspect approximately 135°) and uncommonly north-west (aspect approximately 315°) (Fig. 2d).

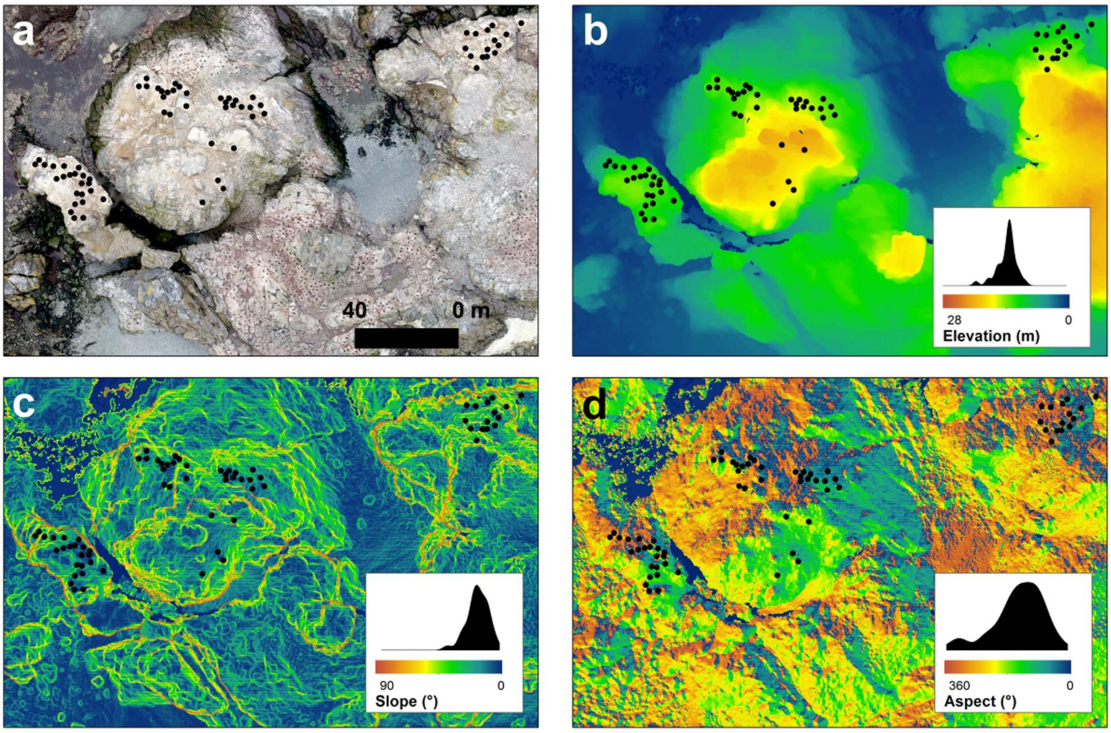

Fig. 2 a Orthomosaic image with all Antarctic Shag nests marked (black circles). **b - d** Antarctic Shag nests in relation to elevation above sea level, slope and aspect. A colour version of this figure is available online.

Discussion

Quantifying the distribution and abundance of animals is fundamental to ecological studies and environmental monitoring, but can be difficult and therefore intermittent in remote places such as Antarctica. Here, we provide an update on the size of the Antarctic shag colony breeding at Harmony Point, Nelson Island. This colony numbered above 100 breeding pairs in the late 1980s (n = 2 counts), but decreased subsequently, averaging 57 breeding pairs in the mid-1990s (n = 2 counts) and 41 breeding pairs between 2000 and 2005 (n = 6 counts) (Casaux and Barrera-Oro 2016). The last published estimates for the Harmony Point colony reported an average of only 36 breeding pairs in 2009 and 2010 (Casaux and Barrera-Oro 2016). Our breeding population estimate of 69 breeding pairs in 2018 is the highest count since the late 1980s. However, since the exact dates of counting and the accuracy of past counts are unknown, it is difficult to compare historical ground-based counts (Casaux and Barrera-Oro 2016) with the UAV-derived estimates presented here. There can be substantial intra-seasonal variation in the number of active nests, with fewer breeding pairs present at a site near the end of the breeding season because failed nests are typically abandoned (Schrimpf et al. 2018). That said, we considered all occupied nests as active, and it is possible that some of these nests may still have been occupied by failed breeders or non-breeders. It is also possible that ground-based counts have underestimated the breeding population in the past, given that it is difficult to access the outcrops on which the shags breed. Alternatively, the apparent (but unverified) increase in breeding pairs may be due to a genuine increase in abundance since 2010 as observed at the southern and eastern range edges.

In addition to obtaining an accurate estimate of the size of the breeding colony, our UAV survey provided spatially-integrated landscape data that we used to describe fine scale nest-site selection in relation to topography. UAV surveys and structure-from-motion processing therefore provide unique opportunities to advance our understanding of spatial ecology, habitat selection and ecophysiology by rapid and simultaneous mapping of organisms and the three-dimensional structure of the landscape (Sardà-Palomera et al. 2017, see also McDowall and Lynch 2017). Slope and aspect may be important factors leading to habitat partitioning in closely related species. In Patagonia, Rock shags (*L. magellanicus*), for example, breed on cliffs or open rocky outcrops with steep slopes, while imperial shag (*L. atriceps*) colonies are mostly located on level substrates (Punta et al. 2003). In the case of Antarctic shags breeding on open rocky outcrops, slope and aspect may lead to fine scale variation in thermal and wind stress within a breeding colony, which may have demographic consequences.

UAV-derived estimates of seabird colony sizes can be more accurate and precise than conventional ground-based observer counts, thereby increasing statistical power to detect changes in population trends (Hodgson et al. 2016, 2018). Many shag populations are hard to monitor because they breed in difficult to reach sites and are sensitive to human disturbance while breeding. As inshore foragers, shags can become more powerful sentinel species for local marine ecosystems if their populations can be better monitored using new approaches such as UAV surveys that improve data collection and reduce investigator disturbance (Borrelle and Fletcher 2017).

Acknowledgements

This study was conducted during a Norwegian Polar Institute expedition to Nelson Island (Project No 15208). All research was conducted under relevant national permits. We thank the Chilean Antarctic Institute (INACH) for logistic support. Tom Hart and another reviewer provided constructive comments on the manuscript.

Compliance with Ethical Standards

We have no conflict of interest to declare.

References

Allan BM, Ierodiaconou D, Hoskins AJ, Arnould JPY (2019) A rapid UAV method for assessing body condition in fur seals. Drones 3:24. https://doi.org/10.3390/drones3010024

Anderson K, Gaston KJ (2013) Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Front Ecol Environ 11:138–146. https://doi.org/10.1890/120150

Borrelle SB, Fletcher AT (2017) Will drones reduce investigator disturbance to surface-nesting birds? Mar Ornithol 45:89–94

Borowicz, A, McDowall P, Youngfesh C et al (2018) Multi-modal survey of Adélie penguin mega-colonies reveals the Danger Islands as a seabird hotspot. Sci Rep 8:3926. https://doi.org/10.1038/s41598-018-22313-w

Casaux R, Barrera-Oro E (2016) Linking population trends of Antarctic shag (*Phalacrocorax bransfieldensis*) and fish at Nelson Island, South Shetland Islands (Antarctica). Polar Biol 39:1491–1497. https://doi.org/10.1007/s00300-015-1850-5

Chabot D, Francis CM (2016) Computer-automated bird detection and counts in high-resolution aerial images: a review. J Field Ornithol 87:343–359. https://doi.org/10.1111/jofo.12171

Goebel ME, Perryman WL, Hinke JT, Krause DJ, Hann NA, Gardner S, Leroi DJ (2015) A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biol 38:619–630. https://doi.org/10.1007/s00300-014-1625-4

Hodgson JC, Baylis SM, Mott R, Herrod A, Clarke RH (2016) Precision wildlife monitoring using unmanned aerial vehicles. Scientific Reports 6: 22574. https://doi.org/10.1038/srep22574

Hodgson JC, Mott R, Baylis SM, Pham TT, Wotherspoon S, Kilpatrick AD, Raja Segaran R, Reid I, Terauds A, Koh LP (2018) Drones count wildlife more accurately and precisely than humans. Methods Ecol Evol 9:1160-1167. https://doi.org/10.1111/2041-210X.12974

Kennedy M, Spencer HG (2014) Classification of the cormorants of the world. Mol Phylogenetics Evol 79:249–257

Linchant J, Lisein J, Smeki J, Lejeune P, Vermeulen C (2015) Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. Mammal Rev 45:239–252. https://doi.org/10.1111/mam.12046

McClelland GTW, Bond AL, Sardana A, Glass T (2016) Rapid population estimate of a surface-nesting seabird on a remote island using a low-cost unmanned aerial vehicle. Mar Ornithol 44:215–220

McDowall P, Lynch HJ (2017) Ultra-fine scale spatially-integrated mapping of habitat and occupancy using structure-from-motion. PLoS ONE 12: e0166773. https://doi.org/10.1371/journal.pone.0166773

Mulero-Pázmány M, Barasona JA, Acevedo P, Vicente J, Negro JJ (2015) Unmanned aircraft systems complement biologging in spatial ecology studies. Ecol Evol 5:4808–4818. https://doi.org/10.1002/ece3.1744

Paleczny M, Hammill E, Karpouzi V, Pauly D (2015) Population trend of the world's monitored seabirds, 1950–2010. PLoS ONE 10: e0129342. https://doi.org/10.1371/journal.pone.0129342

Phillips RA, Silk JRD, Massey A, Hughes KA (2019) Surveys reveal increasing and globally important populations of south polar skuas and Antarctic shags in Ryder Bay (Antarctic Peninsula). Polar Biol 42:423–432. https://doi.org/10.1007/s00300-018-2432-0

Punta G, Yorio P, Saravia J, García Borboroglu, P (2003) Breeding habitat requirements of the imperial cormorant and rock shag in central Patagonia, Argentina. Waterbirds 26:176–183

Sardà-Palomera F, Bota G, Viñolo C, Pallarés O, Sazatornil V, Brotons L, Gomáriz S, Sardà F (2012) Fine-scale bird monitoring from light unmanned aircraft systems. Ibis 154:177–183

Sardà-Palomera F, Bota G, Padilla N, Brotons L, Sardà F (2017) Unmanned aircraft systems to unravel spatial and temporal factors affecting dynamics of colony formation and nesting success in birds. J Avian Biol 48:1273–1280

Schrimpf M, Naveen R, Lynch HJ (2018) Population status of the Antarctic shag *Phalacrocorax* (*atriceps*) *bransfieldensis*. Antarct Sci 9:151–159. https://doi.org/10.1017/S0954102017000530

Silva MP, Favero M, Casaux R, Baroni A (1998) The status of breeding birds at Harmony Point, Nelson Island, Antarctica in summer 1995/96. Mar Ornithol 26:75–78

Weimerskirch H, Prudor A, Schull Q (2018) Flights of drones over sub-Antarctic seabirds show species- and status-specific behavioural and physiological responses. Polar Biol 41:259–266. https://doi.org/10.1007/s00300-017-2187-z