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Short Note

Finally Within Reach: A Drone Census of an Important, But Practically Inaccessible, Antarctic Fur Seal Colony

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Long-term monitoring studies of large marine predator populations are fundamental to the conservation and management of marine ecosystems (Boyd et al., 2006; Moore, 2008). The body condition (Costa et al., 1989), foraging behavior (Trillmich & Dellinger, 1991; Melin et al., 2008), and population dynamics (Merrick et al., 1995; Monson et al., 2000) of pinnipeds can provide useful indices to inform ecosystem-based fisheries management (Weise & Harvey, 2008; Melin et al., 2010). In the rapidly warming Antarctic Peninsula region (Vaughan et al., 2003; Cook et al., 2005; Turner et al., 2014), the Antarctic fur seal (*Arctocephalus gazella*) is a key indicator species (Agnew, 1997; Boyd & Murray, 2001).

Accurate counts of individuals are fundamental to population management but can be challenging to obtain for pinnipeds in remote polar environments (Taylor et al., 2007; Southwell et al., 2008). The standard census approach for otariids, such as the Antarctic fur seal (hereafter AFS), is to obtain synoptic counts of newborn pups (Bonner, 1968; Bengtson et al., 1990). A series of AFS pup surveys throughout the South Shetland Islands over the last 35 years (Figure 1) illustrated that AFS population dynamics in the archipelago are largely driven by pup production from breeding colonies at Cape Shirreff, Livingston Island, and on the adjacent San Telmo Islands. These two colonies produced 68 to 85% of all pups born in the South Shetland Islands between 1987 and 2008. Although annual counts have been conducted at Cape Shirreff since the 1990s, surveys of the San Telmo Islands have not been completed since 2008. Despite the proximity of the San Telmo Islands to Cape Shirreff (~1 km west), surrounding reefs make access by sea dangerous and difficult (Figure 2).

Over the last decade, unoccupied aerial systems (UAS), or drones, have become common tools for wildlife monitoring (Goebel et al., 2015; Christie et al., 2016; Durban et al., 2016; Johnston, 2019). Drones are relatively inexpensive, and UAS surveys frequently obtain data less invasively (Krause et al., 2021) and as or more accurately than traditional ground-based methods (e.g., Krause et al., 2017; Hodgson et al., 2018). The goal of this study was to utilize a medium-range vertical takeoff and landing (VTOL) UAS to obtain pup counts from the San Telmo Islands during late December after most pups have been born but before they suffer substantial predation from leopard seals (*Hydrurga leptonyx*; Krause et al., 2015, 2020).

All UAS flights and ground surveys were conducted within the United States' Antarctic Marine Living Resources Program (U.S. AMLR) study area

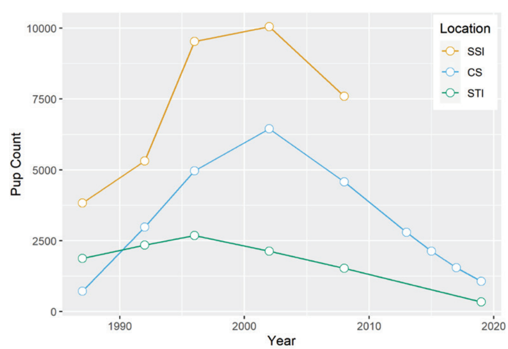

Figure 1. Total synoptic pup counts (live and dead) from the South Shetlands archipelago (SSI; gold), and from the subset populations at Cape Shirreff (CS; blue) and the San Telmo Islands (STI; green), between the 1986-1987 and the 2018-2019 Antarctic seasons. All seasons are referred to by the year the season ended. Pup counts were taken from Bengtson et al. (1990), Croll et al. (1992), Aguayo & Torres (1993), Meyer et al. (1996), Torres et al. (1998), Goebel et al. (2003, 2008), and U.S. Antarctic Marine Living Resources (AMLR) (unpub. data, 2013, 2015, 2017).

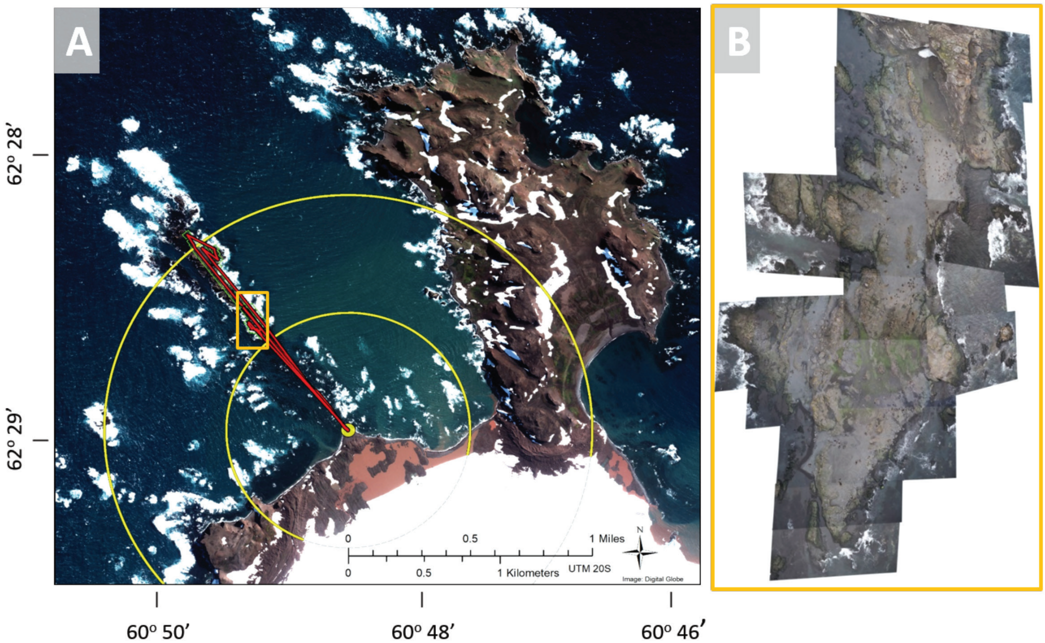

Figure 2. (A) A satellite image of Cape Shirreff, Livingston Island, and the San Telmo Islands—the yellow dot and concentric circles represent the take-off/landing location and 800 m distance markers, and the red line traces the flight path of the APH-28; and (B) an example of the UAS-captured photomerge for the south island.

around Cape Shirreff, Livingston Island, Antarctica (62.468° S, 60.775° W). We flew an APH-28 (Aerial Imaging Solutions, Old Lyme, CT, USA) battery-powered VTOL UAS for all missions. The APH-28 is easily transported across rough terrain, is low weight (1.6 kg; payload capacity: 1.8 kg) and weatherproof, and features a live-video display ground station. The field configuration included a downward-facing Olympus E-PM2 digital camera (16.1 megapixel, micro four-thirds format, 0.23 kg) with an Olympus M. Zuiko 25 mm f/1.8 lens, and a 1, 2, or 3 battery configuration (ThunderPower 6s 440 mAmp Li-PO) as payload. The camera was set to record large super fine JPEG and RAW images, ISO 1250, aspect ratio: 4:3, shutter priority mode (shutter speed 1/2,000), as described in previous studies (Durban et al., 2015; Goebel et al., 2015). Calibration flights utilizing a medium contrast (8:1) resolution target (RST-704, Series C) produced undistorted photographs with a ground-resolved distance of 1.0 cm at 30 m altitude (NOAA Fisheries, unpub. data, August 2014).

A flight crew of four (pilot, ground station operator, and two spotters) obtained full coverage of breeding beaches on the San Telmo Islands during two consecutive, standardized mapping missions (total of 68 waypoints, set to allow ≥ 30% overlap between images) on 31 December 2018. Two photographs were taken per waypoint at 66 m altitude. The clearest image was selected per waypoint, and a composite photomerge was created for each breeding area using *Adobe Photoshop CS6* (e.g., see Figure 2). Pups were identified and counted using the "Count Tool" in *Photoshop*.

To account for potential bias in UAS counts due to pups being obstructed by terrain (Reyes et al., 1999) or otherwise non-uniform availability during the survey (Brack et al., 2018), we conducted similar mapping missions on Cape Shirreff and coupled these missions with contemporaneous ground surveys. Four breeding areas (Copi, Hue, Daniel, and Marko) within the main Cape Shirreff breeding colony were surveyed using identical UAS equipment and flight characteristics on 31 December 2018 and 1 January 2019. These beaches were chosen because they have similar terrain to the San Telmo Islands in which pups may be concealed from overhead UAS imagery (e.g., Franco-Trecu et al., 2019). Ground censuses were conducted in concert with these flights by three independent observers. UAS-derived counts from the four Cape Shirreff breeding colonies were assessed against the "true" ground counts, and a correction factor was calculated to adjust UAS-derived pup counts for the San Telmo Islands.

Table 1. Antarctic fur seal (*Arctocephalus gazella*) pup census counts from UAS-captured photographs and concurrently by field biologists in the colony. Error was calculated as % Error = |[1-(UAS Count/Ground Count)]*100 |; mean correction factor = 1+ mean % Error.

AFS colony	UAS-derived pup count	Ground pup count (±SD)	% error
Daniel	34	34.33 (±0.58)	0.97
Marko	62	63.00 (±1.00)	1.59
Copi	65	66.67 (±1.53)	2.50
Hue	78	79.33 (±1.15)	1.68
Mean correction factor:	1.017		

The APH-28 proved to be a minimally invasive, robust, and accurate survey tool. The longest survey flight reached 1.7 km from the ground station (Figure 2), had a 26.1 min duration, and experienced no radio or video signal loss. Visual contact was maintained throughout the flight. While pup counts were similar between our ground and aerial methodologies (Lowry, 1999), the UAS-derived counts consistently underestimated the "true" ground counts on Cape Shirreff (Table 1), likely due to the rocky, steep terrain obstructing pups from a top-down view. However, validation error rates were low (< 3%) and resulted in a mean correction factor of 1.017 (Table 1). Drone surveys provide a permanent record of the census, and a similar UAS-based approach may alleviate risk and reduce costs for future pinniped surveys in remote areas (Moreland et al., 2015; Sweeney et al., 2015).

The corrected census count from the San Telmo Islands was 333, which represents a 79% reduction since the most recent survey in 2008 and a 90% reduction from the recent peak of production in 1997 (Figure 1). Pup production on Cape Shirreff has been similarly reduced since its peak in 2004, suggesting a catastrophic decline to the South Shetland population. Such rates of decline are unusually steep for pinniped populations (Hanks, 1981). Given the historical importance of Cape Shirreff and the San Telmo Islands to the AFS population dynamics in the South Shetlands archipelago, these declines emphasize the need to synoptically survey all known and potential breeding sites across the region as soon as is practicable.

Local declines in abundance of large marine predators may arise for several reasons, including emigration, increased mortality, or reduced reproduction. Antarctic fur seals demonstrate high rates of philopatry (Forcada & Staniland, 2009); therefore, it is unlikely that declines like those illustrated here are due to emigration. A growing body of research indicates that predation from leopard seals control this AFS population from the top down (Boveng et al., 1998; Krause et al., 2020). However, rapid environmental change within the region is also expected to exert bottom-up control on predator populations like AFS (Massom & Stammerjohn, 2010). Warming sea-surface temperatures may be limiting access of AFS to their main prey, Antarctic krill (*Euphausia superba*), by shifting its distribution and abundance (Klein et al., 2018). Further, competition for krill by recovering cetacean populations (Zerbini et al., 2019) or a growing fishery (e.g., Watters et al., 2020) may play a role in determining AFS pup production. A thorough analysis of AFS population dynamics, including the effects of potential environmental factors, is needed for this important indicator species.

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