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SHORT NOTE

A pilot(less) study on the use of an unmanned aircraft system for studying polar bears (*Ursus maritimus*)

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Abstract

Unmanned aircraft systems (UAS) are increasingly popular tools for studying wildlife ecology. The non-invasive aspect of UAS and the ability to collect a large amount of high-resolution imagery should be of interest to polar bear (*Ursus maritimus*) researchers who face logistic challenges with field work and developing minimally invasive methods. We opportunistically observed the behavioural reactions of three adult male polar bears during UAS surveys in the summer of 2016. We recorded vigilance behaviours and compared them to previously published vigilance behaviours during wildlife-viewing activities by Dyck and Baydack (2004). The number of vigilance events was 13.4 ± 3.7 (SE) and vigilance bout lengths was 18.7 ± 2.6 s (SE), which is similar to reported results by Dyck and Baydack (2004). To estimate detection probabilities of polar bears from UAS imagery, we had two independent observers review mosaics and 80% of known bear locations were identified. Our preliminary results suggest that UAS are capable of detecting polar bears using RGB imagery in a relatively non-invasive manner. Before UAS can be integrated into large-scale polar bear studies, further research is required to formally assess behavioural impacts with unhabituated individuals in the wild, and model factors influencing detection probabilities.

Keywords Unmanned aircraft · Polar bear · Remote sensing · Behaviour · Drone

Introduction

Measuring the distribution and abundance of species is fundamental to ecological research and monitoring (Smith et al. 2012). Therefore, understanding how species distributions and abundances change over time is pivotal to understanding the effects of climate change. This is especially pertinent in the Arctic where climate change is occurring faster than in other regions of the world, leading to changes in species' abundance and spatiotemporal distributions (Stroeve et al. 2007; Higdon and Ferguson 2009; Kovacs et al. 2011). For some subpopulations of polar bears (*Ursus maritimus*), climate change has been directly linked to decreased population numbers, decreased body size, and reduced cub recruitment (Regehr et al. 2007; Obbard et al. 2010; Stirling and Derocher 2012). The declines have been largely attributed to increased temperatures leading to decreased sea ice extent during late spring to early fall which limits polar bear access to their primary prey species, ringed seals (*Pusa hispida*) (Stirling and Derocher 2012). In other subpopulations, the effects of climate change are not yet apparent, as indicated by long-term stability or increases in abundance (Stapleton et al. 2016; Aars et al. 2017). Monitoring of both areas with declining and increasing populations is essential for understanding how polar bears are responding to changes in habitat and prey species associated with climate change.

Total censuses of polar bear subpopulations are impractical, though abundance estimates and details on habitat use are valuable to conservationists and wildlife managers. In the western Hudson Bay, such estimates are largely based on mark-recapture studies in which bears are anesthetized from a helicopter (Jonkel et al. 1972; Derocher and Stirling 1995; Lunn et al. 2016). While evidence suggests these capture techniques have minimal long-term impact on the bears (Ramsay and Stirling 1986; Messier 2000; Thiemann

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et al. 2013), these operations are financially costly and often do not align with cultural values of Arctic residents (Peacock et al. 2011; Stapleton et al. 2014a; Wong et al. 2017). Polar bear abundance estimates can be made using distance sampling from aircraft which excludes the need to physically capture bears (Aars et al. 2009; Stapleton et al. 2014a; Stapleton et al. 2016). However, this method still burdens researchers with the expenses and logistic difficulties of manned aircraft flights. Additionally, manned aircraft flights pose a significant safety risk to researchers and may disturb wildlife due to their low altitude and slow speeds (Sasse 2003). Other remote sensing methods such as satellite imagery show promise for studying polar regions, but remain subject to error based on limited imagery resolution and cloud cover (Loarie et al. 2007; Stapleton et al. 2014b; LaRue et al. 2015; LaRue et al. 2017).

With the risks associated with manned flights and the current limitations of satellite imagery in mind, the rising technology of unmanned aircraft systems (UAS) has great potential for studying polar bears and aspects of their ecology. Decreasing costs of UAS and subsequent increasing commercial availability are making these tools more accessible to researchers (Anderson and Gaston 2013; Chabot and Bird 2015; Linchant et al. 2015; Christie et al. 2016). UAS have been shown to be effective at surveying large mammals in a variety of environments, including African savanna elephants (*Loxodonta africana*) (Vermeulen et al. 2013), leopard seals (*Hydrurga leptonyx*) (Goebel et al. 2015) and humpback whales (*Megaptera novaeangliae*) (Christiansen et al. 2016). These tools can collect a large amount of high-resolution imagery very quickly which also provides a digital archive for future analyses and researchers (Hodgson et al. 2013). Moreover, UAS are largely cited as a less invasive survey methodology than traditional manned aircraft flights (Vermeulen et al. 2013; Linchant et al. 2015).

The non-invasive aspect of UAS technology should be of extreme interest to polar bear researchers as they seek to develop minimally invasive management efforts to increasingly comply with aboriginal traditions and institutional animal care protocols. However, a recent review of UAS studies revealed that some species are more likely than others to show behavioural responses to UAS surveys (Mulero-Pázmány et al. 2017). Research has shown that polar bears are prone to anthropogenic disturbances (Dyck and Baydack 2004; Andersen and Aars 2008; Smultea et al. 2016), so it is not unreasonable to suggest that polar bears may have adverse reactions to UAS surveys. An additional challenge facing UAS is the ability to discriminate polar bears from their background environment in imagery (snow, ice and gravel beach ridges). Preliminary research has shown that the spectral signatures of polar bear pelts are sufficiently different from clean snow to allow discrimination (Leblanc et al. 2016). Yet the primary difficulties encountered with high-resolution satellite imagery were the identification of false-positives and inability to developed automated detection based on reflectance (LaRue et al. 2015). UAS could provide higher resolution imagery to ameliorate these problems while offering variability in sensor capability (e.g. thermal, near infrared, multispectral and ultraviolet) to suit research-specific needs (Berni et al. 2009; Anderson and Gaston 2013). Before unmanned aircraft can be used for large-scale studies of polar bears, operating protocols must be developed that demonstrate minimal disturbance levels while facilitating high detection probabilities of polar bears.

In the summer of 2016 during coastal UAS surveys, we were able to opportunistically observe three adult male polar bears and capture them in UAS imagery. Here we describe the behavioural reactions of three bears to UAS surveys, and calculations of detection probabilities for potential future use in UAS studies. We also detail some of the logistic and technological considerations for the future use of UAS for studying polar bear ecology.

Methods

Study area

This study took place on the Cape Churchill Peninsula, within Wapusk National Park, Manitoba, Canada (Fig. 1). Flight operations were conducted over tidal flats, sand bars and beach ridges along the coast of Hudson Bay. This area is predominately low-lying, with the exception of sand bars and glacial beach reaches made up of gravel with intermittent shrub patches (*Salix sp*., *Betula glandulosa*, *Myrica gale*).

Aircraft specifications and flight parameters

Flights were conducted using a Trimble UX5 (colour: black, wingspan: 100 cm, weight: 2.5 kg, cruise speed: 80 kmhr^{-1}, operational temperature range: − 25 to 55 ℃, maximum operational wind speed: 50kmhr^{-1}), a fixed-wing rear-propelled aircraft powered by removable lithium polymer batteries (14.8 V, 6000 mAh). UX5 takeoffs are initiated using an elastic catapult launcher. Once the flight area has been covered, the UX5 begins its descent and eventually belly lands as the aircraft lacks skid gear of any kind. All flight plans were preprogrammed line-transects using Trimble Access Aerial Imaging V2.0.00.40 (Trimble, Sunnyvale, CA) and georeferenced in real-time using the UX5's built-in GPS system with 80% overlap of adjacent images. In-flight stability and thus image quality are optimized by flying crosswind, rather than into a headwind or with a tailwind, therefore, flight path direction and angle of approaches are dictated by environmental factors such as wind speed and

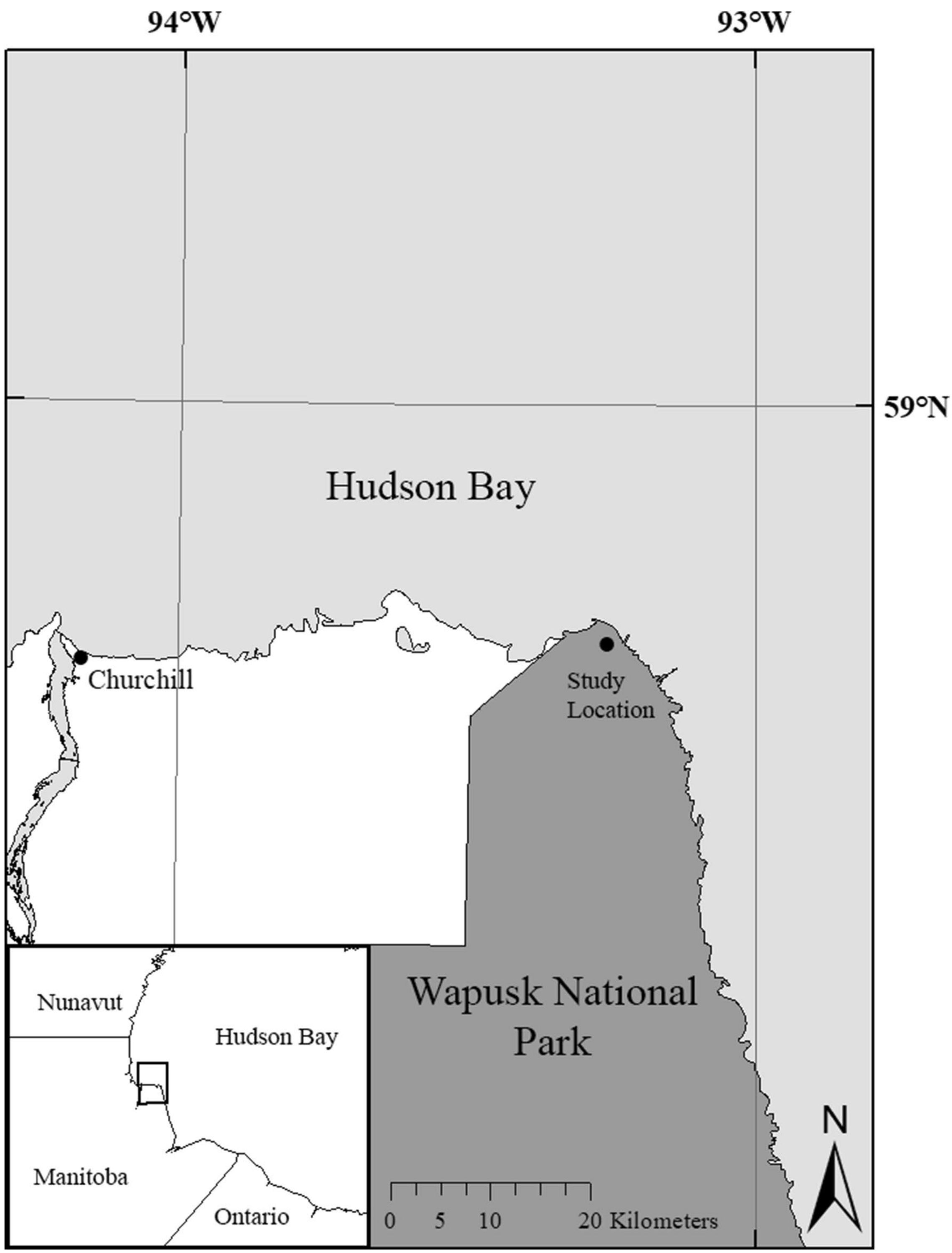

Fig. 1 Map of Wapusk National Park, Manitoba, Canada. Canadian provinces and territories inset map layers provided by ESRI online

direction. Still images were collected in true colour (3 visible bands: Red Blue Green) and were taken at systematic intervals along flight paths with a Sony NEX-5R 16.1 MP camera (Sony Corporation of America, New York, NY). Pictures were taken by trigger approximately once every second while on flight paths, and were saved in JPEG format automatically to the camera's SD card. At an altitude of 75 m AGL, the image footprint is 118 × 78 m. At 100 m AGL, the footprint is 157 × 104 m. Camera settings for all flights were as follows: no flash, exposure time 1/4000, automatic white balance and automatic ISO. Imagery was downloaded following completion of individual flights and used to create landscape mosaics. Flights were conducted on 26 July 2016 from 1123 to 1715.

Transportation to and from the study site was by helicopter (Bell 206L-3). Following standard safety protocols, polar bears were located by observers in the helicopter at 150 m (approximately 500ft) above ground level (AGL) to minimize disrupting the bears upon arrival. To avoid carryover effects of behavioural changes due to helicopter landing, we waited approximately 25 min before commencing UAS flights. UAS operations consisted with initial surveys of two bears at 120 m AGL, followed by 75 m AGL surveys of the same two bears. We then surveyed a third bear at 75 m AGL, but were unable to complete a 120 m AGL survey for this individual due to time constraints (five flights total).

Behavioural observations and classifications

Bear behaviour was recorded by a single observer (C. Felege) using a Leica 20–60 × 72 mm spotting scope (Leica Camera, Wetzlar, Germany). Video was recorded through the spotting scope using a Samsung Galaxy S7 smartphone (Samsung Group, Seoul, South Korea) during UAS surveys. Video was reviewed by a single observer (A. Barnas) on Windows Media Player (Microsoft, Redmond, WA). Behaviours were recorded and categorized following procedures provided by Dyck and Baydack (2004). We classified behaviours as either non-vigilant (sleeping, laying, walking, sitting, etc.) or vigilant. Vigilance was assumed when the bear was seen lifting its head to shoulder level or above while laying down (Dyck and Baydack 2004), but we also included obviously raised heads while sitting or walking as vigilant. We recorded the number of seconds individual bears spent on behaviours, as well as the number of individual behaviour events. Video was reviewed for individual bears from the time of unmanned aircraft takeoff until landing.

Imagery analysis

UAS imagery was downloaded from the aircraft after each flight. Mosaics were created using Pix4Dmapper Pro (Pix4D, Switzerland, V3.3). For survey altitudes of 75 and 120 m AGL, the nominal ground sampling distance of imagery was 2.4 and 3.8 cm, respectively. Individual mosaics were loaded into ArcGIS 10.4 (ESRI, Redlands, CA) and a search grid that composed of 100 × 100 m cells was placed over the imagery to facilitate search efforts and reduce the chance of missing areas during searches. Cells with missing imagery (black patches) and obvious discolouration as a result of the mosaic creation process were removed from the search area. It should be noted that majority of anomalies are located at the edge of the mosaic far away from the survey plot of interest and thus should have little impact on the search process. Cells which contained people were also eliminated from the search area, since this would influence observers to suspect no bears were within the cell.

We used a hybrid double-observer method to calculate the detection probability for polar bears from UAS imagery (Griffin et al. 2013; Lubow and Ransom 2016). Two observers were asked to first independently review the UAS imagery. These observers were selected based on previous experience of identifying polar bears from aircraft, though neither were present during UAS operations, nor had any prior information on the number or location of bears in the imagery. For each observer, total search time was recorded for each 100 × 100 m cell. Note that each bear in the imagery occupied its own cell (i.e. bears were not clustered as a family group, which would influence detection). Following completion of searches, observers were then allowed to compare identifications. By doing so, false-positives and false-negatives are reduced, though false-negatives would remain if both observers failed to identify a bear that was present in the imagery.

Data analysis

Comparison of relatively short periods of behavioural observations to previously published long-term activity budgets of polar bears (see Stirling 1974) would likely lead to erroneous conclusions. Instead, we restrict ourselves to comparing descriptive statistics (specifically, mean and SE) of vigilance estimates to those found by Dyck and Baydack (2004), who observed individual bears for similarly short bouts of time (approximately 30 min for each individual) during periods of tundra vehicle activity. Specifically, we report the number of head-ups (vigilance), the length of individual vigilance events, and the length of the period between individual vigilance events, for comparison with Dyck and Baydack (2004).

Detection probabilities were calculated based on observer's ability to detect and correctly identify bears as a proportion of the number of known bears in the imagery. Mean time to search cells with SE was calculated from the pooled times from both observers.

Results

In 2016, we conducted five UAS survey flights; average flight time was 28.4 ± 0.68 min ($n = 5$). Since bear observations were made from takeoff to landing, the mean observation time for bears is identical to mean flight time. For all UAS flights, the average number of head-ups during flights was 13.4 ± 3.7, which falls within the results observed by

Dyck and Baydack (2004) for both paired and unpaired polar bears (Table 1). Vigilance bout length during UAS flights were higher on average (18.7 ± 2.6 s) than Dyck and Baydack (2004), as were the between bout intervals (101.0 ± 18.1 s, Table 1). There appear to be small differences in vigilance responses to UAS survey altitude, though we are careful to restrict inferences here due to small sample sizes, repeated exposures and lack of controls. For a complete breakdown of individual responses during each UAS flight, see Online Resource 1.

There were 148 cells searched, totaling 1.48 km^2 searched by each observer. Observer 1 took 49 min, 55 s to search the entire area, while Observer 2 took 1 h, 2 min and 41 s. Mean search time for 0.01 km^2 cells was 22.8 ± 0.91 s ($n = 296$, range: 5—106). Polar bears were detected with 80% success ($n = 5$) by observers after review. Substantial variation existed between observers in initial search results (Table 2). Observer 1 correctly identified the bear in 4 of 5 mosaics (Fig. 2a-d), had 1 false-positive, and 0 false-negatives. The second observer correctly identified 3 bears, had 4 false-positives (Fig. 2f) and 2 false-negatives. After review, both observers agreed on 4 of the identified bears and correctly eliminated the false-positives, though both observers missed the same bear resulting in a shared false-negative (Fig. 2e). For both observers the lower altitude surveys (75 m AGL) yielded more correct identifications, and had a lower mean search time for cells (Table 2).

Table 2 Search summary statistics for two independent observers identifying polar bears from UAS imagery at 75 and 120 m AGL (above ground level)

	Observer 1	Observer 2
75 m AGL		
Mean search time per cell (s) ± SE	18.8 ± 1.2	19.2 ± 1.4
Correct identifications	3	2
False-negatives	0	1
False-positives	0	0
120 m AGL		
Mean search time per cell (s) ± SE	21.7 ± 1.4	31.6 ± 2.6
Correct identifications	1	1
False-negatives	1	1
False-positives	0	4

Discussion

In general, we found behavioural responses similar to those observed near polar bear tourism vehicles by Dyck and Baydack (2004), indicating similar levels of disturbance to a common-place practice in the region. Though notably there was moderate individual variation in response to UAS operations (Online Resource 1), flights did not appear to adversely affect polar bears by inciting any flee responses as documented in response to snowmobiles (Andersen and Aars 2008). Though bears did not physically appear to be adversely impacted by UAS surveys, there is some support that small rotary-wing UAS at much lower survey altitudes (20 m AGL) may cause short-term physiological responses (increased heart rates) in black bears (Ditmer et al. 2015). We were unable to account for possible UAS noise disturbance in this study. Larger gasoline powered UAS models may introduce significant noise disturbance, but smaller electric models in windy polar regions have demonstrated noise attenuation at altitudes greater than 30 m AGL (Goebel et al. 2015). The lack of any flee responses by surveyed bears is a strong indication that UAS surveys produced less disturbance than traditional mark-recapture methods. We do caution that the bears occupying our study site are commonly flown over by both helicopters and fixed-wing aircraft during polar bear tourism activities, so it is possible that these bears were habituated to anthropomorphic stressors.

Several issues remain regarding the detection of bears from UAS imagery. We found that by using multiple observers to search for polar bears, we were able to eliminate false-positives and some false-negatives, corroborating findings of Stapleton et al. (2014b). However, the long

Table 1 Descriptive statistics of adult male polar bear ($n = 3$ individuals) behaviour during UAS flights presented as mean ± SE (range), for the number of head-ups (HU), vigilance bout length in seconds (VBL), and between bout interval in seconds (BBI). Also included are comparable behavioural data from Dyck and Baydack (2004: Table 1) on male polar bears ($n = 29$ individuals) observed in the presence of Tundra vehicles

	Unmanned aircraft flights			Tundra vehicles present (Dyck and Baydack 2004)[a]	
	All flights ($n = 5$)	75 m AGL ($n = 3$)	120 m AGL ($n = 2$)	Unpaired males ($n = 23$)	Paired males ($n = 6$)
HU (#)	13.4 ± 3.7 (7–27)	15.0 ± 6.0 (8–27)	11.0 ± 4.0 (7–15)	12.9 ± 1.5 (4–33)	17.0 ± 1.9 (11–24)
VBL (s)	18.7 ± 2.6 (2–141)	16.0 ± 1.9 (2–52)	24.2 ± 6.9 (3–141)	13.2 ± 1.9 (4.8–50.6)	17.8 ± 4.8 (7.8–40.7)
BBI (s)	101.0 ± 18.1 (5–813)	94.4 ± 23.2 (6–813)	114.1 ± 28.9 (5–572)	93.2 ± 11.1 (24.6–184.1)	81.3 ± 8.9 (52.6–104.4)

[a]Unpaired males were bears that were observed only when tundra vehicles were present, whereas paired males had observations during tundra vehicle activity (reported here), and during periods without tundra vehicle activity which is not reported here, see Dyck and Baydack (2004)

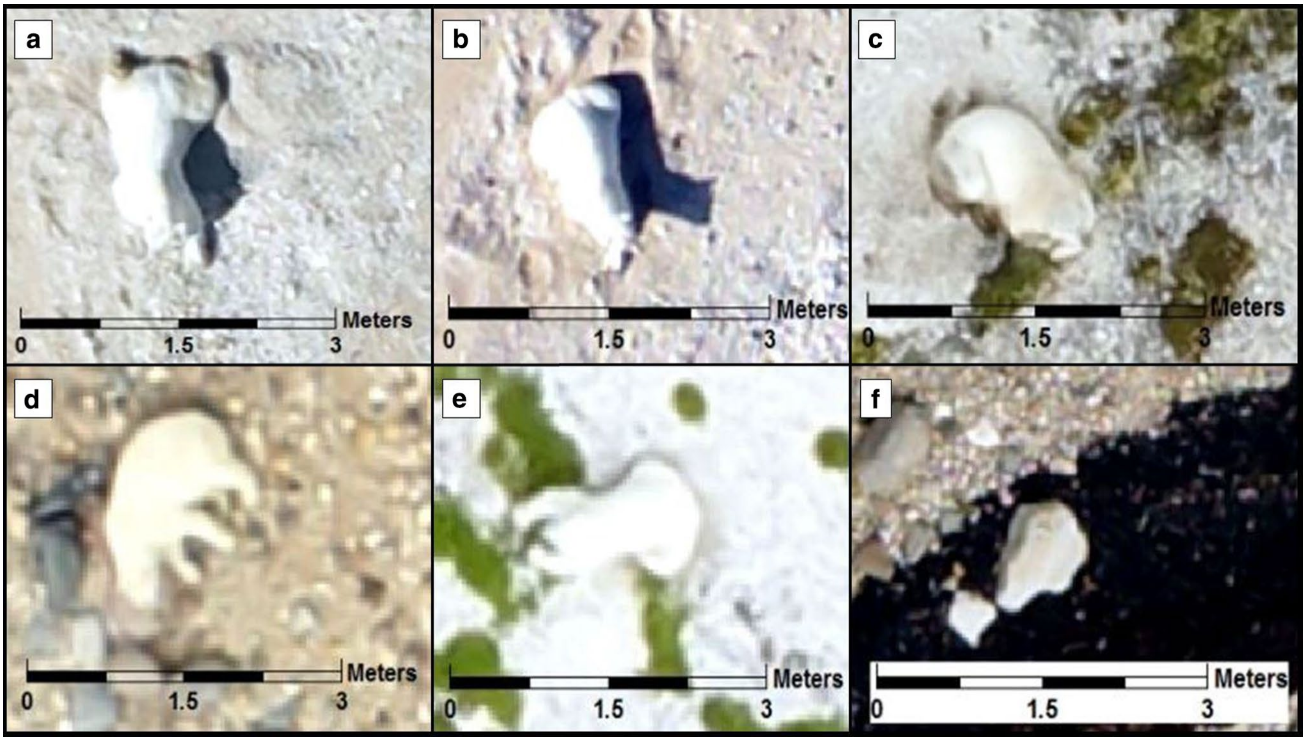

Fig. 2 Trimble UX5 UAS imagery of polar bears from survey flights. Boxes **a**–**c** are taken at 75 m above ground level (AGL), while **d** and **e** are at 120 m AGL. Box **f** is an example of a rock identified as a false-positive by an observer at 75 m AGL

search time required to complete all the grid cells implies manual searches of imagery will be ineffective for larger scale studies. Search times were faster in lower altitude surveys, but lower altitudes require longer flight times and will likely increase the disturbance. Future small-scale projects using UAS imagery to locate polar bears should employ multiple observers, and we recommend employing those who have experience detecting polar bears from aircraft or imagery. Further, we recommend the use of reference imagery to improve detection, considering that once Observer 2 detected the first true-positive, they claimed their ability to detect bears greatly improved. In our imagery, the false-negative that both observers missed was a bear laying on beach ridge gravel, resulting in little contrast between the bear and its background (Fig. 2e). To facilitate future large-scale UAS studies of polar bears, formal analyses should be done to determine the relative importance of various factors (e.g. UAS sensor type, environmental background, image processing method) on detection, as has been done for other taxa (Chabot and Bird 2012; Hodgson et al. 2013; Linchant et al. 2015). Any large-scale studies should explore the use of additional sensors coupled with automated detection software to reduce manual search times. Previous research using infrared indicates that polar bears should be detectable with such sensors, and future work should explore the use of thermal and multispectral images (Brooks 1972; Preciado et al. 2002; Amstrup et al. 2004).

We stress that while our findings are novel and have implications for the future use of UAS in polar bear research, we recognize the limited scope of our study and that much work is needed before UAS can be efficiently implemented. Current unmanned aircraft regulations in Canada restricted us to flying the UX5 within line-of-sight, which is a major impediment to the spatial coverage required to survey polar bears in the wild and requires proximity of researchers to bears on the ground. Aircraft specifications regarding battery life and platform design (fixed-wing vs rotary-wing) will be an important consideration for researchers to ensure sufficient flight time is met to cover study areas of interest. Moreover, depending on the time of year, the field site where we conducted our study can be heavily populated by aircraft engaged in polar bear tourism activities. The future development of unmanned aircraft for polar bear research will need to carefully follow evolving government protocols, and researchers will have to work closely with industry aircraft operations in study regions to prevent conflicts.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest or competing interests to declare. UAS flight operations were approved by Transport Canada in accordance with a Special Flight Operations Certificate (File: 5802-11-302, ATS: 15-16-00058646, RDIMS: 11717338), Wapusk National Park permit WAP-2015-18846, and the University of North Dakota Institutional Animal Care and Use Committee approval#A3917-01, protocol#1505-2.

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