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ARTICLE

Comparing manned to unmanned aerial surveys for cetacean monitoring in the Arctic: methods and operational results[1]

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Abstract: Manned aerial surveys are routinely used to assess cetacean distribution and density, often over large geographic areas. Unmanned aircraft systems (UAS) have been identified as a technology that could augment or replace manned aerial surveys for cetaceans. To understand what research questions involving cetacean distribution and density can be addressed using manned and UAS technology in the Arctic, we conducted paired aerial surveys for cetaceans near Utqiaġvik (Barrow), Alaska. We present the methods and operational results from the project, and challenges encountered during the field work. Fall arctic weather varied dramatically over small spatiotemporal scales and harsh environmental conditions increased the maintenance required for repeated UAS operations. Various technologies, such as temperature and humidity sensors, a software system that provided near-term forecasts of highly variable weather, and a surface-based air traffic radar feed, directly contributed to the ability to conduct routine, successful, beyond line-of-sight UAS flights under these situations. We provide recommendations for future projects to help streamline project planning and enhance researchers' ability to use UAS to collect data needed for ecological research.

Key words: unmanned aerial system, UAS, cetaceans, marine mammals, aerial survey.

Résumé : Les levés réalisés au moyen d'aéronefs pilotés sont couramment utilisés pour évaluer la répartition et la densité de cétacés, souvent sur de grandes régions géographiques. Les systèmes d'aéronef sans pilote (UAS) ont été signalés comme étant une technologie qui pourrait compléter ou remplacer les levés aériens avec pilote sur les cétacés. Dans le but de comprendre quelles questions de recherche liées à la répartition et à la densité de cétacés peuvent être étudiées utilisant la technologie avec et sans pilote dans l'Arctique, nous avons réalisé des levés aériens combinés sur les cétacés près d'Utqiagvik (Barrow), en Alaska. Nous présentons les méthodes et les résultats opérationnels du projet et les défis qui se sont présentés lors du travail sur le terrain. Les conditions météorologiques automnales en Arctique variaient radicalement, et ce,

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sur de petites échelles spatio-temporelles et des conditions environnementales difficiles ont causé un entretien accru nécessaire au bon fonctionnement des opérations répétées des UAS. Les différentes technologies, comme des capteurs de température et d'humidité, le système logiciel donnant des prévisions à court terme du temps hautement variable et les informations de trafic aérien par radar au sol, ont directement contribué à la capacité d'effectuer des vols UAS de routine réussis au-delà de la ligne de vision sous ces conditions. Nous présentons des recommandations pour des projets futurs dans le but de simplifier la planification de projet et d'améliorer la capacité des chercheurs à utiliser les UAS afin de recueillir les données nécessaires pour la recherche écologique. [Traduit par la Rédaction]

Mots-clés : système d'aéronef sans pilote (UAS), cétacés, mammifères marins, levé aérien.

Introduction

Manned aerial surveys from fixed-wing aircraft have been used successfully for decades to achieve diverse scientific and wildlife management goals. Aerial surveys are of particular utility for assessing distribution and abundance of marine mammals (Garner et al. 1999; Buckland et al. 2001) because they can cover large areas in a relatively short period of time, and have been the foundation of many estimates of abundance of marine mammals; for instance, 27 of the 45 recognized marine mammal stocks in Alaska have abundance estimates based on manned aerial surveys (Muto et al. 2016). However, use of manned aircraft for marine mammal surveys does have some well-known and often-cited limitations, including impacts of observer fatigue on data collection, the potential to disturb wildlife, and cost (Hodgson et al. 2013).

Surveys conducted using unmanned aircraft systems (UAS) may be unaffected by some of the limitations of manned aircraft and could be a reliable, efficient, cost-effective, and operationally flexible alternative to surveys conducted with manned aircraft. UAS have only recently been used in ecology and wildlife research, but their use is increasing rapidly, and has increased even within the past 5 years (Chabot 2018). A search of Web of Science for publications from 2005 to 2016, followed by a search of citations included in publications found in Web of Science, documents approximately five publications per year addressing the use of UAS for wildlife studies from 2002 through 2011 (e.g., Stark et al. 2003; Acevedo-Whitehouse et al. 2009; Koski et al. 2009; Watts et al. 2010). The number of published studies found involving UAS and wildlife or marine mammal research increased gradually from 2012 to 2014 and peaked at over 25 publications in 2015 as biologists used this new technology to meet existing and new research goals (e.g., Sarda-Palomera et al. 2012; Anderson and Gaston 2013; Christie et al. 2016).

While UAS are being used successfully to collect a variety of wildlife data, the vast majority of projects have involved small, relatively inexpensive UAS that collect information relatively close to where the aircraft is launched (Barasona et al. 2014; Mulero-Pázmány et al. 2015; Christie et al. 2016; Johnston et al. 2017; Laguna et al. 2018). Despite great interest in the potential to use UAS for long-range surveys of marine mammals, studies involving long-range flights have been limited due to cost and the challenge of gaining permission to conduct beyond visual line-of-sight flights with UAS, particularly in the United States.

Over the past several years, researchers have been gradually evaluating whether UAS with the capability to fly well beyond visual line-of-sight can be used for collecting large-scale information on marine mammals that could be used to estimate density, distribution, and abundance. In 2009, Moreland et al. (2015) conducted a within line-of-sight evaluation of a UAS with beyond visual line-of-sight capability to determine if the system could provide an effective way to assess ice-associated seal distribution in the Bering Sea pack ice. In 2013, Koski et al. (2015) evaluated the use of a TD 100E UAS[2] — which has a range and payload capacity comparable to the ScanEagle® and a Nikon D800 camera — and concluded that this system would collect images of bowhead whales adequate for photo-identification of individuals when images are collected at low altitudes. Koski et al. (2013) compared the use of human observers to high definition video and fixed digital imagery to evaluate which system would most likely be helpful for marine mammal surveys when mounted in an unmanned aerial vehicle (UAV). Hodgson et al. (2013) conducted within line-of-sight strip-transect surveys using a ScanEagle® to collect observations of dugongs; Maire et al. (2013) worked with Hodgson and initiated attempts to automate the image analysis process to increase the speed of analysis.

Specific operational, data acquisition, and sampling requirements for using UAS to meet cetacean research or monitoring goals at a large scale have not been tested. Existing UAS technology integrated with a digital camera payload needs to be evaluated to determine how well it performs relative to conventional manned aerial surveys to collect large-scale data on cetaceans. This arctic mission is the first dedicated experiment specifically designed to understand the advantages and disadvantages of using a UAS with long-range capability relative to manned aircraft to collect data for estimating large scale, at-sea marine mammal density.

Our overall objectives are to evaluate the ability of ScanEagle® technology (i.e., platforms, payloads, sensors, and software) to collect data to detect cetaceans, identify species, estimate group size, and identify calves, and to compare results to conventional aerial surveys conducted by human observers in fixed-wing aircraft. The objective of this paper is to describe the field operations in August and September 2015, provide recommendations about conducting similar large-scale UAS operations in the Arctic, and provide cost comparison information for the manned and UAS survey approaches used for this study. This paper describes the materials, methods, and operational results. A comparison of the data resulting from the project is provided separately (Ferguson et al. 2018).

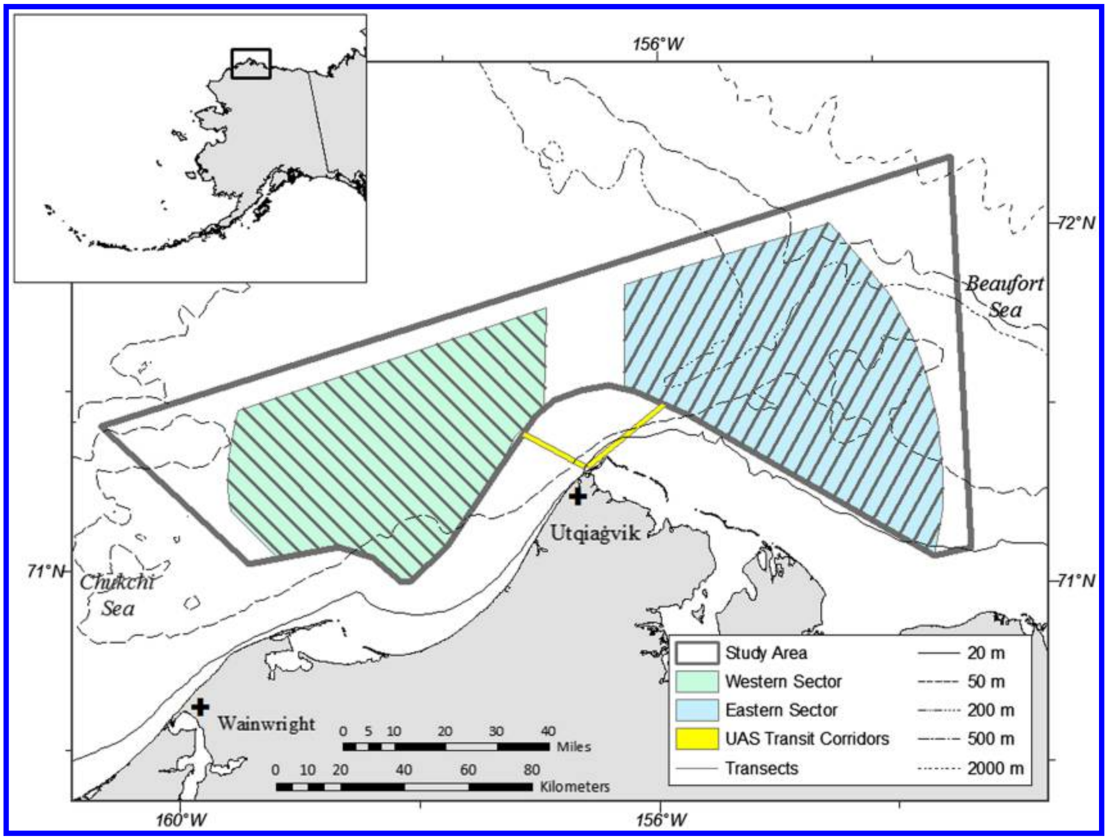
Materials and methods

Study area

Manned and UAS aerial surveys were conducted over the northeastern Chukchi Sea and western Beaufort Sea (Fig. 1). The study area is located between 22 and 111 km (12–60 nautical miles (nmi)) from shore on either side of Utqiaġvik (Barrow), Alaska. This area was selected for UAS operations for three reasons. First, the study area lies within an area where the Federal Aviation Administration (FAA) plans to establish permanent operational areas and corridor routes (for access to coastal launch sites) in the Arctic for the operation of small UAS. We anticipated that this emphasis would enhance our chances of receiving FAA permission for beyond visual line-of-sight flights needed for the project. Second, large cetaceans, particularly gray whales and bowhead whales, are reliably found in high densities in portions of this area during the open water (ice-free) season (Clarke et al. 2014; Citta et al. 2015; Brower et al. 2017). Further, modeling efforts using existing gray whale data collected during previous aerial surveys indicated that the project should be able to achieve a coefficient of variation of 0.3 in estimated gray whale density in this area with approximately 50 h of UAS flight time. Third, the study area is located in international airspace, offshore of the coastal corridor where small aircraft frequently transit between villages on the

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Fig. 1. Study area near Utqiaġvik, Alaska. Unmanned aerial system (UAS) pilots were granted permission by the Federal Aviation Administration for beyond line-of-sight UAS flights in the study area; the east and west offshore survey areas were accessed using one of two corridors that linked the launch site north of Utqiaġvik and the offshore flight areas.



North Slope of Alaska, but in general in an area of low density air traffic. Operating in this low density air traffic area increases the safety of the project by decreasing the probability of encountering other airspace users. The area was separated into east and west sectors to reflect different habitats in the Chukchi and Beaufort Seas, and to allow predetermined transect lines to be flown perpendicular to the various environmental gradients (depth, currents, and marine mammal density) in each area.

Weather during the late summer and early fall in the Arctic is highly variable both temporally and spatially, and can range from cloud-free and sunny to snow, sometimes within the same day. Based on many years of experience conducting manned aerial surveys in the Arctic, the team expected to experience near-freezing and below-freezing temperatures, strong winds, fog, low ceilings, and various types of precipitation. In the high relative humidity and low ambient temperatures common during the late summer and early fall, there is potential for the UAV to experience both structural and carburetor icing. Based on the proportion of days flown historically by the marine mammal aerial survey teams in manned aircraft, we expected to be able to conduct manned and UAS flights on 5–6 days during a 17 day field season planned to occur between 14 and 31 August 2015. We assumed that the UAS flight team could conduct two flights on every good flight day (ceiling >1000 ft, winds <20 km/h at launch) to maximize survey hours.

Outreach

Outreach served two key functions: (*i*) mitigating potential risks to other airspace users due to flying the UAS beyond visual line-of-sight, and (*ii*) ensuring that the field operations would not impact residents in Utqiaġvik. Communication with pilots who might be conducting flights in the area was a critical component of the strategy to mitigate potential risks of operating the UAS beyond visual line-of-sight. Meetings or calls were held with pilots servicing offshore petroleum exploration projects, local commercial airline companies, the Alaska Air Carrier's Association, the FAA Barrow Flight Services Station, Alaska Flight Services, and the U.S. Coast Guard. Daily conference calls were conducted on a publicly accessible phone number every day at 0700 h (local) so local pilots for both manned and UAS operations could exchange information on their flight plans for the day.

A poster (Fig. 2) was electronically circulated to all known individuals (approximately 45 parties), who commonly conduct work offshore over the Beaufort and Chukchi Seas, including local pilots, biologists in agencies or companies, and other interested parties. Forty copies of the poster were displayed in Utqiaġvik and Deadhorse, Alaska, to alert locals about the project and it was made available on the FAA-Alaska Public Notices website. Letters and flyers were sent to big game hunting guides permitted to operate on the North Slope who might base somewhere other than Utqiaġvik, but could be flying at low altitudes along the coast.

Community outreach included mention of the project on a flyer that was sent to ~300 Alaska Native coastal tribal organizations, villages, and corporations approximately 6 months before the project began. Starting at least 6 months before the project, we consulted with local government officials, local wildlife management officials, and Alaska Native community members and organizations. A public service announcement was broadcast on Alaska Public Radio in Utqiaġvik starting on 18 August as the team was setting up at the field site. The team welcomed visitors at the field site, and gave impromptu summaries of the project objectives, descriptions of the equipment, and procedures throughout the field season.

Manned aircraft and human observers

The manned aerial surveys were conducted using a Turbo Commander 690A, a fixed-wing twin-engine turboprop aircraft. Observers were experienced prior participants in surveys of arctic marine mammals, and collected visual line-transect data on marine mammals and relevant environmental conditions consistent with previous studies in the area (Clarke et al. 2014; Ferguson et al. 2018). A high-resolution camera system (see UAS payload details) mounted in a belly port of the Turbo Commander was pointed vertically downward, and collected images every 2 s. This approach is very similar to that used by Koski et al. (2013) to compare human observers to images from cameras onboard the aircraft, with the exception that our study added the direct comparison with vertical images collected by the UAS.

The UAS and payloads

The Insitu ScanEagle® UAS was selected for this study because it is a robust platform with a successful operational history and a flexible payload capability. This platform had been used successfully from the NOAA Ship *McArthur II* in 2009 to collect imagery of ice-associated seals in the Bering Sea (Moreland et al. 2015) and had been used by other projects conducting long-range surveys of marine animals (Hodgson et al. 2013).

The UAS was configured for land- or sea-based operations and includes the airframe, SuperWedge launcher, Skyhook retrieval system, ground control station (GCS), software, and auxiliary equipment. The airframe has a wingspan of 3.1 m (10.2 ft) and is 1.6 m (5.3 ft)

Fig. 2. Flyer distributed to alert local communities and pilots of the upcoming beyond line-of-sight unmanned aerial systems project.

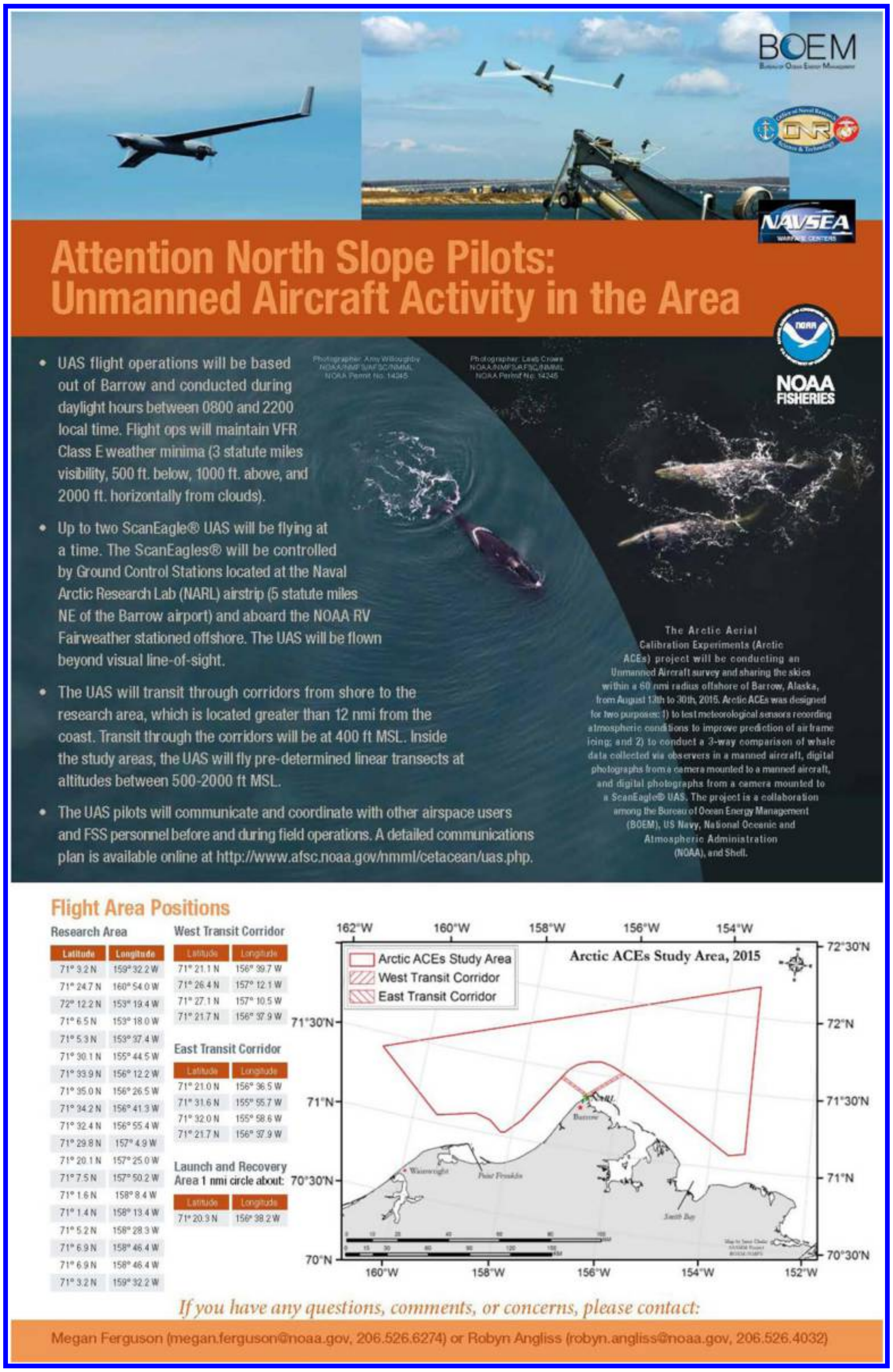


Table 1. Specifications and operations of the camera systems used in the UAV and the manned aircraft.

Specification	UAS	Manned aircraft
Camera model	Nikon D810	
Camera sensor size	35.9 mm × 24 mm	
Lens	Nikkor f2.8	Zeiss Distagon
Lens focal length	20 mm	21 mm
Target altitude	305 m (1000 ft)	320 m (1050 ft)
Target speed	111 km/h (60 kn)	203 km/h (110 kn)
Image interval	100 m (roughly every 3 s)	2 s (roughly 118 m)
Swath dimensions	576 m × 384 m	548 m × 365 m
Ground sampled distance*	7.8 cm	7.1 cm
Actual image resolution, Virginia	6 cm at 320 m (1050 ft)	n/a
Actual image resolution, Utqiaġvik	>3 cm at ~121 m (400 ft)	>11 cm at 305 m (1000 ft)
Onboard image storage	1 TB	
Metadata recorded for each image	Latitude, longitude, altitude, date/time, and various information about the camera and image exposure	

*Ground sampled distance (GSD) is the actual ground distance between the center of each pixel.

long (retrieved from the Insitu.com website on 5 September 2017); the dual-bay configuration used in this study increased the length to 2 m (6.5 ft). The maximum takeoff weight of the UAV is 22.0 kg (48.5 lb), cruise speed is 93–111 km/h (50–60 kn), maximum endurance is 24 h, and maximum altitude is 6000 m (19 000 ft). The aircraft has a rear-mounted engine driving a pusher propeller. Flight operations are controlled with a GCS that can be land-based or ship-based. The software includes pilot interfaces for preflight checks, aircraft control, and monitoring of multiple aircraft on independent missions. The SuperWedge launcher is powered by compressed air, and is manually activated using a pull cord. The launcher accelerates the aircraft to flight speed. The retrieval system captures the aircraft at the end of the flight. The aircraft uses GPS to automatically fly itself into a rope suspended approximately 13.6 m (45 ft) above the ground or deck. A hook on the aircraft wingtip catches the line and stops the aircraft.

Resolution <15 cm has been recommended as adequate for differentiating some species of large cetaceans; given the low light conditions and lack of contrast between dark bowhead whales and dark water, we chose a system that provided improved resolution so we could reliably detect large whales, identify whales to species, estimate group size, and determine whether calves were present. The UAV and Turbo Commander were each equipped with Nikon D810 high-resolution digital single lens reflex (DSLR) cameras capable of providing a minimum photographic ground resolution of 7 cm/pixel and a minimum photographic strip width of 400–600 m (1320–1980 ft) at 320 m (1050 ft) altitude. The camera mounted in the UAV was equipped with a 20 mm Nikkor f2.8 lens. The Turbo Commander camera used a 21 mm Zeiss Distagon lens. Initially, a 21 mm Zeiss Distagon lens was also chosen for the UAV camera to be consistent with the manned aircraft payload, but the weight and length of the Zeiss lens exceeded the UAS carrying capacity. The 20 mm Nikkor lens is shorter, lighter, and allowed for a greater swath width than the Zeiss lens. Table 1 includes a summary of the camera specifications for each platform.

The DSLR system was chosen because of the following:

- The predecessor to the D810, the Nikon D800, had been used successfully in a similar project in the same or similar environment (Koski et al. 2013, 2015). The D810 contained all of the same features as the D800, but allowed for a maximum ISO of twice the D800 to improve image quality in low-light conditions.

- The camera's full-frame sensor with a 20 mm lens provided for a 576 m swath width at survey altitude of 318 m (1050 ft).
- The camera body had slots for both a CF and SD storage card, enabling 1 TB of storage in the camera. 1 TB of storage translates to roughly 10 h of flight time while collecting uncompressed raw images.

In addition to the Nikon D810, the UAV carried the following four payloads:

- An Atmospheric Sensing and Prediction System (ASAPS) Meteorological Sensor, developed by PEMDAS Technologies and Innovations, provided meteorological data real-time to the UAS ground station so the UAS pilots could analyze current meteorological conditions and provide information on the risk of carburetor and airframe icing.
- An electro-optical video camera provided the UAS pilot with situational awareness during flight.
- A GPS pinger was installed to aid in recovery of the UAS in the event of a controlled water landing and to ensure GPS metadata would be included with the D810 images.
- A Mode C transponder that can be detected by airborne Traffic Alert and Collision Avoidance System (TCAS) on manned aircraft and with ground-based air traffic radar.

Digital camera payload flight-testing

The Nikon D810 and 20 mm Nikkor lens were flight tested at the Naval Surface Warfare Center Dahlgren Division (NSWCDD) in Virginia on 20–21 July 2015. The UAS overflew a tri-bar calibration target at predetermined altitudes to assess the accuracy of the camera system and to ensure that the pilots could determine whether the camera was firing. During the test flights, images taken at 320 m (1050 ft) and 111 km/h (60 kn) showed an image resolution of 6 cm; images taken at 121 m (400 ft) and 111 km/h (60 kn) showed an image resolution of 3 cm (1.2 in; Table 1).

Daily flight operations

The NSWCDD was responsible for managing and conducting all aspects of the UAS operations. The UAS ground team, GCS, launch and retrieval systems, communications systems, UAS, and backup equipment were located at a decommissioned runway approximately 8 km (5 miles) north of the Wiley Post–Will Rogers Memorial Airport in Utqiaġvik, Alaska. The NSWCDD shore-based team was staffed to provide the ability to fly two UAS simultaneously, and included an air boss, who was the lead for all UAS flight operations, three individuals who were pilots-in-command (PIC) and UAS technicians, and one individual dedicated to UAS maintenance. Portable tents designed for extreme weather were used to shelter the GCS, components of the UAS, and the survey team. An additional PIC and a second GCS were aboard the NOAA ship *Fairweather*, which was positioned in the study area from 19 August through 30 August to provide situational awareness, enable full UAS coverage of the study area through a hand-off of the UAS to the ship-based pilot, and provide aid in the event of a water landing.

All flights occurred during daylight hours, between 0800 and 2200 h local time, and during periods of favorable weather (wind less than 39 km/h and no visible precipitation).

The UAV was launched and recovered from the shore-based station and accessed the offshore study areas located in international airspace through one of two transit corridors (Fig. 1). The UAV remained at or below 121 m AMSL (400 ft) while inside the corridor. Once in the offshore study area, the UAV targeted an altitude of 305 m AMSL (1000 ft) and an airspeed of 111 km/h (60 kn). The flight tracks were preprogrammed fine-scale transects 4.75 km (2.6 mi) apart. High-resolution digital images were collected every 3 s (100 m distance) over water. The UAV remained within radio line-of-sight of a GCS (50–70 nmi). The pilot monitored the onboard video and ASAPS sensor output and altered course as necessary to avoid precipitation or clouds. Once UAS operations were complete on a particular day, the UAV descended below 400 ft AMSL (121 m) while still in international airspace offshore and entered the transit corridor inbound for recovery.

When weather permitted, the manned aerial survey team took off from the Wiley Post–Will Rogers Memorial Airport at Utqiaġvik and surveyed predetermined transects 9.5 km (5.12 mi) apart in the survey area. The manned aircraft conducted surveys at a target altitude of 320 m (1050 ft), which provided a 15 m (50 ft) buffer relative to the target flight altitude of the UAS (305 m; 1000 ft). The target flight speed of the manned aircraft was 213 km/h (115 kn). Manned aerial survey protocols detailed in Clarke et al. (2017) were followed.

At the beginning of each flight, the aircraft overflew calibration targets so the resolution of the camera systems could be evaluated after the flights. The UAV overflew a tri-bar calibration target on land near the launch and retrieval site at approximately 131 m (400 ft) altitude. The manned aircraft overflew the same tri-bar calibration target at the beginning of multiple flights at approximately 167 m (550 ft). On 26 August, the manned aircraft overflew a larger calibration target positioned on the bow of the NOAA ship *Fairweather*, at 305 m (1000 ft); the UAV overflew the larger target at approximately 121 m (400 ft).

Coordinating UAV and manned aerial survey flights

The survey design assumed that the UAV and manned flights would be synchronized in time and space to obtain independent, replicate samples of whales. There is some risk inherent in deliberately conducting simultaneous flights of manned and unmanned aircraft in close proximity. In-flight safety was ensured by developing procedural methods by consensus among the pilots and science leads for the two field teams, and by using technological methods required by the FAA. Procedural methods included daily morning meetings of both field teams to discuss the plan for the day, a detailed communications plan that involved aviation radio and satellite telephone contact, development of rules for surveying, and contingencies for communication technology failure. Technological methods included the use of TCAS for the manned aircraft, which alerts pilots of nearby aircraft of a possible collision threat based on their range, altitude, and bearing. In addition, NOAA utilized a service that provided real-time, surface-based air traffic radar feed allowing the UAS team to detect aircraft in the area.

The manned aircraft and UAV flew simultaneously and successfully in the survey area. Initial protocols designated a minimum separation distance of 12 km (7.5 mi) laterally and 15 m (50 ft) vertically. Dynamic weather and the need to adapt flight plans in flight exacerbated the complexities of airspace coordination. After a few simultaneous flights of both platforms, the teams opted to increase the spatial separation, allowing only one project aircraft in a sector at a time.

Authorizations

Unmanned aircraft systems surveys were conducted under a FAA Certificate of Authorization (COA) that authorized beyond visual line-of-sight flights in the National Airspace System and international airspace managed by FAA. Navy Interim Flight Clearance was granted to the NSWCDD, which served as the airworthiness document for the ScanEagle® UAS. The marine mammal research was authorized under Marine Mammal Protect Act permit 14245-03, as amended and issued to the Marine Mammal Laboratory by the NOAA Fisheries Office of Protected Resources. The incidental harassment of polar bears and walrus caused by the UAS flights were authorized by permit 212570-1 from the U.S. Fish and Wildlife Service. Use of the area north of Utqiaġvik was authorized under North Slope Borough permits 16-013 and 16-078.

Table 2. Summary of hours flown and number of images collected in the survey area during each flight of the unmanned aerial systems (UAS) and the manned aircraft useful for the density comparison.

	UAV flights		Manned flights		
Date	Flight hours	No. of images	Flight hours	No. of images	Comments
26 August	3.7	2 736	—	—	Successful hand-off of UAS from shore- to ship-based team. Project transects not flown by manned survey team.
29 August	—	—	3.2	5 103	—
30 August	—	—	—	—	Manned flights attempted but aborted due to low ceiling and poor observing conditions.
31 August	6.0	6 246	3.3	4 212	Camera mount damaged on retrieval.
1 September	5.5	5 460	4.8	4 896	—
2 September	5.0	4 995	1.3	1 368	Most manned aircraft flight time outside of survey area due to poor conditions.
6 September	1.6	1 131	—	—	Manned aircraft conducted reconnaissance to assess conditions for UAV flights; retrieval of the UAS damaged boom on the skyhook.
7 September	UAS team packed gear		5.4	8 001	Manned survey team completed all transects in the study area.
Total	21.8	20 568	17.9	23 580	Total images = 44 148 on transect.

Results

The UAS team conducted five flights of the ScanEagle® during the study (Table 2). UAS flight duration in the survey area ranged from 1.6 to 6 h and 20 568 images were collected during the flights. The manned aerial survey team conducted flights on 7 days during the project (Table 2); flight duration in the survey area ranged from 1.3 to 4.8 h and 23 580 images were collected during the flights. The manned aircraft conducted additional surveys outside the survey area when the weather was too poor for effective observations in the survey area. There were 3 days when flights were conducted by both the UAS and the manned aerial survey teams.

The local weather was highly variable, both spatially and temporally. There were often patches of squalls or low clouds offshore that were not apparent from the shore, but could be seen using the live video feed from the UAV and by the crew of the Turbo Commander. The ScanEagle® team kept the UAV away from clouds and attempted to remain clear of precipitation. The team managed the UAV's interaction with the weather by monitoring the onboard video camera and the temperature and humidity data provided by the ASAPS sensor. The UAV frequently encountered theoretical carburetor icing conditions during flights; the team mitigated the potential for carburetor icing by operating the UAV at high revolutions per minute (RPM) to keep the engine warm.

The project design relied on the expectation that two UAS could survey simultaneously to accumulate the estimated number of hours needed for a robust analytical comparison between survey platforms. Unfortunately, due to the complications of coordinating manned and UAV flights, weather, and technical issues, the team did not have the opportunity to fly two UAVs simultaneously. Science results are found in Ferguson et al. (2018).

Observations and recommendations

Despite great interest in using UAS in the Arctic, only a handful of projects have successfully used UAS to conduct research beyond line-of-sight. The use of UAS in the Arctic remains in its infancy and the learning curve is still relatively steep. The following observations and recommendations are provided to guide future UAS projects, particularly those that are directed at marine mammals, occur beyond line-of-sight or that occur in the Arctic.

Use of a shore-based location for the primary GCS

Overall, the location of the shore-based camp north of Utqiaġvik was acceptable for launch and recovery of the UAS. The area was open, and while there were some obstacles nearby, the UAV could be launched and retrieved from multiple directions. The large tents (3 m × 6 m) used to house the GCSs and provide a place for storage and maintenance of the UAS were minimally adequate. Lodging, food, and hardware supplies were located a short drive away in Utqiaġvik, and logistics support was provided by a local company, Ukpeaġvik Iñupiat Corporation (UIC), that specializes in arctic science support. In the planning stages of the project, the initial evaluation was that it would have been substantially more complicated to integrate the UAS on the NOAA research vessel than to stage on the shore. UIC provided polar bear guard services and night security for the site.

We recommend using a hard-sided, temperature controlled workspace for housing the GCS and UAV equipment. The working area inside the tents was minimally adequate but challenging. Equipment was frequently tested and found fully functional in the evening, yet during flight preparations the next morning, new technical issues were discovered and had to be fixed. Many of the technical issues were believed to be caused by low temperatures and high humidity at the field site. If a temperature-controlled area were sufficiently large to allow the UAV to be placed indoors with their wings on, it would shorten the time to launch from approximately 2 h to 45 min after arriving at the site.

Use of a shore-based site as the location for the primary GCS, launch, and retrieval of the UAS meant that the UAS system had to be transported to Utqiaġvik. This is a significant task due to the considerable size and weight of the UAS launch and recovery equipment, and a C130 was needed to transport the gear. Because the U.S. Navy was a partner on this project, transport via C130 was provided free of charge to the project. However, if this had not been available, chartering a commercial C130 flight from the U.S. east coast to Utqiaġvik would have cost approximately $580K (USD). If a shore-based operation is preferred, future projects that require a fixed-wing UAV would benefit from using a UAV that could launch and (or) land on a runway, eliminating the need for bulky launch and recovery systems, or a UAS already staged in the area of interest.

Beyond visual line-of-sight flights of the UAV

The receipt of a COA for these flights was a notable success as the FAA had issued few COAs for beyond visual line-of-sight flights by UAS.

Flying beyond visual line-of-sight is required to collect some types of environmental data, and the permitting and logistical requirements are significant for beyond visual line-of-sight flights in U.S. airspace. The FAA authorized a beyond visual line-of-sight COA for this project based on an air traffic density study and operations were contingent on the implementation of a rigorous communications plan for exchanging critical information with other airspace users and continuously monitoring the surface-based air traffic radar for any aircraft approaching the operations area. The communications protocol proposed to the FAA ensured that local airspace users — including pilots of both manned and unmanned systems — would be aware of our beyond line-of-sight activities in the area each day. The protocol included extensive preseason outreach to pilots.

The UAV has a Mode C transponder that can be detected by airborne TCAS and with ground-based air traffic radar. Through the surface-based air traffic radar feed, the air boss, who was the lead for all flight operations, was able to see the UAV and other air traffic in the survey area. The surface-based air traffic radar was also useful for monitoring offshore air traffic, particularly the project aircraft and local pilots transiting to an offshore drilling area, both of which were flying at approximately the same altitude as the UAV.

The air traffic density study, communications protocols, and air traffic radar were useful in reducing risk to manned aircraft in airspace shared by manned and unmanned aircraft, particularly when UAS were operating beyond visual line-of-sight in areas and at altitudes where manned aircraft also occur.

Operations in arctic fall weather conditions

Icing of the airframe and carburetor are a well-known problem for UAS and can significantly restrict flights. UAS were first flown in the Arctic in the spring of 1999 (Curry et al. 2004); airframe icing and carburetor icing caused the project to lose three aircraft after 16 h of flight time. While fall conditions for this project were substantially warmer than those typical of April, the combination of low temperatures and high humidity meant that icing was a potential problem on many days that were otherwise good flight days. The UAS flight team managed potential in-flight carburetor icing conditions by running the engines at relatively high RPM and faster speeds to keep the engine warm. Additionally, the PIC recorded the commanded throttle and respective RPM reading every 15–30 min to ensure that the engine was not exhibiting degraded performance. The use of fuel-injected engines would not have resulted in increased flight time during this project, but they are a recommended solution for the Arctic because of the high potential for carburetor icing issues. At no time did the team stand down due to predicted carburetor icing conditions prior to flight.

We recommend that UAS manufacturers and operators develop a more precise understanding of when carburetur icing occurs in UAVs. The lack of platform-specific information on the conditions under which carburetor icing may be a problem for a particular UAV will mean that pilots may tend to be unnecessarily conservative about flights in conditions that the equipment manual might call “marginal”. Temperature and humidity data provided real-time by an onboard sensor on the platform will be more useful to the UAV pilots if the relationship between the environmental data and the probability of icing on a particular UAV is better understood. Laboratory tests to verify the conditions under which carburetor icing of various UAVs actually occurs would be helpful.

There are a number of features that could be added to a UAV to improve its capability to fly in an arctic environment. A UAS that could be flown in occasional icing conditions and be approved to go through clouds could access more areas where the weather is sufficient for marine mammal surveys. Platform updates, such as satellite-linked monitoring and control, and modifications to handle icing such as heated pitot tubes, wing boots, and heated propellers would be helpful. For this project, weatherproofing would have been most helpful for the shore-based team because the team had to work on the UAS in light mist as they waited for local squalls to pass the study area, and it was clear that long-term storage in a cold, damp environment damaged the equipment over time.

The availability of weather information at the field site — specifically short-term, high resolution, local information on precipitation — facilitated UAS flights because it informed the pilots of local environmental conditions at the field site, located 8 km (5 mi from the airport, where official FAA weather observations were measured). A portable weather station was used late in the field project to assess information on ceiling altitude at the field site. Due to local variability, the ceiling at the field site was often hundreds of metres higher or lower than the ceiling at the airport; having a weather station at the field site enabled the team to measure minimum launch criteria more accurately and frequently. “NOWcasting” software that provides immediate or short-term forecasts, such as that designed by PEMDAS and used for this project, was helpful to predict short-term variation in weather conditions.

Ship-based UAS operations

The ability to conduct ship-based UAS operations may be helpful to many researchers, but UAS may not integrate readily on vessels commonly used by researchers. A highly customized integration for our project would have required significant time and funds, and multiple test flights.

When not committed to supporting the UAS project, the ship's crew optimized vessel time in the area by conducting hydrological surveys of the coastal areas near Utqiaġvik and deploying U.S. Navy wave-gliders. The ability to conduct multiple important projects simultaneously improves the cost-efficiency of the vessel time.

We recommend vessels used for arctic research be assessed to provide potential users with information relevant to understanding what types of UAS operations are compatible with each vessel. This assessment should include measurements of deck space available for launch and recovery, space for the GCS, and space for storage and maintenance of UAS equipment.

Future beyond visual line-of-sight arctic maritime operations should be based off a vessel in lieu of from a shore-based station. This may limit the vessel–UAS combinations that can be easily implemented, as integrating some UAS on some vessels will be complicated and expensive. However, basing off a vessel was considered the single operational change that would have directly and significantly improved the chances of getting the flight hours needed for the project. Often, weather conditions in Utqiaġvik were sufficiently poor to prevent launch (low ceilings, fog, or winds); however, based on weather reports from the affiliated ship there were offshore areas that could have been accessed if the UAV could have been launched from a vessel. Advantages to basing off a ship for this project included

- ability to move to areas of good weather within the study area for launch and recovery;
- equipment would be stored in a climate-controlled area;
- long-range flights based from shore could require a satellite link; using a mobile GCS on a ship provides a larger range without the need for satellite link;
- no need to transport UAS equipment to a shore-based site; and
- no need for security or bear protection contracts.

Camera resolution

During the test flights prior to the field season, the camera collected images at 318 m (1050 ft) AMSL with a resolution of 6 cm (2.36 in), which was better than the acceptable minimum resolution requirements (7 cm) needed to achieve the project's objectives. However, the light levels at Dahlgren, Va., during the test flights were very high, with low to no cloud cover. This allowed for images to be taken at a much higher shutter speed and lower ISO than those collected in the study area, resulting in higher image quality during test flights. The Nikon camera calibration images from the UAS in the field indicated that the resolution was adequate for large whale detection and species identification, but was poorer (>10 cm) than the initial minimum requirements and testing done in Virginia prior to the field effort. In addition, vibration of the camera systems likely impacted image quality. The camera mounts used in Utqiaġvik were constructed with a cold-intolerant material and became damaged over time upon platform retrieval. While the achieved resolution was adequate to identify large whales, a higher resolution would be needed in area with greater species diversity or smaller target animals.

We recommend investigating structural improvements to the camera mounting system, such as cold-tolerant material for the camera mount and vibration-dampening material between the camera mount and bracket.

If payload weight is a concern, modify the camera to include only the critical mechanisms to make it lighter and easier to integrate. The Nikon D810 camera and associated lens were relatively heavy for the UAV. The weight of the camera system (1.3 kg; 2.8 lb) resulted in having to adjust other components of the UAV to accommodate the camera system. To save weight, the gimbaled turret was removed. Although not critical, it would have been helpful for situational awareness to have retained the turret so the video camera could pan while the UAS was transiting in a straight line. The weight of the UAS also added complexity to the launch and retrieval requirements: if a full tank of fuel were required, a wind of 18.6–27.8 km/h (10–15 kn) during launch would have been required to meet the specifications of pressurizing the launcher.

Non-camera payloads

Due to the location of the ASAPS sensor and the extended dual bay configuration, the wing had to be disconnected from the fuselage for the ScanEagle® to fit in the transport case. Once the wing was reconnected to the fuselage, the ScanEagle® could no longer be placed in the transport case for shipping or on-site storage.

A different configuration of the ASAPS sensor would be helpful, and larger transport cases should be built to accommodate a ScanEagle® with an additional payload bay.

Coordinating UAS and manned aerial survey flights

One of the goals of the project was to conduct coordinated manned and UAS flights simultaneously in close proximity to provide a comparison of whales detected by sensors on the two platforms. To ensure safety during the flights, there were both technological and procedural methods for ensuring spatial separation in flight. Written procedural methods were developed in advance of the field season by consensus by team pilots and project leads. Technological methods included the installation of a transponder in the UAS so nearby aircraft with the TCAS would be alerted of a possible collision threat, and monitoring a surface-based air traffic radar, which allowed the UAS team to monitor aircraft in the vicinity.

For coordinating UAS and manned aircraft flights, TCAS alone is not sufficient for ensuring safe separation due to the limitations of TCAS and difficulties in visually detecting a small UAS flying at high closure rates. A detection and ranging available to the manned aircraft and UAS would increase safety when operations are being conducted in nonsegregated airspace. It is essential that precise relative position information be utilized when there is a future requirement for manned aircraft and UAS to fly in close proximity. UAS-based detect and avoid system would increase safety when UAS operations are being conducted in nonsegregated airspace. Without precise relative position information, manned aircraft and UAS must be separated by predetermined vertical and horizontal boundaries for each aircraft. These boundaries will depend on UAS type (VTOL or fixed-wing), performance (vertical and horizontal velocities), reliability, and flight conditions.

During the project, after a few coordinated UAS and manned flights at the same altitude and as close as ~15 km, the teams increased the spatial buffer between the project aircraft to maintain a level of safety acceptable to the flight teams. The following were the factors that resulted in this change in protocol. Both the airboss at the GCS and the pilots of both the unmanned and manned aircraft could detect each other's location using the surface-based air traffic radar feed and TCAS, respectively, but neither system allowed the pilots

Table 3. Critical project components that directly contributed to successful data collection with the UAS, improved safety, or both.

Project component	Comments
Internet service	Critical for weather forecasting, access to air traffic information.
Surface-based air traffic radar feed	Greatly improved flight safety because the UAS pilots could detect local air traffic; use required by the certificate of authorization.
NOWcasting	Increased ability to predict local weather at a spatial and temporal scale unavailable from NWS forecasts.
ASAPS sensor	Helped UAS pilots know when they were likely approaching a cloud or measureable precipitation. Associated software designed to detect hypothetical carburetor icing conditions, not actual carburetor icing conditions.
Portable weather station	The cloud ceiling at the launch site was often hundreds of metres different from the ceiling at the airport.
Open land area with easy access and low traffic volume	Mitigated risks to the community of UAV flying over land.

to precisely measure the distance between the platforms, so distance was a poor metric for triggering real-time flight decisions. The size of the UAV made it impossible to visually detect at distances beyond 1 or 2 km; the survey team in the manned aircraft never detected the UAV visually.

In addition, because of the limited capabilities of the TCAS I system used in the project, it was not operationally feasible for the manned aircraft pilots to make independent decisions about changing their flight path in response to the UAS flight path until the UAS was within <2 miles of the manned aircraft.

In-flight communications need to be more reliable. The weather in the study area was dynamic, which resulted in frequent changes to flight plans by pilots of both aircraft to find areas conducive to surveying. The pilots used satellite phones to discuss real-time changes in flight plans, but satellite phone coverage in the study area can be intermittent. A relatively user-friendly alternative communications approach was VHF radio; however, VHF communications are limited by the ability to transmit and receive the radio signal, which is affected by weather and the altitude and strength of the broadcasting signal.

Integrating a UAS project into an Alaskan coastal village

Discussions about the proposed UAS project with individuals in the local community began 2 years before the project was funded to identify potential problems with sufficient lead time to mitigate any concerns. A directed outreach effort to local governments, offices, and organizations was initiated at least 6 months before the project started. Longstanding professional relationships and routine discussions with North Slope Borough staff helped the survey team understand what issues might be of concern to local residents so that potential conflicts could be mitigated well in advance of the field project.

Researchers planning to use UAS near a populated area should err on the side of providing more information to the permitting agencies so they have a thorough understanding of the operation prior to permitting, and be prepared to cease operations immediately and discuss concerns if issues are raised. The use of UAS near coastal Alaska villages is relatively new and both UAS operators and local permitting agencies may not yet have a thorough understanding of a UAS projects' footprint in rural and remote areas, so all parties may not know the best questions to ask prior to the project. UAS teams should be prepared to be flexible and adapt their operations to conform to local land use needs.

Table 4. Recommended changes in flight operations for a comparable Arctic survey.

Change in operations	Critical	Not critical	Comments
Base from a ship	X		Basing from a ship would allow the UAS team to move to where the weather is favorable for flights.
Climate-controlled storage of UAS gear	X		Climate-controlled facility would have minimized maintenance likely required due to near-freezing temperatures, rain, and high humidity.
Automated aircraft position broadcasting and detection technology	X		Improves safety by improving ability to avoid other air traffic; enables increased size of survey area.
Dampen camera to reduce vibrations	X		Would improve ground resolution, which would aid in detecting large cetaceans, identifying them to species, estimating group size, and detecting calves.
Weatherproof UAS (instrument flight rules capability, heated pitot tubes, and wing/prop deicing capability)	X	X	Would have been helpful for preflight preparations. May have been helpful for collecting data on some days because the UAS would have been able to better handle highly variable patches of precipitation. However, if there is visible precipitation in all areas, visibility is poor and images are not likely to be useful. Lack of a weatherproof UAS did not severely limit the success of the project, but it would have been helpful for preflight preparations.
Conduct surveys at a lower altitude	X	X	May not be possible given science goals for this project; as flight altitude decreases, swath width decreases, which may be inefficient. Future projects must consider the balance between expected cloud ceiling, platform altitude and swath width.
Use a fuel-injected engine		X	The carb icing chart in the Insitu manual is general, not specific to the ScanEagle®. ScanEagle® platforms were routinely flown in icing conditions during this project with no detected effect on the project. However, if a fuel-injected engine had been used, the team would not have needed to run RPMs high to mitigate for the potential of carb icing, which might have avoided degradation of image quality.
Turret for onboard video system		X	Provides ability to see to the left and right while flying straight — aids cloud avoidance.
Improve camera/camera mount		X	The camera was heavy, which required that the UAS take on less fuel. The camera mount was not built using the requested type of plastic, and turned out to be quite brittle. The combination of the heavy system and the type of plastic likely contributed to the breakage of two camera mounts.

Note: Critical changes are those that that would have resulted directly in increased data collection; other changes might decrease maintenance workload or improve the comfort of the working environment. Changes identified as both critical and not critical were those that did not limit success of our project, but should be considered in the design of similar projects facing challenging weather.

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Conclusions

We identified many project successes and provided detailed recommendations about how we could have better met various operational and technological challenges. Table 3 summarizes the aspects of the project that were critical to successful data collection from UAS, improved safety, or both. Table 4 summarizes the operational changes that are most likely to directly improve data collection by future projects.

Unmanned aircraft systems are sometimes marketed as a "transformative" or "disruptive" technology that will dramatically change how wildlife researchers collect data. This is clearly true in some situations: after a few field seasons of evaluation, NOAA Fisheries is now routinely using a hexacopter UAS to collect mission-critical information on penguins (Goebel et al. 2015), killer whales (Durban et al. 2015), and Steller sea lions (Sweeney et al. 2016).

Analytical results of this project (Ferguson et al. 2018) indicate that long-range UAS surveys provide reliable information on marine mammal density that is comparable to the information collected by manned aerial surveys. However, for long-range surveys for marine mammals, at this time, the use of UAS is promising, but considerably more expensive and logistically complicated than manned aerial surveys. A future project's risk tolerances, scientific objectives, physical footprint, personnel needs, and cost will have to be considered early in the projects' design.

Many researchers are interested in UAS as simply a new and effective means to transport a sensor to an area of interest and are less interested in the UAS technology. At this stage in the process of evaluating UAS and associated technology for use in ecology and other nonmilitary disciplines, it is particularly helpful to highlight operational challenges and possible solutions (Curry et al. 2004; Koski et al. 2015) in addition to reporting research results. Direct comparisons of the ability of different UAS to collect the same or similar data (Johnston et al. 2017) is also particularly helpful. By decribing in detail the unique operational challenges involved in using UAS for beyond line-of-sight flights to study animals in the wild, we hope that others may build on our experience and effectively find similar and broader use of this technology.

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References

Acevedo-Whitehouse, K., Rocha-Gosselin, A., and Gendron, D. 2009. A novel non-invasive tool for disease surveillance of free-ranging whales and its relevance to conservation programs. Anim. Conserv. **13**: 217–225. doi: 10.1111/j.1469-1795.2009.00326.x.

Anderson, K., and Gaston, K.J. 2013. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Front. Ecol. Environ. **11**(3): 138–146. doi: 10.1890/120150.

Barasona, J.A., Mulero-Pázmány, M., Acevedo, P., Negro, J.J., Torres, M.J., Gortázar, C., and Vicente, J. 2014. Unmanned aircraft systems for studying spatial abundance of ungulates: relevance to spatial epidemiology. PLoS ONE, **9**(12): e115608. doi: 10.1371/journal.pone.0115608. PMID: 25551673.

Brower, A.A., Ferguson, M., Schonberg, S., Jewett, S., and Clarke, J. 2017. Gray whale distribution relative to benthic invertebrate biomass and abundance: northeastern Chukchi Sea 2009–2012. Deep Sea Res., Part II. **144**: 156–174. doi: 10.1016/j.dsr2.2016.12.007.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L, Borchers, D.L., and Thomas, L. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford, UK. 432 pp.

Chabot, D. 2018. Trends in drone research and applications as the Journal of Unmanned Vehicle Systems turns five. J. Unmanned Veh. Syst. **6**(1): vi–xv. doi: 10.1139/juvs-2018-0005.

Christie, K.S., Gilbert, S.L., Brown, C.L., Hatfield, M., and Hanson, L. 2016. Unmanned aircraft systems in wildlife research: current and future applications of a transformative technology. Front. Ecol. Environ. **14**(5): 241–251. doi: 10.1002/fee.1281.

Citta, J.J., Quakenbush, L.T., Okkonen, S.R., Druckenmiller, M.L., Maslowski, W., Clement-Kinney, J., et al. 2015. Ecological characteristics of core-use areas used by Bering–Chukchi–Beaufort Sea (BCB) bowhead whales, 2006–2012. Prog. Oceanogr. **136**: 201–222. doi: 10.1016/j.pocean.2014.08.012.

Clarke, J.T., Brower, A.A., Christman, C.L., and Ferguson, M.C. 2014. Distribution and relative abundance of marine mammals in the northeastern Chukchi and western Beaufort Seas, 2013: annual report. OCS Study BOEM 2014-018. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, Wash. 98115-6349. 330 pp.

Clarke, J.T., Brower, A.A., Ferguson, M.C., and Willoughby, A.L. 2017. Distribution and relative abundance of marine mammals in the eastern Chukchi and western Beaufort Seas, 2015: annual report. OCS Study BOEM 2017-019. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, Wash. 98115-6349.

Curry, J.A., Maslanik, J.A., Holland, G., Pinto, J., Tyrrell, G., and Inoue, J. 2004. Applications of aerosondes in the Arctic. Bull. Am. Meteorol. Soc. **85**: 1855–1862. doi: 10.1175/BAMS-85-12-1855.

Durban, J.W., Fearnbach, H., Barrett-Lennard, L.G., Perryman, W.L., and Leroi, D.J. 2015. Photogrammetry of killer whales using a small hexacopter launched at sea. J. Unmanned Veh. Syst. **3**(3): 131–135. doi: 10.1139/juvs-2015-0020.

Ferguson, M.F., Angliss, R.P., Kennedy, A., Lynch, B., Willoughby, A., Helker, V., Brower, A.A., and Clarke, J.T. 2018. Performance of manned and unmanned aerial surveys for estimating arctic cetacean density and associated uncertainly. J. Unmanned Veh. Syst. This issue. doi: 10.1139/juvs-2018-0002.

Fritz, L. 2012. By land, sea, and air: a collaborative Steller sea lion research cruise in the Aleutian Islands. Alaska Fisheries Science Center Quarterly Report, January–February–March. NOAA, National Marine Fisheries Service. Available from http://www.afsc.noaa.gov/Quarterly/jfm2012/divrptsNMML1.htm.

Garner, G.W., Amstrup, S.C., Laake, J.L., Manly, B.F.J., McDonald, L.L., and Robertson, D.G. (eds.). 1999. Marine mammal survey and assessment methods. A.A. Balkema, Rotterdam, the Netherlands and Brookfield, WI, USA. 177 pp.

Goebel, M.E., Perryman, W.L., Hinke, J.T., Krause, D.J., Hann, N.A., Gardner, S., and LeRoi, D.J. 2015. A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biol. **38**(5): 619–630. doi: 10.1007/s00300-014-1625-4.

Hodgson, A., Kelly, N., and Peel, D. 2013. Unmanned aerial vehicles (UAVs) for surveying marine fauna: a dugong case study. PLoS ONE, **8**(11): e79556. doi: 10.1371/journal.pone.0079556. PMID: 24223967.

Johnston, D., Dale, J., Murray, K., Josephson, E., Newton, E., and Wood, S. 2017. Comparing occupied and unoccupied aircraft surveys of wildlife populations: assessing the gray seal (*Halichoerus grypus*) breeding colony on Muskeget Island, USA. J. Unmanned Veh. Syst. **5**(4): 178–191. doi: 10.1139/juvs-2017-0012.

Koski, W.R., Allen, T., Ireland, D., Buck, G., Smith, P.R., Macrander, A.M., Halick, M.A., Rushing, C., Sliwa, D.J., and McDonald, T.L. 2009. Evaluation of an unmanned airborne system for monitoring marine mammals. Aquat. Mamm. **35**: 347–357. doi: 10.1578/AM.35.3.2009.347.

Koski, W.R., Thomas, T.A., Funk, D.W., and Macrander, A.M. 2013. Marine mammal sightings by analysts of digital imagery versus aerial surveyors: a preliminary comparison. J. Unmanned Veh. Syst. **1**: 25–40. doi: 10.1139/juvs-2013-0015.

Koski, W.R., Gamage, G., Davis, A.R., Mathews, T., LeBlanc, B., and Ferguson, S.H. 2015. Evaluation of UAS for photographic re-identification of bowhead whales, *Balaena mysticetus*. J. Unmanned Veh. Syst. **3**(3): 22–29. doi: 10.1139/juvs-2014-0014.

Laguna, E., Barasona, J.A., Triguero-Ocaña, R., Mulero-Pázmány, M., Negro, J.J., Vicente, J., and Acevedo, P. 2018. The relevance of host overcrowding in wildlife epidemiology: A new spatially explicit aggregation index. Ecol. Indic. **84**: 695–700. doi: 10.1016/j.ecolind.2017.09.039.

Maire, F., Mejias L., Hodgson, A., and Duclos, G. 2013. Detection of dugongs from unmanned aerial vehicles. *In* Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems 2013. Tokyo, Japan.

Moreland, E.E., Cameron, M.F., Angliss, R.P., and Boveng, P.L. 2015. Evaluation of a ship-based unoccupied aerial system (UAS) for surveys of spotted and ribbon seals in the Bering Sea pack ice. J. Unmanned Veh. Syst. **3**(3): 114–122. doi: 10.1139/juvs-2015-0012.

Mulero-Pázmány, M., Barasona, J.Á., Acevedo, P., Vicente, J., and Negro, J.J. 2015. Unmanned Aircraft Systems complement biologging in spatial ecology studies. Ecol. Evol. **5**(21): 4808–4818. doi: 10.1002/ece3.1744.

Muto, M.M., Helker, V.T., Angliss, R.P., Allen, B.A., Boveng, P.L., Breiwick, J.M., Cameron, M.F., Clapham, P.J., Dahle, S.P., Dahlheim, M.E., Fadely, B.S., Ferguson, M.C., Fritz, L.W., Hobbs, R.C., Ivashchenko, Y.V., Kennedy, A.S., London, J.M., Mizroch, S.A., Ream, R.R., Richmond, E.L., Shelden, K.E.W., Towell, R.G., Wade, P.R., Waite, J.M., and Zerbini, A.N. 2016. Alaska marine mammal stock assessments, 2015. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-323. 300 pp. doi: 10.7289/V5/TM-AFSC-323.

Sarda-Palomera, F., Bota, G., Vinolo, C., Pallares, O., Sazatornil, V., Brotons, L., Gomariz, S., and Sarda, F. 2012. Fine-scale bird monitoring from light unmanned aircraft systems. Ibis, **154**: 177–183. doi: 10.1111/j.1474-919X.2011.01177.x.

Stark, H., Parthasarathy, P., and Johnson, R.N. 2003. Considerations in designing a marine-mammal-ship collision avoidance system based on aerial imagery by an unmanned airborne vehicle. Opt. Eng. **42**(1): 11–17. doi: 10.1117/1.1525276.

Sweeney, K.L., Helker, V.T., Perryman, W.L., LeRoi, D.J., Fritz, L.W., Gelatt, T.S., and Angliss, R.P. 2016. Flying beneath the clouds at the edge of the world: using a hexacopter to supplement surveys of Steller sea lions (*Eumotopias jubatus*) in Alaska. J. Unmanned Veh. Syst. **3**(3): 114–122. doi: 10.1139/juvs-2015-0010.

Watts, A.C., Perry, J.H., Smith, S.E., Burgess, M.A., Wilkinson, B.E., Szantoi, Z., Ifju, P.G., and Percival, H.F. 2010. Small unmanned aircraft systems for low-altitude aerial surveys. J. Wildlife Manage. **74**: 1614–1619. doi: 10.1111/j.1937-2817.2010.tb01292.x.

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