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ARTICLE

Evaluation of a ship-based unoccupied aircraft system (UAS) for surveys of spotted and ribbon seals in the Bering Sea pack ice[1]

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Abstract: The remote pack ice of the arctic and subarctic seas is challenging to access, yet extremely important to understand and monitor. The pack ice holds the key to understanding ecosystem responses to climate change and is vital habitat for many species including ice-associated seals. Unoccupied aircraft systems (UAS) are a new class of tools that may overcome the traditional challenges associated with expansive offshore surveys. We conducted UAS flights over the pack ice during a spring 2009 National Oceanic and Atmospheric Administration (NOAA) cruise to the Bering Sea to determine whether advances in UAS technology can enable effective large-scale, systematic ship-based surveys for seals in the seasonal ice of the Bering, Beaufort, and Chukchi Seas. A fixed-wing ScanEagle UAS was successfully launched and recovered from the NOAA ship *McArthur II* to conduct small-scale transect surveys up to 5 nautical miles (M) from the ship's position. More than 27 000 images were collected from 10 flights over the Bering Sea pack ice and seals were identified in 110 of these images. Review of the images indicated a marked reduction in disturbance to seals when compared to images collected from occupied, low-altitude helicopter surveys. These results suggest that large-scale UAS surveys of arctic and subarctic habitat in United States airspace will be possible with improvements in technology, reduced operational costs, and the establishment of inclusive airspace regulations.

Key words: UAS, BLOS, ScanEagle, ice-associated seals, ice seals, aerial survey.

Résumé : La banquise éloignée des mers arctiques et subarctiques est difficile d'accès, toutefois il est extrêmement important de la comprendre et de surveiller son évolution. La banquise est la clé pour comprendre la réaction de l'écosystème aux changements climatiques et constitue un habitat vital pour un grand nombre d'espèces, y compris les phoques associés à la banquise. Les systèmes d'aéronefs sans pilote (UAS) constituent une nouvelle catégorie d'outils qui permettront peut-être de surmonter les défis traditionnels reliés aux levés extracôtiers étendus. Nous avons mené des vols de UAS au-dessus de la banquise lors d'une croisière de la NOAA en mer de Béring au printemps 2009 afin de déterminer si les progrès en technologie UAS peuvent permettre des levés systématiques à grande échelle à partir de navires donnant efficacement de l'information au sujet des phoques dans les glaces saisonnières des mers de Béring, de Beaufort et des Tchouktches. On a réussi à lancer un UAS ScanEagle à voilure fixe à partir du navire *McArthur* NOAA et à le récupérer afin de faire des levés à petite échelle à virée transversale à une distance allant jusqu'à 5 milles marins (M) de la position du navire. On a collecté au-delà de 27 000 images lors de 10 vols au-dessus de la banquise de la mer de Béring et identifié des phoques dans 110 de ces images.

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[1]This article is one of a special series of invited papers on the use of unmanned vehicle systems in wildlife studies.

L'examen des images a révélé une diminution de la perturbation affectant les phoques comparativement aux images collectées à partir d'un hélicoptère piloté à basse altitude. Ces résultats suggèrent que les levés à grande échelle de l'habitat arctique et subarctique en espace aérien américain au moyen d'UAS seront possibles grâce aux améliorations de la technologie, aux coûts opérationnels moindres et à la création d'une réglementation de l'espace aérien inclusif.

Mots-clés : UAS, BLOS, ScanEagle, phoques associés à la banquise, phoque de la banquise, levé aérien.

Introduction

Monitoring ice-associated seals (spotted, ribbon, ringed, and bearded seals) in remote arctic and subarctic environs presents a number of unique challenges. Traditional aerial ("manned" aircraft) surveys are expensive and inefficient for collecting information from low altitudes over the pack ice far from shore. Advances in camera resolution over the past few years have allowed aircraft to survey at higher altitudes, but this advantage is often lost due to persistently low cloud cover. Efforts to reach seal populations in the most remote areas of the pack ice have included flying helicopter surveys from ice-breaking vessels (Cameron and Boveng 2007; Cameron et al. 2008; Ver Hoef et al. 2014) and utilizing remote airstrips for manned fixed-wing aircraft (Bengtson et al. 1995; Fedoseev et al. 1988; Frost et al. 2004; Moreland et al. 2013). Helicopter surveys can access the most remote areas, but the flight distance is limited to 50 nautical miles (M) from the support vessel by fuel and safety considerations. Fixed-wing aircraft equipped for long-range fights still have difficulty reaching the most remote regions due to inclement weather and the distance to secondary landing strips. An additional challenge with these surveys is the rapidly changing sea-ice habitat during our survey window. Conducting these surveys in a short period of time minimizes the issue of working in a changing habitat, and ultimately improves the accuracy of the final abundance estimates.

Unoccupied ("unmanned") aircraft systems (UAS) have been in use for a variety of scientific applications (Curry et al. 2004; Jones et al. 2006; Watts et al. 2010; Knuth et al. 2013) and have the potential to supplement our fixed-wing survey efforts (Moreland et al. 2013). UAS are less restrictive than occupied aircraft, capable of flying longer and farther and at lower altitudes with reduced disturbance to seals. With technological advances, it is possible to outfit a UAS with an instrument payload providing adequate resolution for detection and species identification. The UAS industry has been expanding their interest from a military focus towards civilian and scientific missions, which has pushed the Federal Aviation Administration (FAA) to address shared airspace safety considerations. Once airspace issues are resolved, UAS may be a viable tool for many wildlife research applications requiring long-range mission profiles. In this paper we review both the performance of the ScanEagle for our survey application as well as the required processes for operating UAS from a NOAA vessel. Our initial objectives were as follows:

1. Safely demonstrate launch, operation, and recovery of the UAS ScanEagle from a NOAA vessel in Bering Sea pack ice.
2. Establish appropriate camera settings for the collection of sea ice and ice seal images from a UAS platform.
3. Compare UAS ice seal surveys to previously conducted helicopter surveys of the Bering Sea pack ice.
4. Evaluate potential disturbance to ice seal behavior from the ScanEagle UAS at low altitude.

Methods

In spring 2009 we evaluated the effectiveness of using UAS to collect sightings data for ice-associated seals in a subarctic environment. From 21 May 2009 to 8 June 2009, 10 flights were conducted from the NOAA ship *McArthur II*, during a ribbon (*Histriophoca fasciata*) and spotted seal (*Phoca largha*) telemetry research cruise conducted at the Bering Sea ice edge (Cameron et al. 2009).

We selected Boeing's fixed-wing ScanEagle (Fig. 1) for its maritime capabilities, payload capacity, endurance, and availability at a reasonable cost from a collaborating partner institution. It has a 1.2 m long body and 3 m wingspan, payload capacity of 6 kg, a cruising speed of 25 m/s, and flight endurance of 20+ h on 7.5 L of gasoline. We flew three different ScanEagle aircrafts that were owned and operated by the University of Alaska, Fairbanks. This UAS is specifically designed to be launched and recovered by a ship while at sea. They were launched by pneumatic catapult and captured by a modified SkyHook system (Fig. 2). The aircraft was piloted from a ground control station (GCS) set up in

Fig. 1. ScanEagle UAS ready for launch by pneumatic catapult on the NOAA ship *McArthur II*. The payload bay is located just behind the nose cone and contains a downward facing Nikon D300 fitted with a 35 mm lens for a 35 mm equivalent focal length of 53 mm.

laboratory space onboard the ship. Tracks were preset in the navigation system but could be easily modified in real-time through the GCS map interface. Command and control was maintained through radio link and preprogrammed lost-link protocols were loaded into the aircraft's flight control memory in the case the platform lost communication with the GCS. Our mission required a team of two pilots and an additional certified observer to look for other aircraft in the area. Pilots served as certified observers when not piloting the aircraft and observers rotated shifts on the deck of the ship, maintaining communication with the pilot via handheld VHF radio.

The UAS' modular design allowed us to fly with either the default, integrated payload, or to install our own high-resolution cameras in a separate payload bay. We equipped two of our aircraft with a Nikon D300 camera fitted with a 35 mm lens (35 mm film equivalent focal length of 53 mm) to meet our minimal ground resolution requirement of 2.0 cm/pixel for species identification from a survey altitude of 122 m (400 ft). This threshold was established during previous helicopter surveys and has since been validated with a species misclassification analysis (McClintock et al. 2015). This camera was mounted in a cylindrical payload bay with a maximum payload allowance of 7.5 lb. The camera payload was not fully integrated into the ScanEagle. It could be powered on and off from the GCS, but image trigger settings were manually set and initiated before flight. The payload bay window was covered with a thin plastic film to protect the camera. Images were geo-referenced and captured every 4 s. The images were stored on 16 GB cards, downloaded at the end of each flight, and later examined for the presence of seals. The third aircraft had the standard integrated electro-optical video camera mounted in the nose cone, which streamed video to the GCS in real time.

Authorization

We received permission to operate the ScanEagle in US-controlled airspace over the Bering Sea by acquiring a Certificate of Authorization (COA) from the FAA (Federal Aviation Administration 2007). This COA was the first granted by the FAA that allowed UAS flights beyond visual range. All UAS operations previously allowed by the FAA were restricted to 1 M from an observer. Though the COA application and approval process took approximately 2 months, we were in conversations with the FAA regarding our project for more than a year. Our requested airspace included the Bering Sea east of the Russian Exclusive Economic Zone with a 20 M buffer around all land and a 5 M buffer around

Fig. 2. The SkyHook recovery system is composed of a line suspended between the ship's crane and a lower boom. A clip at the end of either wing of the ScanEagle captures the line.

corridors for known commercial flight paths at altitudes below 914 m. Within that area, we requested permission to fly up to 50 M from the ship. The COA request was supported by an airspace study commissioned by University of Alaska, Fairbanks to demonstrate the low risk of encountering other aircraft in the proposed operational area. The final COA specified a more restricted airspace that included a buffer of 20 M from the Russian Exclusive Economic Zone and any inhabited land masses.

The UAS operational airspace extended to an altitude of 914 m and a radius of 5 M from the ship. When the aircraft was within 3 M of the ship, one certified observer was required to be on the deck of the ship looking for other aircraft in the area. When the UAS was between 3 and 5 M distant, two observers were required. The FAA also required us to notify specific air traffic control centers and file a NOTAM (Notice to Airmen) whenever we planned to fly. Independently, we developed a notification list that included the United States Coast Guard (USCG) and other research parties that may be operating in the area. These two groups were the most likely to be encountered at our planned flight altitude. The USCG conducts search and rescue operations at low altitude from ice-breaking vessels and it is possible for other researchers to be conducting long-range low-altitude surveys in the area. Parties on this list were notified prior to every UAS launch. Three commercial aircraft were observed during our UAS operations at an estimated altitude above 9000 m.

The ScanEagle aircraft did not carry a transponder and the ship was not equipped with an air radar system to help identify aircraft, so it was important to develop a system to quickly determine if we were sharing airspace with another aircraft. The system consisted of a grid overlay of our COA airspace providing unique cells (1° longitude by 1/2° latitude) and an Excel spreadsheet that could quickly identify an occupied cell by entering a lat/long position. A copy of this map was given to the pilot of a walrus survey planned for areas overlapping with our proposed flight zone and the USCG. If radio contact was made with a pilot in the area who did not have the map, we could use the system to identify their airspace from the GPS position reported during the radio call. Ultimately, the walrus survey never flew into the area identified by our COA, but if they or the USCG had, this system would have allowed for quick communication and separation of airspace. The officer on duty on the bridge of the ship and the UAS pilot in command at the GCS independently monitored aviation channel 121.5 and marine 16 for the duration of all UAS flights.

In addition to receiving a COA from the FAA, we were also required to obtain permission from NOAA's Office of Marine and Aviation Operations (OMAO) to launch a UAS from a NOAA vessel. This project marked the first integration of an aircraft system on a NOAA vessel. As such, the process took approximately one year to complete. The OMAO required a test flight in controlled airspace prior to our Bering Sea operations. We conducted preliminary test flights from the NOAA ship *Oscar Dyson* in October 2008 and two additional test flights on 4 May 2009, using the NOAA ship *McArthur II*. Both sets of tests used restricted airspace R-7601 at the Whidbey Island Naval Air Station (Admiralty Inlet in the Puget Sound, WA). These test flights also provided an opportunity for OMAO to establish flight operational procedures and training for the officers and crew, something that is not standard on NOAA vessels. Flight operation and emergency protocols were adopted from the United States Navy and the USCG and modified for NOAA ship UAS flight operations.

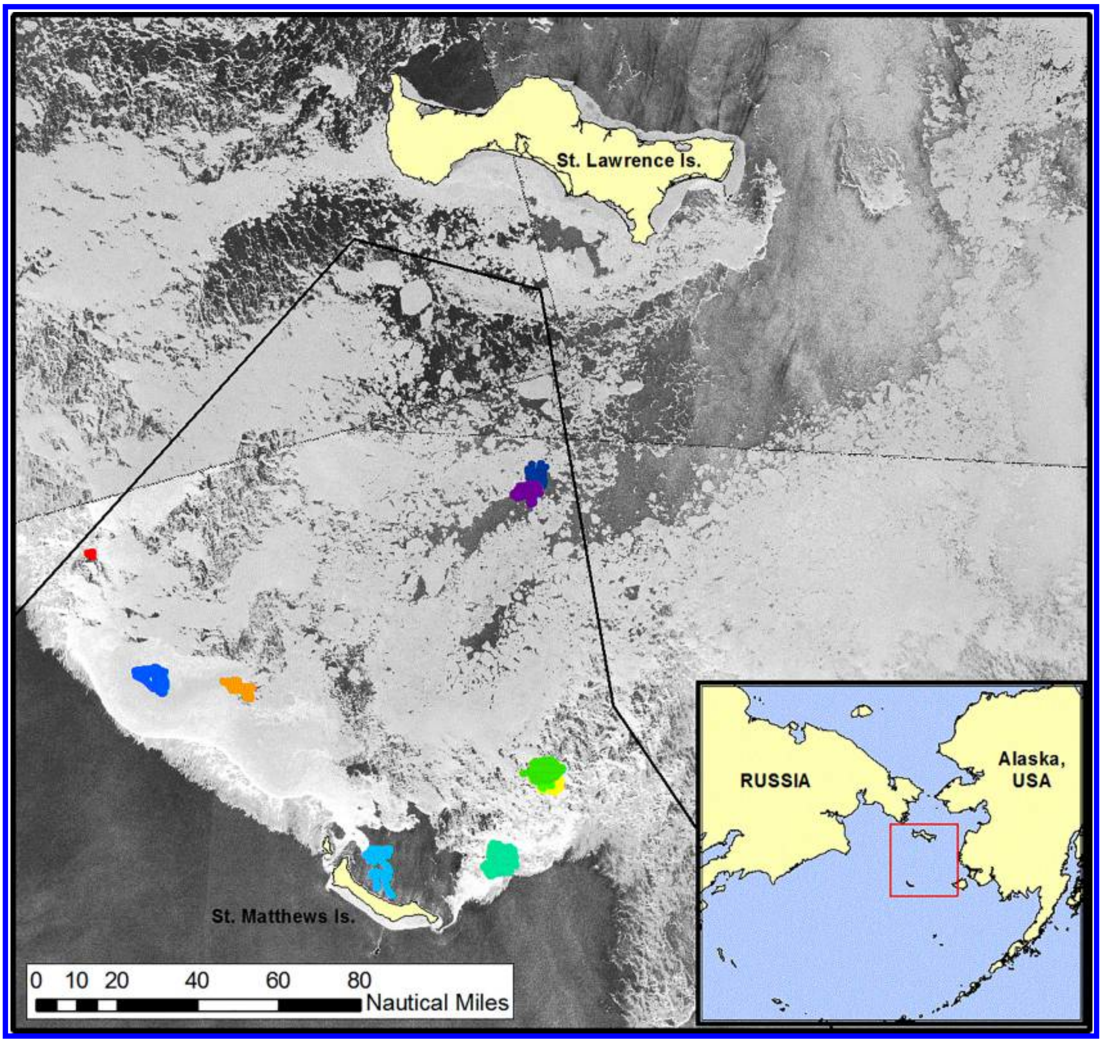
Bering Sea operations

A total of 10 UAS flights were conducted from the *McArthur II* at the Bering Sea ice edge between 21 May 2009 and 8 June 2009 (Fig. 3). Prior to each flight a safety brief was held with the captain, officer on duty, chief scientist, both pilots, and chief boatswain. The digital SLR camera payload (Nikon D300) was carried on eight flights and collected over 27 000 images of sea ice at predetermined altitudes of 90–200 m (300–650 ft) for image quality analysis. Some sample images demonstrate the quality of images acquired at altitudes of 91–122 m and the ability to identify species (Fig. 4). These images are of a lower quality for species identification due to the sheet of plastic covering the payload bay, and therefore not comparable to images collected during our previous helicopter surveys or our more current fixed-wing surveys, both of which were conducted without any protection between the cameras and the outside environment. Flight duration ranged from 24 min to 8.5 h and was limited by weather and camera card memory. The ScanEagle was recovered early on five of the 10 fights because of fog, snow, or rain. The camera card filled prior to capture on the longest flight. Total flight time over our target area was 17 h and 15 min.

Disturbance

To quantify the effect of a ScanEagle UAS survey on animal behavior compared to previous helicopter surveys conducted at similar altitudes, 50 images containing seals collected from the ScanEagle, and 50 images containing spotted and ribbon seals collected during helicopter surveys in the same area (Cameron and Boveng 2007) were evaluated. Potential disturbance was ranked using the following criteria: 0, no apparent response; 1, head up or foreflippers extended; 2, seal moving (alternating flippers, body shape); and 3, seal entering water. This scale provides a conservative estimate of disturbance, but cannot account for behaviors happening prior to or after image capture. Helicopter surveys were conducted from a Bell 206L Long Ranger III at a target altitude and air speed of 122 m (400 ft) and 95 kn. A Nikon D2X camera fitted with a 35 mm lens was mounted inside the helicopter, facing

Fig. 3. UAS flights conducted from the NOAA ship *McArthur II* in the Bering Sea during an ice seal research cruise in spring 2009. Colored lines represent tracks of each UAS flight within FAA approved airspace (black line) flown over sea ice (Radarsat image from 18 May 2009) Sea ice is seen as light grey.



downward, shooting through Plexiglas. Image quality prohibits reliable species identification though adult ribbon seals with distinct ribbon markings were identified in 32% of the helicopter images and 40% of the UAS images. Based on known species distributions, the timing and location of surveys, and our species misclassification rates (McClintock et al. 2015), unidentified pinnipeds are likely to be a mix of spotted seals and young ribbon seals. Selected helicopter images were collected south of St. Lawrence Island between 15 April 2007 and 20 May 2007. Both surveys took place during the time period ribbon and spotted seal pups were being nursed and maturing. Most images contained only one seal (41 and 47 of 50 images from helicopter and ScanEagle, respectively). For images containing more than one seal, the highest behavior code observed was recorded for this analysis.

Evaluation and conclusions

The ScanEagle performed well during the Bering Sea flight operations and was piloted and recovered in snow, fog, and light rain. Icing was observed on two flights. The nose-mounted video camera allowed the pilot to identify icing during the first Bering Sea flight and the aircraft was recovered immediately. On the second icing occasion, the engine was running rough during flight

Fig. 4. Images of Bering Sea ice seals: ((*a*) ribbon, and (*b*) spotted) taken from the ScanEagle UAS at altitudes of 91 and 122 m, respectively, during the *McArthur II* UAS ice seal cruise.

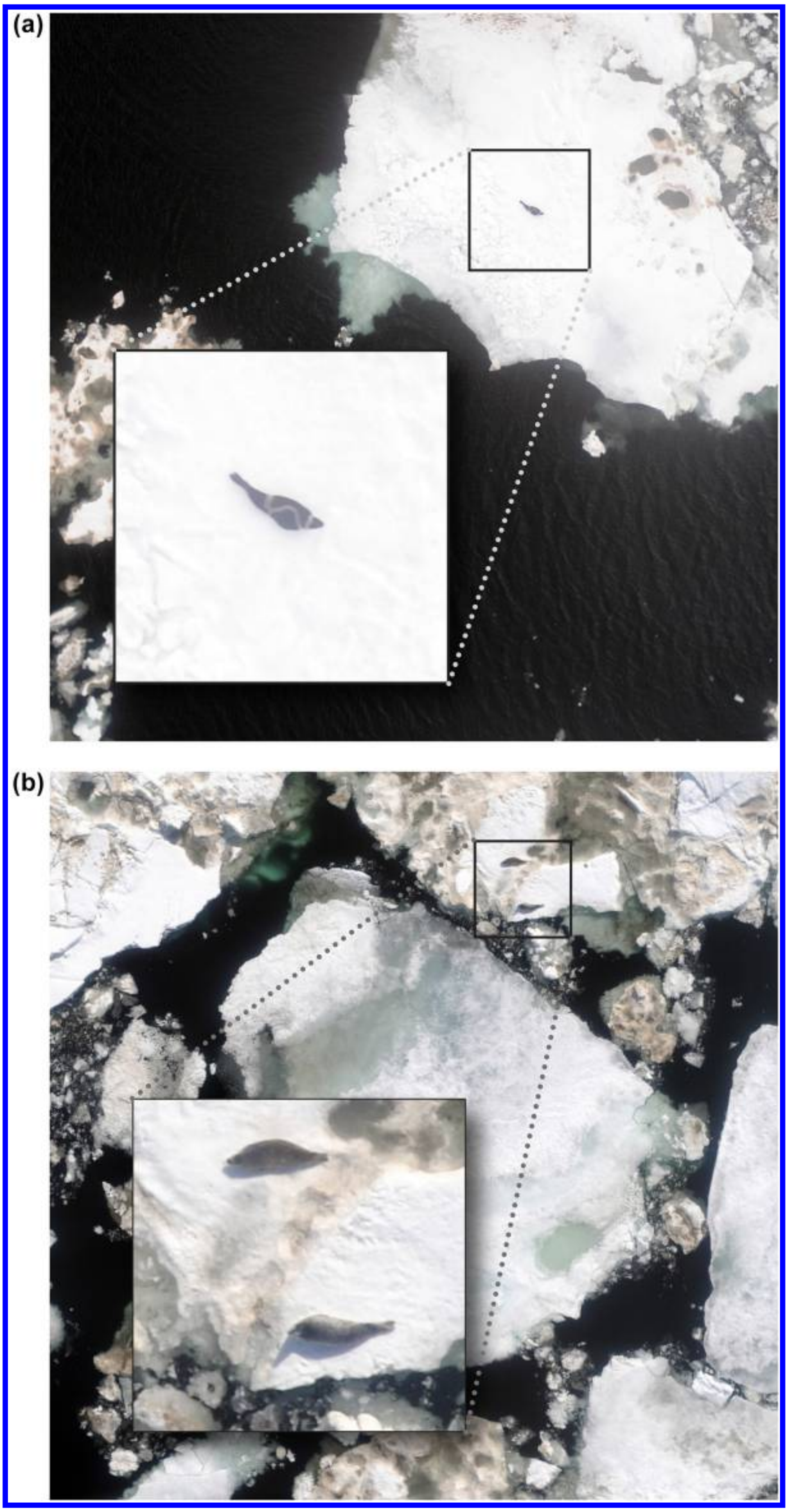


Table 1. Proportional disturbance levels as estimated from images of spotted and ribbon seals collected at the central Bering Sea ice edge by a Bell 206L Long Ranger III helicopter in 2007 and a ScanEagle UAS in 2009 (n = 50).

Level	Criteria	Helicopter	ScanEagle
0	No response	0.12	0.58
1	Head up or foreflippers extended	0.62	0.42
2	Moving	0.24	0.00
3	Entering water	0.02	0.00

but ice was not identified until after recovery. There was 1/16 in of ice on the leading edge of both winglets. Ice was also observed on the propeller. Because of the atmospheric conditions typical at the time of Bering Sea surveys, most flights will occur in icing conditions predicted by temperature and humidity sensors. Curry et al. (2004) implemented a number of solutions to arctic operations, which include insulating electronics, adding heating tubes, converting the engine to fuel-injection to avoid carburetor icing, adding an icing indicator sensor, and utilizing an anti-icing aircraft coating. An additional sensor to detect ice accumulation would provide important information to the pilot, but more permanent anti-icing and deicing solutions are required for long-range surveys in the arctic or subarctic.

Payload

Our initial payload review indicated a need to control the camera from the GCS to maximize the onboard storage system and aid image analysis by not collecting images prior to reaching the survey area or survey altitude. Continuous photography of a survey area for broadly distributed ice-associated seals results in hundreds of thousands of images, the vast majority of which do not contain seals but which must all be reviewed to ensure adequate seal detection rates. Due to the limits of onboard storage for this UAS and the processing demand of continuous photography, it would be much more efficient to collect imagery only while the aircraft is in the survey area of interest. We are currently developing an automated detection and image processing system that may be mounted in a UAS.

Airspace

Airspace regulations for UAS remain the most significant hindrance to large-scale Bering Sea survey efforts. Although we were able to fly beyond visual line of sight, we were still required by the FAA to visually scan for larger aircraft within a 5 M radius. In addition to the development and approval of sense-and-avoid technology, the FAA and their international counterpart agencies will likely need to establish rules of separation between various classes of UAS and other aircraft before UAS will be a full replacement for traditional, occupied aircraft for survey objectives such as ours.

Disturbance

Balancing data collection and disturbance of animals by survey aircraft is a difficult and important challenge for population biologists. This issue is magnified by increasing numbers of species that are being afforded legal protection due to concern about habitat loss from the disrupted, warming Arctic climate; the need for surveys is acute but they must be conducted without significant population impacts. Response to disturbance by the survey aircraft may also bias the data. Moving animals can hinder collecting accurate count data and complicate analyses, potentially overestimating abundance, if seals are photographed twice, or underestimating abundance if seals enter the water before being photographed. Our comparison of potential disturbance based on aerial imagery alone indicates a marked reduction in disturbance during UAS flights (Table 1). It is important to note that analysis of images obtained directly under the aircraft cannot detect animals moving away from the track line or diving prior to image capture. Anecdotally, seals have been observed diving ahead of an approaching helicopter and after it has passed, while researchers in small boats who observed our UAS flying over seals hauled out on ice floes reported no signs of disturbance, even for animals flown over repeatedly. The reduction in disturbance is a great improvement over low-altitude helicopter surveys.

Survey coverage and encounter rate

Traditional aerial surveys using line-transect observers or multiple cameras can cover more area per unit of track line than a UAS such as the ScanEagle with a single camera and smaller field-of-view. At an altitude of 122 m, the effective strip width of observer-based helicopter surveys conducted in 2007 was 350 m. At 122 m, with the Nikon D300 and 35 mm lens, the width of coverage in the 2009

UAS surveys was only 83.5 m. The UAS also travels at approximately half the speed of a helicopter, so it takes seven to eight times longer for the UAS to cover the same area as an occupied helicopter survey. This challenge may be offset, however, by the endurance and fuel efficiency of the ScanEagle. More recent fixed-wing, instrument-based surveys match the effective strip width of observer surveys using multiple cameras and can also fly at faster airspeeds. However, these surveys still have trouble reaching the most remote regions of the pack ice.

The reduced swath width also reduces the encounter rate for the target species. An effective strip width of 350 m provides an encounter rate of 0.22 seals/M of transect flown for all four species of ice-associated seals present in the Bering Sea (unpublished data). Using these data to estimate the encounter rate with the swath width of 83.5 m we can expect to photograph only 0.06 seals for every nautical mile of survey effort. This encounter rate would not provide adequate sample sizes for each species.

Full-scale arctic and subarctic operations are dependent on action from both government and industry partners to advance UAS regulations, anti-icing and de-icing solutions, as well as automated detection and processing software. Long-range UAS based from a research ship or from land would improve our coverage of the Bering Sea pack ice and would likely become a useful supplement to our current instrument-based, fixed-wing surveys for ice-associated seals where data are collected only by thermal and visible spectrum cameras (see Sigler et al. 2015 for details).

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