An inventory and evaluation of unmanned aerial systems for offshore surveys of marine mammals

W.R. KOSKI*, P. ABGRALL* AND S.B. YAZVENKO⁺

Contact email: bkoski@lgl.com

ABSTRACT

A literature review, internet searches and communications with personnel working with unmanned aerial systems (UAS) were used to identify the capabilities of UAS throughout the world. We assessed their ability to replace manned aerial surveys for marine mammals, sea turtles and seabirds and to monitor, in real time, sea ice and other physical features that might influence marine mammal distribution. The vast majority of the systems identified were either too expensive or their capabilities did not meet minimum standards necessary to perform the tasks required of them in real time. Eight systems were identified that might be able to perform some of the desired tasks. Several other systems had similar capabilities but had not been tested or would require upgrades. Installation of high-definition (HD) video and better stabilisation systems would improve UAS performance. It is recommended that development of HD video with real-time data transmission and improved stabilisation systems for UAS be pursued and that side-by-side comparisons of a few of the best systems be conducted.

KEY WORDS: INDEX OF ABUNDANCE; MONITORING; NOISE; SHORT-TERM CHANGE; SURVEY-AERIAL; VIDEO; UNMANNED AERIAL SYSTEM

INTRODUCTION

Dwindling oil and gas supplies and increased demand for existing reserves have prompted exploration and production (E&P) activities to expand into offshore areas that were considered inaccessible in the past. In many jurisdictions, concern about the potential impacts of these activities on marine resources, particularly marine mammals, sea turtles and seabirds, has created a requirement for E&P companies to assess and monitor marine resources to help minimise impacts of their activities on these resources. Because some species of marine mammals appear to react to the presence of E&P activities at distances that cannot be monitored from the platforms conducting the activities (Miller *et al.*, 1999; Richardson *et al.*, 1995), observations from other vessels or aircraft are sometimes required to document such behaviour. In these cases, accepted monitoring and mitigation methods cannot be used when vessels are too far offshore to safely conduct manned aerial flights, and some E&P activities face temporal and spatial restrictions. Thus, new tools and methods are urgently needed to effectively monitor marine resources in offshore areas so that activities can be conducted there without having adverse impacts on species of concern.

Marine mammals have been the main marine resource of concern because they tend to be more sensitive to sounds produced by offshore activities than sea turtles or seabirds. Currently, visual vessel-based marine mammal monitoring programs are conducted from most seismic vessels (and some other E&P platforms) used for offshore oil and gas exploration (Johnson *et al.*, 2007; Moulton *et al.*, 2006; Patterson *et al.*, 2007; Stone, 2003) and, more recently, academic geophysical research (Holst *et al.*, 2005). Observations have also been conducted from artificial islands where production facilities are present (Richardson, 2006). The focus of these monitoring programs has been to detect marine mammals that are close to the activity so that mitigation measures can be implemented to avoid adverse effects on them by such measures as reducing or ceasing activities when marine mammals are observed within project-specific safety distances. When the zone of responsiveness has been too large to monitor from a vessel, aerial survey programs have been conducted at sufficient distances ahead of the vessel to allow surveyors to modify the timing and locations of activities so that the activities do not impact those species, particularly sensitive components of the population such as mother-calf pairs (Yazvenko *et al.*, 2007a; 2007b). An alternative method of real-time monitoring marine mammal presence has been by the use of towed passive acoustic monitoring systems (PAM) to record or detect animal vocalisations. PAM can be used at night and during periods of bad weather. However, detection rates are often lower than with visual methods, locations of calling animals are often not precise enough to use for estimating density or to determine if animals are within defined safety radii of the activity and call detection range often is not sufficiently large to monitor safety radii around intense energy sources such as large airgun arrays. In addition, towed PAM arrays are not effective for species with low vocalization rates or near noisy activities that cause animals to cease or reduce calling. If the technology were verified, unmanned aerial systems (UAS) launched and recovered from a vessel may be able to provide unique platforms to monitor marine mammal distribution and abundance in areas where aircraft cannot safely operate. They may be able to survey a large enough area to monitor sound-based safety radii such as those required to be monitored by the US National Marine Fisheries Service (NMFS) for marine

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* *LGL Limited, environmental research associates, 22 Fisher St., P.O. Box 280, King City, Ontario, L7B 1A6, Canada.*
⁺ *LGL Limited, environmental research associates, 9768 Second Street, Sidney, British Columbia, V8L 3Y8, Canada.*

mammals around intense energy sources and, unlike manned aircraft, would not be restricted as to how far from land they could operate.

Selection of UAS that might be suitable for use in offshore areas is challenging because the technology is new and rapidly evolving, a large number of systems are available and few systems have been tested specifically in offshore areas. Today, about 45 countries fly more than 600 different UAS models; in the USA alone, there are approximately 280 companies, academic institutions, and government groups developing more than 200 different UAS designs ranging in price from $1,000 to $26 million (www.thirtythousandfeet.com/uav.htm).

Currently, surveys with manned aircraft are conducted in nearshore and offshore areas within ~200km of shore to obtain unbiased real-time estimates of animals present because the aerial survey platform does not influence the distribution or behaviour of the animals that are being counted. In far offshore areas, where aerial surveys are not conducted due to safety concerns, ship-based surveys are used to survey animals. It is known that many species of marine mammals and seabirds are either attracted to or avoid vessels (e.g. Barlow *et al.*, 2006; Würsig *et al.*, 1998), resulting in biased estimates of distribution and abundance. If UAS are found to be a suitable platform for conducting marine wildlife surveys, then unbiased estimates of their distribution and abundance in offshore areas could be obtained. These data can be used to assess and manage potential impacts of various types of activities on marine mammals.

UAS can also be used to collect environmental data that might influence marine mammal distributions. Sea ice affects marine mammal distribution and UAS can provide real-time information on ice and ice movements and other physical features of the offshore environment. In many situations these data could not be collected using methods such as satellite imagery because of cloud cover over the survey area or because resolution of the imagery does not provide sufficient detail. Even low-resolution imagery from UAS equipped with infrared sensors may be more effective than manned surveys to detect some marine mammals such as polar bears and walruses.

With all of the above uses in mind, the objectives of this study were to:

- compile UAS characteristics deemed important for monitoring marine animals and physical features such as ice, and compile research on UAS that might be applicable for their use in offshore areas and harsh environments;
- review and assess each UAS with respect to its cost, availability and technical characteristics;
- evaluate the ability of existing UAS and sensors to meet requirements for use in offshore areas and review studies that have tested this technology;
- identify areas of further technological development that would improve the ability of UAS to accurately detect, classify and track marine mammals, turtles and seabirds; and
- identify political or regulatory barriers (including patents) to advancing the state of knowledge and acceptance of the technology.

METHODS

Initially, a list of the range of capabilities of UAS and sensors was developed. Capabilities of UAS vary from model airplanes that are controlled by a joystick within a range of a few kilometres to high-altitude UAS used for military applications that have ranges of 1,000s of km and can fly at 15,000m above sea level. The information on the low-tech UAS, in particular, is voluminous, and setting boundaries on

Table 1

Criteria used to evaluate whether UAS are suitable as real-time data collection platforms for wildlife surveys.

Vehicle characteristic	Requirements
Size	UAS of all sizes were considered, but if range (<200km) or flight duration (<4h) would not permit launch and recovery from land, then vehicles needed to be small enough to be handled by 1–2 people aboard a vessel.
Cost	Aircraft needed to be <$250,000 because of risk of loss and the need for multiple aircraft for back-up or to house different sensors for different applications.
Payload capacity	A payload capacity of 2kg or more was deemed necessary to carry sensors and fuel.
Vehicle control	Both real-time flight control and pre-programmed flight control were considered, but real-time flight control to 50km is necessary.
Distance of operation from base	UAS needed to be able to fly >20km from launch location if launched and recovered from a vessel and >200km if launched and recovered from land. See also Vehicle control requirements.
Flight duration	Minimum flight duration was 1h if operated from a vessel or 4h if operated from land. For most applications, flight duration in the survey area needed to be >4–6h.
Operating capabilities	UAS need to be able to operate in remote areas, such as the Arctic, with minimum logistics support and during most conditions when manned aircraft could fly.
Speed	A minimum airspeed of 46km h^{-1} is needed to permit flying during moderate winds.
Fuel	Fuel or power for the UAS had to be readily available and non-hazardous. Gasoline was considered acceptable.
Launch/recovery requirements	The aircraft could be launched and recovered either from land or from a vessel, depending on flight duration (see Flight duration).
Sensor capabilities	A wide variety of sensors was considered to meet a wide variety of needs. These included, but were not limited to, sensors to detect marine mammals (visual, infrared, UV, night vision); map ice conditions; measure water temperature, ocean currents, chlorophyll, weather variables including wind speed and direction, air temperature, humidity and cloud cover.
Sensor size	Sensors as large as 20kg were evaluated, but to be useable on current UAS sensors needed to be no heavier than 2–5kg.
Video resolution	Video resolution needed to be 640 × 480 pixels or better.
Image stabilisation	Imagery needed to be stabilised to reduce motion/vibration and to allow clear imagery when scanning a large area.

the information that would be integrated into the evaluation was necessary. Based on prior experience with using UAS in marine mammal monitoring (Koski *et al.*, 2009; 2007; Lyons *et al.*, 2009), a set of criteria for evaluation of UAS was developed (Table 1). The most important criteria included the ability to launch and recover the aircraft from a mid-size vessel; flight endurance of at least 4 hours; payload capacity of 1.5–2kg to accommodate high-quality sensors; a broadband datalink which allows National Television System Committee (NTSC), Phase Alternating Line (PAL) or Advanced Television Systems (ATSC or HD) video to be streamed back to a control station; and reasonable cost.

Based on the criteria in Table 1, a list of UAS and sensors was prepared using various data sources, i.e. technical reports, internet searches, UAS newsletters and contacts with UAS suppliers or people who have conducted research on UAS and various types of sensors. Personal contacts with companies' representatives provided much useful information. In some cases, a system that was best suited for offshore surveys was in development or only recently available, and therefore would otherwise have been missed. Alternatively, some systems that seemed highly suitable were rejected based on the additional information obtained from these individuals or because they were no longer in production.

Studies were identified that have evaluated UAS and potentially useful sensors for use in marine wildlife surveys. Because of the relative scarcity of the published and grey literature, internet and personal communications turned out to be the main sources of information on the present status in this area. A variety of websites were browsed, including manufacturer's sites, the sites of various UAS associations, meetings and exhibitions; various blogs were included in the subsequent analysis and forums related to UAS.

Technical parameters for each UAS and sensor that met the criteria in Table 1 were tabulated. The requirements in Table 1 were intentionally set low so that marginal systems would be included with the hope that future upgrades would improve performance. The tabulated data also included an assessment of availability for civilian use, and contact names and numbers of suppliers. When tables were completed, each system was evaluated as being good, fair-good, fair or poor based on the criteria in Table 1. During the ranking, emphasis was placed on cost, control (remote or autonomous), flight duration, operating range, the requirements for real-time vs. delayed data collection and analysis, and the potential to train biologists to operate such a system. In the evaluation and ranking, we considered two markets separately because of political and military boundaries: North America, Europe, Israel and Asia vs Eastern block countries, which included Russia and the countries of the former Soviet Union.

Research and testing that have been done on UAS and sensors were also reviewed and considered during evaluation (see Results and Discussion).

Finally, areas were identified where further technological development would improve the ability of UAS to provide the data required including the ability to accurately detect, identify and track marine animals. The political, regulatory and patent barriers to advancing UAS technology were also identified.

RESULTS AND DISCUSSION

Of the 600 or so UAS that are advertised, in production or in development, about 400 were briefly evaluated. Of these, 162 UAS (aircraft or aircraft plus sensors) and 15 sensors were entered into an evaluation matrix and information on their capabilities was summarised from the various sources mentioned above. Only 12 UAS (7.4% of those evaluated in detail) were considered 'good' prospects for use as a real-time survey platform for marine mammals in offshore areas. Eight additional systems (4.9%) were considered 'fair to good'. The majority of the systems were considered fair or poor and would require significant improvements before they could be used (Table 2).

The eight most promising systems are discussed here, and a general discussion of capabilities and deficiencies in other systems is included in the next section.

Table 2

Summary of numbers of UAS and payloads evaluated in detail.

	Aircraft	Aircraft plus payloads	Payloads	Total
Good	7	5	3	15
Fair to good	4	4	–	8
Fair	30	12	7	49
Poor	36	21	1	58
Could not be evaluated	12	1	4	17
Not available	10	4	–	14
Too expensive*	13	3	–	16
Total	112	50	15	177

*These systems would be classified as good if they were affordable.

Top-rated UAS

Eight UAS were considered to be potentially appropriate for use as real-time survey platforms for marine mammals in offshore areas, two from eastern block countries and six from other regions of the world. None of these systems have been fully tested to establish their efficacy for detection of marine mammals or other tasks for which UAS might be used. Because most of these systems have not been tested, it is likely that some of these UAS would need improvements before they could be used for many applications. Some have not been tested in the Arctic, where cold and icing pose problems not encountered in other regions. The strengths and limitations of each of these systems are discussed below.

The **Insight A-20** (also called the ScanEagle; Insitu Group, Bingen, WA and Evergreen Helicopters, McMinnville, OR) is one of the top-rated UAS in the size and cost range considered practical and is one of only three UAS that have undergone or are undergoing systematic testing of their capabilities as a platform for surveying and observing marine mammals in real time. The other systems tested for use with marine mammals, the Warrigal 2 and the systems tested by the University of Rostock, did not make the list of top-rated UAS (see below). The Insight A-20 was included among the top-rated systems because of the testing that has been done during 2006–2009 and because it appears to meet or exceed the capabilities of the other top-rated systems. In particular, the Insight A-20 can be manually controlled and sensor data can be obtained in real time out to 150km from the control station (depending on flight altitude and antenna height at the base station). Pre-programmed routes can be flown beyond 150km. The long endurance of the Insight A-20 (>20h) facilitates efficient surveying of large areas and minimises the number of launches and recoveries. It is small enough to be easily handled on a vessel (3.1m wingspan) and has an efficient launch and recovery system that can be deployed from an offshore platform or a vessel. It has a sophisticated ground control station (GCS) that provides real-time display and processing of imagery and storage of all data collected. The current video system (NTSC) appears to cover an area approximately the same as a single observer in a manned aircraft and with similar detection probabilities (Koski *et al.*, 2009). If a high definition (HD) video system were installed, it would allow coverage of a larger survey area than was possible during the tests conducted by Koski *et al.* (2009). It is likely that a HD video system would make the Insight, and other systems listed below, suitable for surveying birds and most species of marine mammals (see Discussion on HD video below).

The **Manta B**, which is a larger version of the Silver Fox (Advanced Ceramics Research, Inc., Tucson, AZ), is slightly smaller (2.7m wingspan) and less expensive than the Insight A-20, but has fewer capabilities. Its ability to operate in the Arctic has been proven during research in Greenland. However, currently it cannot meet the 'distance under control' requirements for many offshore marine mammal surveys (control to only 37km), and its endurance of >6h is marginal for large scale aerial surveys since it can be launched, but not recovered, from a vessel. A marine recovery system (in a net) is currently being developed and tested, which would improve its usefulness. The Manta B or Silver Fox could be used to conduct marine mammal surveys in nearshore areas or in offshore areas once the marine recovery system is verified.

The **Arcturus T-16 XL** (Arcturus UAC, Rohnert Park, CA) meets most of the performance criteria for use in offshore areas. It has a 24h flight duration and it can be launched and recovered (in a net) from a vessel. It is slightly larger (3.9m wingspan) than the Insight and Manta B, which would make it slightly more difficult to handle on a vessel. It is less expensive than either the Insight or the Manta B. The major flaws of the Arcturus T-16 XL are the small range under control (16–24km) and the fact that it has not been tested in Arctic conditions. In particular, extending the range under control would markedly increase the value of this system for offshore marine mammal surveys. In its current condition, it could potentially be used to conduct surveys which do not require acquisition of real-time data.

The **CryoWing** (Norut Northern Research Institute, Tromsø, Norway) is one of the UAS that could be used for collection of real-time data on marine mammals in offshore areas. It is relatively inexpensive (€30,000 for the aircraft) but among the larger UAS (3.8m wingspan) that could be deployed from a vessel. CryoWing has been specifically designed by a Norwegian team of scientists to operate in the Arctic and has been tested there. It has flight endurance of up to 20h at speeds of up to 160km h^{-1} and it can be manually controlled out to >70km from the control station. Pre-programmed routes can be flown beyond 300km. The current video system is PAL, which has slightly higher resolution than NTSC but is of similar clarity because of a slower refresh rate. Datalink options include 3G GSM (up to 1Mbit), and up to 7Mbit dedicated radiolink, which might permit use of HD video, but HD video has not been investigated or tested. The main weakness of the CryoWing is that it is not recoverable on a vessel (it is launched by a catapult that could be used on a vessel but it lands on its belly), so it would need to be recovered from land. Its long flight duration and the ability to pass control from one control station to another or pre-program the landing at the end of the flight makes this feasible. In this situation the UAS would become separated from the vessel after the first flight. As an alternative, it could be launched and recovered from land, but this is not practical if operations are far from shore. It is a light system (30kg) but has a relatively large wingspan (3.8m), which would make it slightly more difficult to handle than some of the smaller aircraft if vessel launch and recovery were implemented.

The **Elbit Skylark II LE** (Elbit Systems Ltd, Haifa, Israel) is a system recently developed by one of the world leaders in the UAS industry. The cost of the system was not given by the supplier who did not respond to our request for information. It appears to be one of the more advanced systems but has not been tested in the Arctic. It can carry 9kg of payload, has flight endurance of up to 17h at speeds of up to 74km h^{-1}, and can be manually controlled out to 50km from the GCS. The payloads of Skylark II are among the most sophisticated in its class; a gimballed and stabilised triple-sensor payload (Micro-CoMPASS) includes a colour CCD daylight camera, 3rd generation thermal-imaging night camera and a laser illuminator. Skylark II LE is not currently recoverable on a vessel, but a vessel-based launch and recovery system is undergoing sea trials. Considering the pace of its evolution, Skylark II LE is one of the systems to watch in the next 1–2 years. Elbit has been successful in obtaining recent military contracts, suggesting that it is one of the best UAS that are available. Their failure to respond to our requests, however, suggests that they may be too busy to be responsive to requests from non-military users.

The **Fulmar** (Aerovision Vehículos Aeros, S.L. San Sebastian, Spain) is one of the top rated UAS in the size and cost range (€20,000 for one fully equipped aircraft) considered for use as a platform to conduct real-time surveys of marine mammals. Fulmar has been specifically designed by a Spanish team of scientists to operate at sea, and its capabilities appear to meet most requirements for offshore use. In particular, it can be launched and recovered from a vessel into a net or by descending and sea-landing on a pneumatic skate. It is waterproof, and a satellite radio beacon is incorporated into the aircraft for recovery. Fulmar has flight endurance of up to 8h at speeds of up to 150km h^{-1}, it can be manually controlled out to 100km from the GCS and pre-programmed routes can be flown farther. The data link with the control station at 900 Mhz is out to 100km at 128kbps but the real-time video link at 2.4 Ghz has a maximum range of 50km. It is a light system (19kg) with a medium wingspan (3.1m) and can carry 8kg of payload including fuel.

The **ZALA 421-16** (A-Level Aerosystems, Izhevsk, Russia) is the top rated UAS for the Russia/FSU market. It has a 1.6m wingspan and the cost is €200,000 for two aircraft and a GCS. It is a newly released system (2009) and so is untested. Projects involving ZALA 421-16 on behalf of Rosneft, a Russian oil company, were conducted in offshore Arctic waters during summer 2010. Gazprom, a Russian natural gas company, has contracted the ZALA 421-16 and other A-Level aircraft to monitor its network of onshore pipelines in the Arctic and elsewhere; and the State fisheries committee is considering the ZALA for missions to search for illegal fishing boats offshore of the Kamchatka Peninsula. The ZALA 421-16 appears to meet most baseline requirements for use in offshore cold-water environments. It has flight endurance of 5–7h with speeds of 80–120km h^{-1} (marginal for some needs), can be deployed and retrieved from a vessel, can transmit real-time video to a GCS at distances up to 50km and can be manually controlled out to >70km from the GCS. Pre-programmed routes can be flown beyond 200km. As with the CryoWing, the communications bandwidth can be increased to 7 Mbits (possibly to 20 Mbits), which might make real-time transmission of HD video or medium-resolution (12 megapixel) still images possible.

The **R-100 Marine** (UAVia Pte Ltd, Kiev, Ukraine) can be launched and recovered from a vessel, is small (1.8m wingspan) and can be controlled up to 100km from the GCS. The current version has only 4h endurance (battery powered) but a 10h version (gasoline powered) is being developed. As with most eastern block systems, the R-100 Marine appears to be costly ($1.0M for 3 aircraft and GCS) and it has not been tested for surveys of marine mammals.

Other UAS

There are several other systems that are available or under development or that might become suitable for use for offshore surveys of marine mammals as systems are upgraded. These include the Aerosonde MK-4 and Shadow (Aerosonde Pty Ltd, Notting Hill, VIC, Australia and AAI Corp, Hunt Valley, MD), V-Bat (MLB Co., Mountain View, CA), Warrigal 2 (V-TOL Aerospace Pty Ltd, Brisbane, Queensland, Australia), Resolution (Airborne Technologies, Inc, Wasilla, AK), Skyblade IV (Singapore Technologies Aerospace, Paya Lebar, Singapore), Aerostar and Orbiter 3 (Aeronautics Defence Systems Ltd, Yavne, Isreal) and the S4 Ehécatl (Hydra Technologies, Zapopan, Mexico).

There are several large and sophisticated UAS used for military applications that exceeded the requirements of a system for use during offshore wildlife surveys. However, the cost of operating these systems would be prohibitive, which eliminated them from consideration. In addition, many of these systems are classified and are available only for military use. As the technology advances, and more research and development are done, some of the features in these large, sophisticated systems may become available to the smaller, more practical systems.

A review such as this relies on information provided by vendors and manufacturers. Thus, no actual tests or side-by-side comparisons of systems were made. Based on our experience working with several different UAS, the most common deficiencies have been poor image quality (primarily due to lack of image stabilisation), low or marginal flight duration and the lack of the ability to launch and recover the UAS from a vessel or offshore platform (Table 3). Because these deficiencies have been overcome in some systems, future generations of many of the UAS examined may address these deficiencies. In many cases, systems have not addressed these deficiencies because the

Table 3

Improvements needed for UAS systems to be useful to researchers working in offshore waters.

Limitation	Description of problem	Can this be improved?
Video resolution	The resolution of current systems does not permit monitoring of large areas because the pixel size or resolution is not high enough.	Yes, higher resolution video cameras are available and being tested by some providers. A study with HD video showed it to be as good as manned surveys for estimating densities and identification of birds (Mellor and Maher, 2008). Digital SLR cameras can be used if real-time data collection is not required.
Image quality	Movement and vibration degrade image quality.	Yes, in three ways. The more sophisticated UAS have built in image stabilisation systems and some high end cameras have image stabilisation built into the lens or camera body. In addition, post processing of the imagery can produce a clearer image. That is available in real time for some systems.
Real-time data transition rates	Real-time data transmission rates are limited which prevents use of higher resolution sensors in real time.	Yes, the technology exists for the military.
Limited range with real-time control of UAS	Some applications require real-time acquisition of data.	Better and higher antennas will increase range of control. Satellite linked data transmission is possible at increased cost.
Simultaneous use of multiple sensors	Smaller UAS can only support one sensor at a time because of payload limitations.	Sensors continuously get smaller and some of the larger models can hold multiple sensors. This can also be solved by flying two aircraft, each with a different sensor, at the same time.
Weather-proofing of systems	The ditching of a UAS into sea-water would damage the electronics and, in some cases, possibly the aircraft itself.	Yes, a few systems are designed for offshore operations. Waterproof casings can be designed for almost any system (or system components) and make them operational in offshore environments.
Icing	Systems can be prone to icing in certain arctic conditions.	Systems can be designed to better monitor this risk and reduce the likelihood of icing. Heat can be provided to key locations on the aircraft to reduce or prevent icing.
Launch and recovery limitations	Some systems that are otherwise suitable cannot be launched and recovered at sea	Yes, the smaller aircraft could be captured in nets or on a wire like the Insight™.
Cost	Many systems are too expensive.	Costs will come down substantially when these systems are used for commercial purposes. Current use is by the military and few units have been sold in comparison to the potential civilian market.

market for such systems had not been identified before we contacted the system marketers.

Studies on UAS

To date, few studies have been conducted with UAS either in offshore Arctic regions or for surveys of marine mammals. Six studies were identified that focused on marine mammals. The first was conducted in 2002 by the Office of Naval Research using the Silver Fox and the technology has advanced substantially since that test, so the findings are outdated. Even at that time, the researchers were able to detect and identify humpback whales (NOAA, 2006).

A 2006 study by Shell was the first systematic test of the ability of a UAS to detect objects of interest in a marine environment (Buck *et al.*, 2007; Ireland *et al.*, 2007; Koski *et al.*, 2009; 2007). The surveys were flown in winter conditions in Washington State (they included freezing rain, fog and high winds), which are similar to conditions that would be encountered in the Arctic during the late summer and autumn. Kayaks were used to simulate the dorsal surfaces of whales at the surface that would be available to be seen by marine mammal observers (MMOs) during manned aerial surveys. The kayaks were placed randomly in the search area and the MMOs, who were blind to kayak locations, used a systematic grid to search for them using an Insight A-20. Detection rates varied with sea conditions (greatest influence), kayak colour and kayak inflation, but detection rates with search swaths up to 600m were similar to those reported in the published literature for manned aerial or vessel-based surveys (Koski *et al.*, 2009). The authors concluded that the system tested (Insight A-20) was suitable for surveys of large cetaceans or large groups of small cetaceans, but noted that the search swath was narrower than that covered by a manned aircraft. The narrower search area could be compensated for by the longer flight duration of the UAS and by flying during periods with ceilings <300m when manned aircraft are not permitted to fly because they could disturb marine mammals.

A follow-up 2008 study by Shell and ConocoPhillips (Lyons *et al.*, 2009) showed that the Insight A-20 could be operated successfully in offshore Arctic waters. It was flown for 32h over a 10-day period, and several cetaceans and pinnipeds were sighted and captured on video. The 2008 study was constrained by US Federal Aviation Administration (FAA) requirements to remain within one nautical mile of the vessel and requirements for a cloud ceiling of at least 300m before the UAS could be flown. This prevented a useful evaluation of the efficiency of the UAS in comparison to surveys by manned aircraft.

From mid-May to mid-June 2009, the National Marine Fisheries Service (NMFS) conducted a series of tests in the Bering Sea with a ScanEagle launched from the NOAA research vessel *McArthur II.* The ScanEagle was fitted with a downward-facing digital SLR camera to identify and estimate densities of seals occupying pack-ice habitat in the Bering Sea (Cameron *et al.*, 2009). Although the tests were constrained by FAA operating requirements, the study confirmed the abilities of a UAS to operate in a variety of sub-arctic weather conditions and to obtain imagery of sufficient quality to distinguish the different species, ages, and occasionally, even the gender of ice-associated seals.

Two additional studies are underway to investigate the use of UAS for surveying marine mammals. One is at the University of Queensland, Australia, (Monaghan, 2008) and the other is at the University of Rostock, Germany (Grenzdörffer, 2008). Both studies are ongoing and results are pending.

Memorial University, Canada, and Provincial Aerospace Limited are testing an Aerosonde MK-4 for the potential monitoring of illegal fishing and pollution in the North Atlantic off Newfoundland and Labrador. This study is ongoing and results are not available yet. Of more importance to the present review, this group is also working on the development of an autonomous collision avoidance system for small UAS. As noted in the next section, development of such a device is important to permitting considerations for use of UAS in many areas.

NOAA and Airborne Technologies are testing the Resolution (one of the UAS listed in the ‘Other UAS’ section) for detection of abandoned fishing gear. An interesting finding by Churnside *et al.* (2009) during these tests was that an infrared sensor could detect whale tracks in temperate areas by thermal disturbance at the water surface. During earlier tests in the Arctic, however, biologists were unable to locate bowhead whales or their tracks with infrared sensors even though the whales could be seen in imagery collected using low resolution colour video (W. Koski, unpubl. data).

University of Colorado scientists used the Aerosonde MK-3 to study ice roughness and surface temperatures and they identified and implemented modifications to the UAS to permit flying in the Arctic (Curry *et al.*, 2005). The modifications suggested during these early UAS studies have resulted in increased safety and efficiency of UAS operations in the Arctic.

A study of the test of a Cineplex gyroscopically stabilised high-definition (HD) (1080 × 1920) colour video has been included in the review because HD video is being modified for use in some of the UAS reviewed. Mellor and Maher (2008) tested this system in a small fixed-wing aircraft flying at 600m above sea level with a 30–40m surface coverage. The objective of the test was to determine if the HD video in a fixed-wing aircraft was suitable for obtaining information on species, distribution and abundance of seabirds near offshore wind farms. The target species included alcids (Alcidae), common scoters (*Melanitta nigra*) and cormorants (*Phalacrocorax* spp.), which are dark-coloured birds that are difficult to detect and identify during manned aerial surveys. The smaller of these species are approximately 35cm long when swimming on the water. The study concluded that the target species could be detected and identified easily in the imagery that was obtained, and that birds were less likely to be disturbed than during lower-level manned surveys.

Problems with UAS use

There are many problems involved in using UAS to replace manned aerial surveys. These include acceptance of the technology by regulatory bodies that issue permits, responsiveness by UAS providers, export restrictions on UAS and aviation-related restrictions on flying UAS in many jurisdictions. However, the main problem with their use for conducting marine mammal surveys is that they have not been systematically tested and data collected from UAS have not been compared with those from manned aerial and ship-based surveys.

Benefits of using UAS

UAS with video streams or digital still cameras would have many advantages over manned aerial surveys. When still photography is used, there is constant detectability across the search swath, or if there is reduced detectability near the edges, it can be quantified through analysis of the imagery. The lateral distances from the trackline can be measured rather than estimated and would be more precise. Group sizes can be counted more accurately and the relative sizes of animals (adults vs subadults vs calves) can be determined from the film, resulting in collection of more information than is collected during most manned aerial surveys. Also, all data can be reviewed by more than one observer permitting estimation of counting and detection errors, which tend to be much lower during analysis of photographs than during manned aerial surveys (Heide-Jørgensen, 2004). The ability to review imagery eliminates the need to conduct double platform or independent observer experiments to quantify detection bias.

Another benefit of still and video imagery is that an estimation of the surfacing time of whales can be obtained by analysing sequential images as was done by Heide-Jørgensen *et al.* (2009). This alleviates the need for other studies to obtain estimates of availability bias. As a result of the ability to review imagery, Ferguson and Angliss (2010) note that a more precise estimate of group density might be obtained from UAS surveys than manned aerial surveys (using conventional distance sampling methodology and assuming the UAS platform allows for accurate species identification) because UAS data may be able to better account for or eliminate detection biases.

A potentially large benefit to users of UAS over manned aerial surveys or observers on vessels is that data streams from UAS can be transmitted in real time from the GCS, where data are received from the UAS, to all parts of the world through the internet. Some systems like the Insight A-20 and CryoWing have used this capability for some studies, and although not demonstrated for many systems, it is a relatively simple process to implement, provided that high speed internet access is available at the GCS. By using this capability, groups conducting offshore surveys could minimise the numbers of people on vessels in offshore areas and do some data processing in the office in real time. Because bunk space is usually limited during offshore activities, and it is safer and more cost-effective to have personnel working in the office rather than the field, this would provide significant cost and safety benefits to the users.

CONCLUSIONS

Many of the UAS investigated during this study would be suitable for collecting data on marine mammals and their habitats (i.e. ice cover and oceanic fronts), but only a small fraction of them may be useful for replacing manned aerial surveys. Those UAS that might be suitable have sensors with sufficient resolution to conduct surveys of large cetaceans or of large groups of small cetaceans, but the search area is smaller than that covered by a manned aircraft and the survey speed is slower; thus, a ~3–4h survey by a single UAS would be needed to obtain similar coverage as a 1h survey by two MMOs in a single manned aircraft. However, estimates from UAS may be more precise because they eliminate or can better correct for perception bias (Ferguson and Angliss, 2010). Given that some UAS can survey for up to 24h without refuelling, whereas manned aircraft cannot survey more than ~3–6h, and that UAS can fly at lower altitudes without disturbing animals, a UAS may be able to obtain the coverage needed to replace manned aerial surveys. In some situations, UAS might obtain coverage when a manned aircraft could not survey because of low cloud in the survey area or at the aircraft base.

The highest HD video currently available provides 6.75 times the number of pixels in a frame than does NTSC video; as a result, it could cover an area three times wider than NTSC video with the same resolution. Introduction of stabilised HD video into a UAS probably would provide imagery that would be as good, or better, than data collected during manned aerial surveys. As demonstrated during the Mellor and Maher (2008) study, in some cases HD video could provide better data than manned surveys because species identification from the video may be better than that possible during manned aerial surveys. In part, this is because of the ability to review characteristics of a sighting from the digital record, which cannot be done during real-time manned aerial surveys. Thus we would recommend that development of HD-video capture and transmission be encouraged. HD video may be the break through that would permit use of UAS for surveys of birds and small marine mammals in offshore areas.

Image stabilisation is another limiting factor in the use of UAS for wildlife surveys. UAS are small and unstable platforms for capturing visual data. Development of better stabilisation systems for sensors would increase the quality of imagery and permit more efficient surveying.

See-and-avoid systems should be developed for UAS. One of the major road blocks to using UAS in most jurisdictions is the lack of a see-and-avoid system that would prevent a UAS from colliding with an aircraft.

This study evaluated the ability of UAS to collect real-time data and that requirement eliminated from consideration many platforms that can collect data on board the UAS for later analysis. Digital still cameras provide higher resolution than video cameras, allowing coverage of a larger area and/or identification and counting of smaller species of marine mammals than can be conducted using video. UAS are therefore ideal platforms to use for high-resolution photographic surveys, particularly in nearshore areas such as the fjords in Greenland (Heide-Jørgensen, 2004) or nearshore areas in Canada (Richard *et al.*, 1994; Stenson *et al.*, 2002) where photographic surveys have been used to estimate numbers of narwhals (*Monodon monoceros*) and harp seals (*Pagophilus groenlandicus*).

In summary, several UAS are available that would be suitable for monitoring offshore ice conditions, oceanographic fronts, wave height and some other physical features of the offshore environment, but more testing is needed before UAS can be used as replacements for manned aerial surveys of marine mammals and birds. Side-by-side testing should be conducted using the most promising systems, and high-resolution digital still photography should be tested for counting marine mammals at haul-out sites and for estimating densities of marine mammals in offshore areas. Development of better image stabilisation systems and implementation of higher-resolution video is recommended to improve the capabilities of current UAS.

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