

Assessing use of and reaction to unmanned aerial systems in gray and harbor seals during breeding and molt in the UK¹

P. Pomeroy, L. O'Connor, and P. Davies

Abstract: Wildlife biology applications of unmanned aerial systems (UAS) are extensive. Survey, identification, and measurement using UAS equipped with appropriate sensors can now be added to the suite of techniques available for monitoring animals – here we detail our experiences in using UAS to obtain detailed information from groups of seals, which can be difficult to observe from land. Trial flights to survey gray and harbor seals using a range of different platforms and imaging systems have been carried out with varying success at a number of sites in Scotland over the last two years. The best performing UAS system was determined by site, field situation, and the data required. Our systems routinely allow relative abundance, species, age-class, and individual identity to be obtained from images currently, with measures of body size also obtainable but open to refinement. However, the impacts of UAS on target species can also be variable and should be monitored closely. We found variable responses to UAS flights, possibly related to the animals' experience of previous disturbance.

Key words: UAS, wildlife, seals, photo-ID, photogrammetry, behaviour.

Résumé : L'utilisation des systèmes aériens sans pilote (UAS) en biologie faunique ne cesse d'augmenter. Les levés, l'identification et les mesures utilisant les UAS munis de capteurs appropriés font maintenant partie de l'ensemble des techniques disponibles pour surveiller les animaux - ici, nous exposons en détail nos expériences d'utilisation des UAS pour obtenir des informations détaillées sur des groupes de phoques, qui peuvent être difficiles à observer à partir de la terre. Des vols d'essais pour faire le levé des phoques gris et communs utilisant une gamme de plateformes et de systèmes d'imagerie ont été réalisés avec un niveau de succès varié à un nombre de sites en Écosse au cours de deux dernières années. On a déterminé l'UAS le plus performant selon le site, la situation sur le terrain et les données requises. Nos systèmes permettent de couramment obtenir l'abondance relative, les espèces, la classe d'âge et l'identité particulière à partir d'images, y compris les mesures de la masse corporelle mais pouvant être perfectionnées. Cependant, les effets des UAS sur les espèces cibles peuvent varier et doivent être surveillés de près. Nous avons trouvé des réactions variées aux vols d'UAS, probablement lié à l'expérience des animaux suite à des perturbations antérieures.

Mots-clés : système aérien sans pilote (UAS), faune, phoques, photo-identificateur, photogrammétrie, comportement.

Received 27 February 2014. Accepted 8 June 2015.

P. Pomeroy and L. O'Connor. Sea Mammal Research Unit, School of Biology, University of St Andrews, St. Andrews, Fife KY16 8LB, UK.

P. Davies. Horizon AP, East Lilburn Farm, Alnwick, Northumberland NE66 4ED, UK.

Corresponding author: P. Pomeroy (e-mail: pp6@st-andrews.ac.uk).

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

This article is open access. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0) http://creativecommons.org/licenses/by/4.0/deed.en_GB.

Introduction

Biologists and ecologists have been quick to appreciate the data-gathering opportunities that remote small unmanned aerial survey systems offer, particularly as functionality and availability improve (e.g., Jones et al. 2006; Anderson and Gaston 2013; Goebel et al. 2015). One of the most attractive aspects of a functional unmanned aerial system (UAS) is the ability to obtain information that is otherwise simply not possible or prohibitively expensive using traditional methods (Koh and Wich 2012; Watts et al. 2012; Hodgson et al. 2013). Established manned aerial census methods continue to provide counts of animals as a fundamental requirement for providing population-scale estimates of abundance and annual production, but their use includes considerations of risk to personnel, financial cost, and limitations of information gained. UAS capabilities are now diverse enough to allow researchers to tailor systems to specific data acquisition tasks, with much finer resolution, for example, to distinguish different age, sex, and size classes or where possible, individuals. Remote measurement, condition assessment, and more sophisticated imaging is also possible.

The Sea Mammal Research Unit (SMRU) meets statutory obligations to provide advice to UK and Scottish governments on seal populations. Seal population trajectories are assessed using (manned) synoptic aerial surveys of seals at breeding for gray seals and molt for harbor seals to provide data to inform population models (Lonergan et al. 2007; SCOS 2013). In parallel, individual-based studies of life history provide estimates of vital rates for the population models (Smout et al. 2011; Cordes and Thompson 2014). Collecting life history information for population parameters requires long-term detailed information on individuals, currently provided by direct observations on animals known from flipper tagging, but also using photo-ID of natural pelage patterns (Hiby et al. 2013). Physical capture of animals is limited and comparatively costly; indirect observations potentially offer wider and cheaper coverage. Tools that allow greater access to seals, whether on difficult-to-reach parts of breeding colonies or haulouts, offer new, cheaper, powerful insights into animal distribution, site use, and demography.

From 2012 we investigated UAS for local, small-scale applications when seals were on or near shore, around seal breeding colonies and haulouts. The main aims of these trials were to determine utility of systems available, particularly in determining counts, group composition, and images of sufficient clarity for photoID, as well as obtaining data on the responses of animals to these novel stimuli.

Use of UAS systems “for gain” are controlled by UK legislation and limited according to the weight of the aircraft. Here we restrict work to the category with least stringent controls: aircraft under 20 kg. UK legislation places limits on the operational envelope of such craft. We tested equipment at familiar sites used by seals, restricted by the Civil Aviation Authority (CAA) operational limits, to assess:

1. technical suitability of available platforms for seal work;
2. whether image quality at operational ranges is fit for photo-ID and measurement; and
3. animal reaction to aerial platforms.

Materials and methods

UAS platforms

UAS were assessed initially from manufacturer’s specifications, or custom-specified and discussed with manufacturers. Those chosen for further evaluation were assessed directly for flight performance and image acquisition characteristics before deployment in the field for animal work. We concentrated on electric motor rotary wing UAS only, to minimize noise from the aircraft and allow a closely targeted survey of particular areas or groups of animals, including the hover capability (vehicles and cameras used are listed in Appendix A).

The nature of the seal survey work that we wanted to perform (identification to species, age class, and if possible for photo-ID and measurement) predetermined some of the UAS system requirements. Initial trials used a DJI450 quadcopter to assess animal reactions and trial basic imaging techniques. Subsequently, basic platform requirements were: minimum of 10 min flight time with imaging payload; steady and stable imaging platform (flight controllers with good GPS position hold in hover); ability to fly and hold station in winds up to 15 mph; on-board telemetry systems to provide real-time monitoring of battery voltage, height above ground, distance from origin, flight time elapsed, and camera status. Telemetry information was displayed on a video screen in a ground station comprising receivers, video screen, and batteries, housed in rugged waterproof cases (Pelicase).

We used a two-person flight team. One acted as pilot, in charge of the mission and controlling the positioning of the UAS. In most configurations we employed a live first-person view (FPV) video feed from a small video camera (GoPro III or equivalent), fixed to look forward and slightly down, on the

Table 1. UAS trial flights near seal haulouts in the UK reported here.

Location	Dates	UAS	Species, stage	Flight missions
North Rona, Outer Hebrides	Oct. 2012	DJI 450	Gray seal, breeding	1*
North Rona, Outer Hebrides	Oct. 2013	Cinestar 6	Gray seal, breeding	5
Abertay Sands, Tayside	Jan. 2013 – Jul. 2014	Cinestar 6	Gray seal, molting	23 [†]
Abertay Sands, Tayside	Jan. 2015 – present	Vulcan 8	Gray seal, post-molt	4
Isle of May, Firth of Forth	Nov. 2012	DJI 450	Gray seal, breeding	5
Isle of May, Firth of Forth	Nov. 2014	Vulcan 8	Gray seal, breeding	21
Loch Fleet, Sutherland	May 2014	Cinestar 6	Harbor seal, pre-breeding	1
Loch Fleet, Sutherland	Jul. 2014	Skyjib 8	Harbor seal, breeding	3

*Incomplete flight.

[†]Three flights were incomplete tests of seal behaviour.

UAS. This assisted the pilot in positioning the UAS relative to the target animals. Our preferred set-up for most applications was not to fix the main imaging camera in position (for example, looking vertically down from above). We determined quickly that a better solution was to have a camera mounted on a separately controllable gimbal. This allowed the second member of the flight team, the camera operator, to move the gimbal independently of the aircraft to obtain suitable images (e.g., oblique images of seals from above for pelage identification). Therefore an additional critical element for the imaging system was a first-person view feed from the main imaging camera to a second video screen, showing the images being recorded. Given the characteristics of the flight platform and the limits these place on proximity to the subjects, images of sufficient detail and resolution must be obtained.

Imaging options

Early trials of a compact camera at fixed focal length (Canon Ixus 135) were unsatisfactory and our attention turned to high-resolution video camcorders with zoom capability. The Sony HDR-CX760 and PJ650, offering $\times 10$ optical zoom, good performance in low light, mechanical image stabilization, and allowing HD video and still image capture (up to 24.1 MP and 20.1 MP, respectively) were used extensively. Using a camera video link adaptor (Gentles UK Ltd.), the camera operator had independent remote control of video zoom and grabbing stills.

Successful flying platform – imaging combinations were tested further with animal groups. In most trials several aspects of flights were being assessed: performance of aircraft, performance of imaging, and reaction of animals to UAS. In one field trial, the Skyjib UAS platform was used to acquire images from a Panasonic GH4 camera with 45 mm lens shooting 4K video and these images were compared with images obtained in the same session on the same day from the Sony HDR-CX760 at full zoom.

Images acquired from the UAS were assessed for use in photogrammetry and analysis of body condition. Objects of known dimensions were included in some images to allow an assessment of ground-resolved distance at typical working altitudes. Still images were used throughout the study; these were acquired from video, which is more useful for determining dynamic behavior and reactions of animals.

Test flights were flown incrementally towards groups of animals whilst videoing the approaches, usually from the pilot or operator's position. Distances between operators, animals, and UAS were obtained from a combination of on screen display data, reference to known map locations, dead reckoning, and visual estimation of distances between objects using seal body lengths (adult gray seals are approximately 2 m from nose to end of flippers). Behavioural reactions were noted in real time (to allow adjustment of flight plan or early termination of flight if disturbance exceeded threshold level) and post hoc from simultaneous videos recorded from the ground. We set a precautionary reaction threshold to reduce disturbance to animals, based on observed natural behaviour. Seals show a characteristic alert behavior in which the head is raised and the animal looks around actively (Table 1). Adjustments to intended flying patterns were made when reactions for >10% of the animals present were greater than head-up alerts. In practice this meant either retreating the UAS or terminating the test run. Depending on the main purpose of the flight, approach flight profiles were: Cinestar 6, start approach from altitude 50–30 m, minimum range 200 m, approach to 50 m range if possible, descend or approach gradually until flight time elapsed or reaction threshold reached; and Vulcan 8, as Cinestar 6, but start from 60 m altitude to allow for noisier machine.

Legal compliance

UAS were registered and permitted with the UK CAA, which governs UK airspace. Our aircraft were permitted and flown in compliance with CAA directives under CAP 722 (Civil Aviation Authority, UK 2015). In brief, aircraft must be flown at heights not exceeding 122 m at a maximum distance of 500 m from the controller and within their sight at all times. Other restrictions applying to people, buildings, and structures were not encountered in typical operations around seal locations. Flying notifications were posted as required. In addition, UAS were included specifically in the University's insurance policy, providing public liability cover.

Seal work was conducted under UK HO license 60/4009. Ethical approval for flight trials around animals was obtained from the University of St Andrews School of Biology Ethics Committee.

Results

UAS-imaging combinations

The main part of our trials featured two UAS systems (*i*) Cinestar 6 and (*ii*) Vulcan 8 multicopters ($n = 34$ and 25, respectively, Table 1, Figs. 1a and 1b, respectively). The newer platform (Vulcan 8) uses slower Tiger motors and larger propellers offering an increase of 50%–100% on previous flying time, a critical factor in positioning and time over animals to obtain useful images. In general, the noise from UAS is related to the number of motors, and although positioning and speed of motors and propeller size and pitch have an effect, there was no doubt that the Vulcan 8 is noisier than the Cinestar 6.

The Cinestar two-dimensional gimbal system in operation initially worked adequately, but was bulky and added to the overall mass of the UAS (Fig. 1a). It has been superceded by brushless gimbals, such as the Zenmuse. Different optical systems were tested on a brushless gimbal on the Skyjib airframe in July 2014. The advantages of smoother control and motion damping with the brushless gimbal were obvious in operation and it was added as a supplement to the specification for the newer Vulcan system.

Both UAS platforms were used with the Sony HDR-CX760 or PJ650 camcorders for image acquisition. Both have optical zoom and this functionality allowed us to obtain real-time close-up images of areas of interest from horizontal ranges of up to 100 and 40 m in height (e.g., Figs. 2, 3a, and 4).

Photo-ID

Gray seals

Both Sony camcorder models performed well in the photo-ID role: images obtained from 30 m height and up to 50 m range at full zoom were sufficiently detailed to allow gray seal pelage patterns to show up and photo-ID (using pattern extraction and matching software ExtractCompare (Hiby et al. 2013) of seals was possible on images taken on multiple occasions at different sites (e.g., Fig. 2).

Harbor seals

One of the purposes of the Loch Fleet flights was to test the possibility of using UAS-acquired images for harbor seal photo-ID, because harbor seals have finer and less pronounced pelage patterns than those of gray seals. In July 2014 our images were captured at higher-than-normal altitudes (50 m) because we were using a noisier octocopter platform (Skyjib) at a time when mother seals were with pups. At around 50 m height and approximately 15 m lateral range to animals, images grabbed from Panasonic GH4 4K video were comparable in quality to those obtained from the Sony CX760 at full zoom (Figs. 3a and 3b). Although IDs were assigned to animals in images, these were made with additional independent observational knowledge of animals and their distribution at the locality during the survey and were from a limited pool of options by an operator familiar with the animals in question (P. Thompson, pers. comm., 2014).

Measures of animals from the air

Body length and diameter measures obtained from UAS imagery were compared with ground measures on occasions when the UAS was directly overhead and a reference object was included in the frame (Fig. 4). Images of immobilised gray seals on measuring boards during long-term studies at the Isle of May in 2014 allowed comparison with ground measures. At a typical 25 m height using full zoom on the Sony camcorders, resolution was around 5 pixel/cm. While this allowed good repeatability of measures in captured images, photo-derived nose-tail measures for six captures differed from direct measures of animals on the ground by between –0.2 and +3.4 cm (Table 2).

Fig. 1. (a) Cinestar 6 hexacopter showing Sony camcorder on Cinestar two-axis gimbal and GoPro 3 video attached to boom supplying pilot's first-person view. (b) Vulcan 8.

(a)



(b)



Fig. 2. Molt haulout of gray seals, April 2013, Abertay Sands, Fife, Scotland (Sony HDR CX760 camcorder). A single young female's left flank is visible, surrounded by males, many of whom are partially molted. This image allowed extraction of the female's flank pelage pattern for comparison with others using ExtractCompare, a custom semi-automated pattern recognition software (Hiby et al. 2013).



Animal reactions to UAS overflight

Progression with UAS development and use meant that not all aircraft were tested with all species, age, or sex groups (Table 1). For brevity, the most extensive results for Cinestar 6, Vulcan 8, and Skyjib platforms are presented.

Reactions to UAS approaches and overflights were variable in both gray and harbor seals. There was also evidence of temporal, species, and individual variation in reactivity to being overflown.

Gray seals

Two aspects of reaction to a UAS were quantified in gray seal trials: the number of trials in which particular behaviours were shown by any animals present (Fig. 5) and the height and distance to animals in which reactions were observed (Table 3). Hauled out molting gray seals showed fewest overt behavioural reactions to being overflown (Table 3, Figs. 2 and 5). With the Vulcan UAS, trials of gray seals at molt showed more signs of disturbance and in one case (a group of around 60 juveniles and yearlings) all fled to the sea with the UAS at a range of 200 m (Table 3). More of the Vulcan trials with breeding gray seals showed reactions in each of the more reactive behaviours than in the Cinestar trials. However, breeding females were more resistant to departing, even when they moved around (Table 3, Fig. 5). Breeding and molting animals first reacted to the Vulcan at greater ranges than for the Cinestar, presumably because of the noise (Table 3). For the Cinestar UAS only, once the altitude of the UAS was lower than 30 m, reactions at molt ranged from head up alert to change position, whereas at breeding there was more behavioural reaction of a lower intensity at lower UAS levels (Fig. 6).

Harbor seals

At Loch Fleet, trials at Loch Fleet on the southern (frequently disturbed) haulout in May 2014 prior to breeding showed little animal reaction at 30 m height (Cinestar 6). Similarly few reactions were shown at this haulout at breeding in July 2014 with the noisier Skyjib machine. However, on the same day in July 2014 at the more isolated northern haulout, a group of harbor seals was extremely nervous, and even at UAS heights exceeding 50 m some animals (adults and pups) moved to the water whilst being overflown.

Discussion

Wherever possible, biological surveys and measurement collections aim to collect data that is representative of the population studied, or at least to be able to account for potential biases in

Fig. 3. (a) Harbor seals at Loch Fleet (July 2014), taken from a height of approximately 50 m. Still image from HDvideo Sony HDR CX760 camcorder ($\times 10$ optical zoom). (b) Harbor seals from a height of approximately 50 m at Loch Fleet (July 2014). Skyjib 8 platform, still image from 4K video, Panasonic DMC-GH4, 45 mm lens (Horizon AP). The images, of similar quality, illustrate the trade-off between using a higher resolution image from 4K video with comparatively low magnifying power in the lens, compared to a medium resolution still image captured from HD video with a powerful zoom lens. Practically, 4K video requires more storage and processing space because of large file sizes.

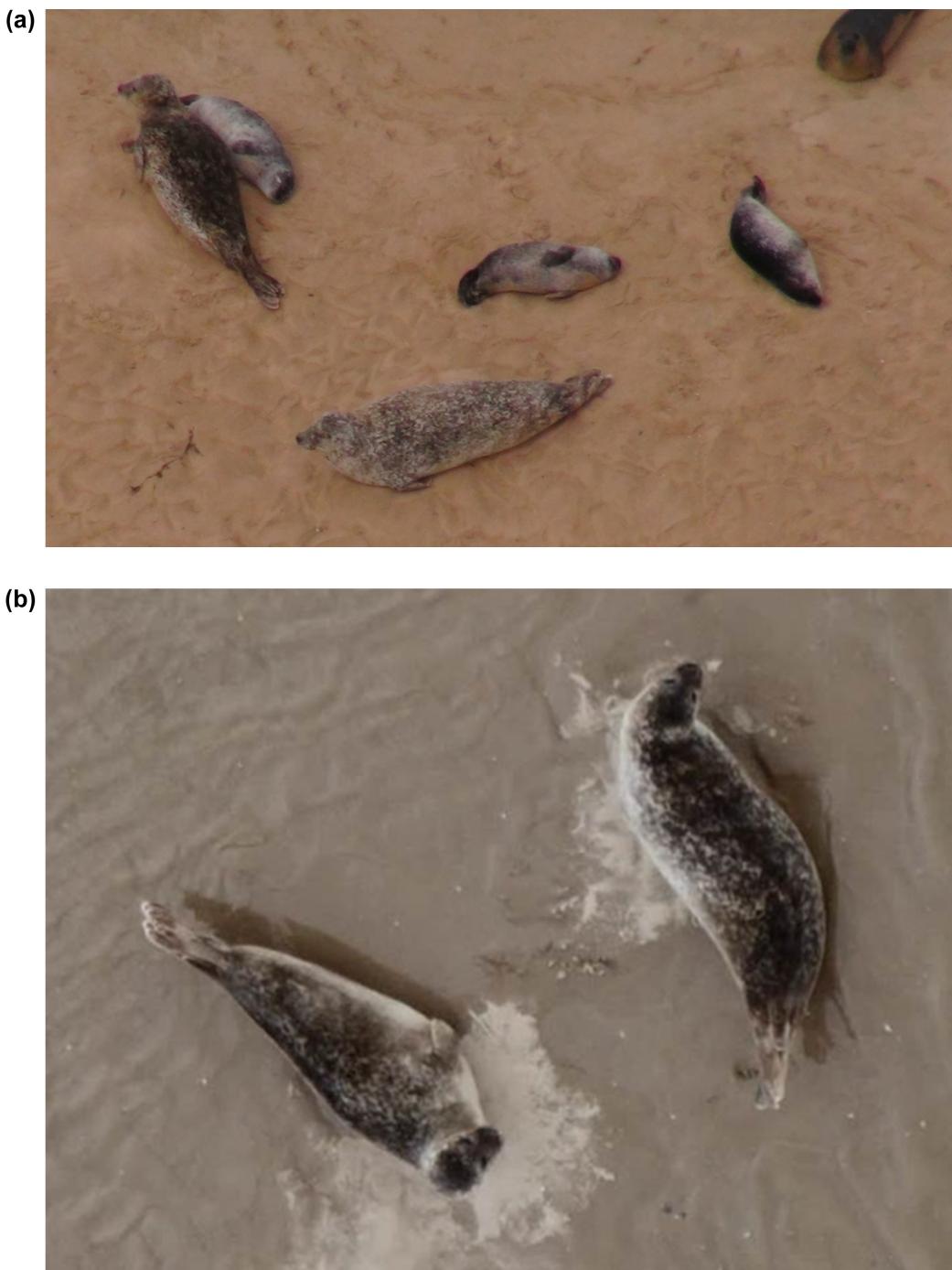


Fig. 4. Overhead view of anaesthetized adult female gray seal (branded “4B” in 1990) on the Isle of May, Nov 2014. Ground resolution approximately 5 pixel/cm. Vulcan 8 with Sony HDR-CX760, full optical zoom at 25 m height.



Table 2. Comparison of estimates of captured and anaesthetised female gray seal total length (nose–tail) obtained from ground measures and UAS overhead images: Vulcan 8 with Sony CX760, Isle of May, November 2014.

Seal	Ground measure (cm)	Overhead image measure, mean, ($n = 10$) \pm sd (cm)
1	171	170.8 ± 0.38
2	173	176.1 ± 0.32
3	170	173.0 ± 0.23
4	165	168.4 ± 0.33
5	172	171.4 ± 0.26
6	165	164.4 ± 0.26

Note: Images were taken from a height of approximately 25 m and scaled by reference boards included in each image.

sampling methods. UAS offer novel opportunities for acquiring data from animals in previously inaccessible locations, but our experiences suggest that UAS suitability for each task must be considered in parallel with the likelihood that animals do not react consistently to these novel stimuli.

Fig. 5. Gray seal behavioural reactions to UAS presence according to UAS platform and seal breeding or molt state. The percentage of trials in which each behavioural category is shown, expressed as: (the number of trials in which any animals showed the behaviour specified/total trials for that state and UAS) × 100. Number of trials as in Table 1. Vulcan 8 molt flights were flown 10 m higher to allow for louder machine.

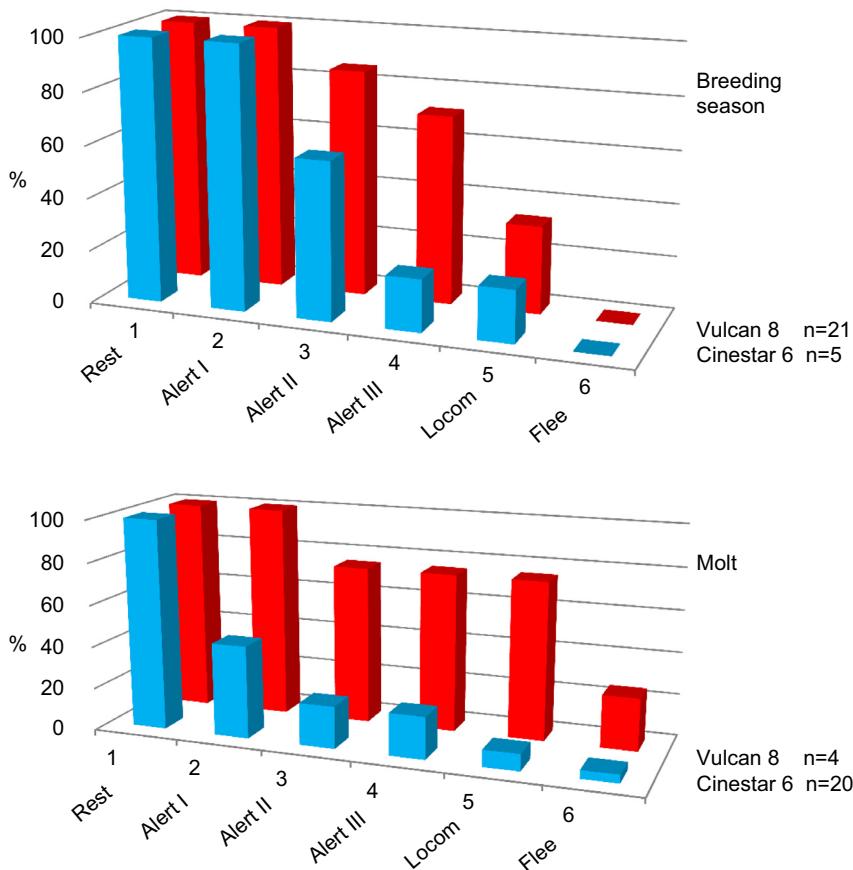


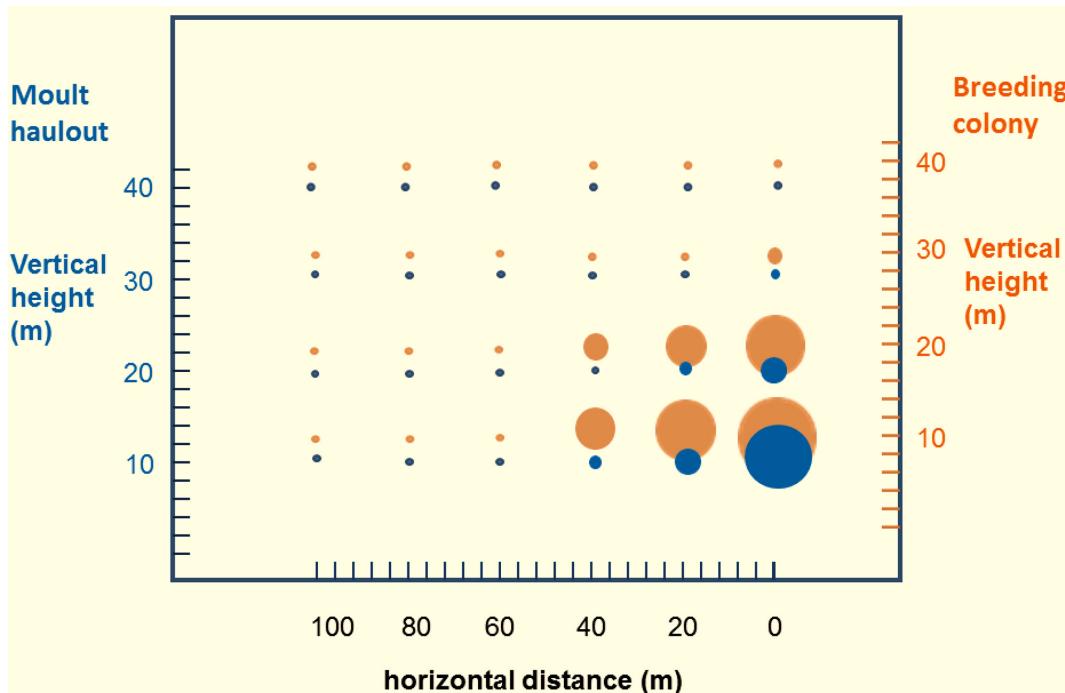
Table 3. Gray seal reactions to UAS presence according to UAS platform, at height (h) and lateral distance (d) from seals at which reactions were first observed in any of the trials specified (N).

Seal behaviour	Gray seals, breeding		Gray seals, molting	
	Cinestar 6, N = 5, h, d (m)	Vulcan 8, N = 21, h, d (m)	Cinestar 6, N = 20, h, d (m)	Vulcan 8, N = 4, h, d (m)
Alert, head up	30, 40	50, 70	30, 30	50, 250
Alert, head up, active head movements (pup check)	25, 30	40, 40	30, 10	50, 220
Alert, shuffling, change position	15, 30	35, 30	30, 10	50, 220
Locomotion	Not seen	30, 40	10, 15	50, 210
Locomotion, flee	Not seen	Not seen	5, 5	50, 200

Photo-ID

Photo-IDentification of individuals for mark-recapture studies can pose many problems, but acquiring images from a UAS that can hover then move as directed to a new location without disturbing the subjects represents a major step forward in data acquisition. Both Cinestar 6 and Vulcan 8 UAS

Fig. 6. Average intensity of behavioural responses of adult gray seals to the same UAS (Cinestar 6) flying the same flight pattern in different biological contexts: molt (March and April, 20 flights) and breeding (October, five flights). Intensity of seal reaction is proportional to diameter of circle. Note that molt haulouts tested comprised mostly males, while breeding tests comprised >90% females with pups.



platforms were capable of and successful in obtaining images usable for photo-ID, although some of the extended flight duration benefits offered by the octocopters were nullified by their louder noise, which meant in some cases that images had to be obtained from farther away.

Seal measurements from the air

True photogrammetry on isolated images of seals on the ground is limited by (i) the current UAS height and location information provided by GPS not being sufficiently accurate; and (ii) consistency in seal measurement. To be truly useful, a system needs to be able to estimate not just length but the three-dimensional shape of the seal, accounting for irregularities in the ground surface. Seals lying on boards represent a “best case” scenario, and even in this case it is difficult to reproduce measures of seal length to within 2%. Multiple imaging solutions to create three-dimensional images are possible, but seals are notoriously difficult to measure consistently even when they are captured and chemically restrained (e.g., de Bruyn et al. 2009).

Disturbance

Seals are disturbed off haulouts into the water by many factors. Some causes may be obvious, but some disturbance events appear without obvious causes. Although detection of human presence can be a major trigger for seals returning to the water in naïve animals, there is evidence of habituation and tolerance of disturbance, which can be seen at haulouts or breeding areas (e.g., Bishop et al. 2015). It is not clear whether this is due to particular animals being resistant to disturbance or a gradual increase in tolerance to a stressor within the group. Researchers are familiar with situations in which a haulout comprising many tens or even hundreds of animals may be disturbed into the water after a single animal (often a juvenile or yearling) becomes alarmed and returns to the safety of the water as a first response. It could be argued that Loch Fleet has individuals ranging widely in their degree of disturbance habituation. It is not clear whether this large variation in reaction is typical of harbor seal haulouts elsewhere. Habituation to some types of disturbance (such as boats) does not necessarily mean that animals will respond similarly to the impact of UAS. It may be that biological context is important in determining the effects of such novel disturbance.

There are few formal attempts to describe the noise produced by UAS with regard to aircraft in use for wildlife survey. The fundamental frequency of the single electric motor of the fixed-wing drone the Sensefly reaches about 60 dB SPL at 1 m and 2 μ Pa at the highest engine speed of 9700 rpm (Marmaroli et al. 2012). Multicopters with four, six, or eight motors produce a more complex sound field depending in part on the orientation and spacing of the motors. Goebel et al. (2015) reported that sound levels recorded at all operational heights from the APH-22 UAS used in their studies were consistently lower than levels recorded from one of the penguin colonies they studied. Most operators work on the basis that the noise produced by their UAS is either negligible in comparison with typical ambient noise, or is dissipated sufficiently by distance from the subject in normal operation. Our results indicate several important points in this regard. First, different UAS configurations produce different sound profiles and these may produce undesirable reactions in the animals of interest. Second, ambient wind conditions can mask UAS noise, which may be advantageous in normal operating conditions but in unusually still conditions the absence of wind (providing otherwise desirable flying conditions) makes UAS noise very obvious. Third, groups of animals of the same species have different reactions to UAS depending on their age, sex, and, in the case of gray seals at least, their biological state (breeding or molting condition).

UAS offer new wildlife data collection opportunities but one of the challenges for users is to optimize the trade-off between required data quality, flying platform performance, imaging payload, and minimal animal response.

Acknowledgements

We thank all who provided assistance, particularly J. Wrangham, P. Anderson, and S. Rodwell. We are grateful to P. Thompson and R. Schick for their invitation to trial systems at Loch Fleet. This work was supported by UK National Environmental Research Council National Capability funding to SMRU, NERC grant No. NE/G008930/1 to PP, through UK DEFRA support to SMRU, and by development grants from MASTS and Chester Zoo.

References

- Anderson, K., and Galston, K.J. 2013. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Front. Ecol. Environ.* **11**: 138–146. doi: 10.1890/120150.
- Bishop, A., Pomeroy, P., and Twiss, S. 2015. Breeding male gray seals exhibit similar activity budgets across varying exposures to human activity. *Mar. Ecol. Prog. Ser.* **527**: 247–259. doi: 10.3354/meps.11254.
- de Bruyn, P.J.N., Bester, M.N., Carlini, A.R., and Oosthuizen, W.C. 2009. How to weigh an elephant seal with one finger: A simple three-dimensional photogrammetric application. *Aquat. Biol.* **5**: 31–39. doi: 10.3354/ab00135.
- Civil Aviation Authority, UK. Unmanned Aircraft Systems Operations in UK Airspace - Guidance. CAP 722, 6th ed. 2015. www.caa.co.uk/CAP722.
- Cordes, L.S., and Thompson, P.M. 2014. Mark-recapture modeling accounting for state uncertainty provides concurrent estimates of survival and fecundity in a protected harbor seal population. *Mar. Mamm. Sci.* **30**: 691–705. doi: 10.1111/mms.12070.
- Goebel, M.E., Perryman, W.L., Hinke, J.T., Krause, D.J., Hann, N.A., Gardner, S., and LeRoi, D. 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.
- Hiby, L., Paterson, W.D., Redman, P., Watkins, J., Twiss, S.D., and Pomeroy, P. 2013. Analysis of photo-ID data allowing for missed matches and individuals identified from opposite sides. *Methods Ecol. Evol.* **4**: 252–259. doi: 10.1111/2041-210x.12008.
- Hodgson, A., Kelly, N., and Peel, D. 2013. Unmanned aerial vehicles (UAVs) for surveying marine fauna: A dugong case study. *PLoS One.* **8**(1): e79556. doi: 10.1371/journal.pone.0079556.
- Jones, G.P. IV., Pearlstine, L.G., and Percival, H.F. 2006. An assessment of small unmanned aerial vehicles for wildlife research. *Wildl. Soc. Bull.* **34**(3): 750–758.
- Koh, L.P., and Wich, S.A. 2012. Dawn of drone ecology: Low cost autonomous aerial vehicles for conservation. *Trop. Conserv. Sci.* **5**: 121–132.
- Lonergan, M., Duck, C.D., Thompson, D., Mackey, L., Cunningham, L., and Boyd, I.L. 2007. Using sparse survey data to investigate the declining abundance of British harbour seals. *J. Zool.* **271**(3): 261–269. doi: 10.1111/j.1469-7998.2007.00311.x.
- SCOS. 2013. Scientific Advice on Matters Related to the Management of Seal Populations: 2013. Available from <http://www.smru.st-and.ac.uk/documents/1803.pdf>.
- Smout, S., King, R., and Pomeroy, P. 2011. Estimating demographic parameters for capture-recapture data in the presence of multiple mark types. *Environ. Ecol. Stat.* **18**: 331–347. doi: 10.1007/s10651-010-0135-y.
- Watts, A.C., Ambrosia, V.G., and Hinkley, E.A. 2012. Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use. *Remote Sens.* **4**: 1671–1692. doi: 10.3390/rs4061671.

Appendix A

Current SMRU UAS legal status

Licence: UK CAA Air Navigation Order (2009) Articles 166 and 167, Dr P Pomeroy SMRU permit No. 239.

Equipment tested

Flying platforms

1. Quadcopter – DJI 450 (SMRU) flight time 8–12 min, max payload 750 g
2. Hexacopter – Cinestar 6 (SMRU) flight time 10–15 min, max payload 1.5 kg
3. Skyjib Octocopter – (Horizon AP) flight time 20–25 min, max payload 5 kg
4. Vulcan Octocopter – (SMRU) flight time 20–25 min, max payload 1.75 kg

Image acquisition options

1. Canon Ixus 135 compact camera (video)
2. GoPro III (stills and video)
3. Sony HDR-CX730 and 760 camcorder, IS, ×10 optical zoom (stills and video)
4. Panasonic DMC GH4 camera with 45 mm lens, shooting 4K video.