CSIRO PUBLISHING

Wildlife Research, 2022, **49**, i–v
https://doi.org/10.1071/WR22006

Foreword

Foreword to the Special Issue on 'The rapidly expanding role of drones as a tool for wildlife research'

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Abstract. Drones have emerged as a popular wildlife research tool, but their use for many species and environments remains untested and research is needed on validation of sampling approaches that are optimised for unpiloted aircraft. Here, we present a foreword to a special issue that features studies pushing the taxonomic and innovation boundaries of drone research and thus helps address these knowledge and application gaps. We then conclude by highlighting future drone research ideas that are likely to push biology and conservation in exciting new directions.

Keywords: animal behavior, animal health, conflict, habitat characterisation, human–wildlife conflict, remotely piloted aircraft systems, unmanned/unpiloted aerial vehicles, unmanned/unpiloted aircraft systems, RPAS, UAS, UAV.

Received 17 January 2022, accepted 25 January 2022, published online 9 February 2022

Drones are now used widely as a tool for wildlife research in both aquatic and terrestrial environments (Christie *et al.* 2016; Chabot 2018; Joyce *et al.* 2019). Also known as remotely piloted aircraft systems (RPAS), unmanned/unpiloted aerial vehicles (UAV), or when combined with the technology and software surrounding their operation and use, unmanned/unpiloted aircraft systems (UAS), drones span a wide variety of sizes and platforms. For wildlife research, typically small UAVs, under 10 kg, are employed because of their wide availability, cost effectiveness, and ability to carry sensors that meet many objectives. Drones can accomplish a variety of tasks ranging from remote sensing to monitoring animal populations and even individuals, from their behaviour to their body condition (Chabot and Bird 2015; Linchant *et al.* 2015; Fiori *et al.* 2017; Kiszka and Heithaus 2018; Torres *et al.* 2018; Fust and Loos 2020; Corcoran *et al.* 2021; Graves *et al.* in press). Moreover, they have the potential to collect data on wildlife populations and individuals in inaccessible areas, in a way that involves lower cost, and less risk, invasiveness and labour than do more traditional approaches, including direct observations from the ground, the water or piloted vehicles (Christie *et al.* 2016; Fiori *et al.* 2017; Wang *et al.* 2019; Corcoran *et al.* 2021; Preston *et al.* 2021). Accordingly, drones are increasingly being recognised for their potential to advance wildlife biology and conservation by enabling, for instance, widespread ground-truthing of satellite imagery and opportunities for multi-modal (e.g. optical and acoustic) animal monitoring, and by facilitating enforcement of animal protections (e.g. by detecting poaching; Chabot and Bird 2015; Nowak *et al.* 2018; Joyce *et al.* 2019; Wang *et al.* 2019; Fust and Loos 2020). However, this promise has yet to be fully realised, in part because of technological and legal constraints, including the limiting effect of battery life and size on load capacity and flight time, as well as flight restrictions that are increasing in many countries around the globe. Furthermore, the use of drone use for many species and environments remains untested and research is needed on validation of sampling approaches that are optimised for unpiloted aircraft (Linchant *et al.* 2015; Christie *et al.* 2016; Corcoran *et al.* 2021).

Featuring studies from both aquatic and terrestrial ecosystems, this special issue of *Wildlife Research* highlights the environmental and taxonomic reach of drone research today for observing wildlife and, as a corollary, the myriad ways in which drones are helping overcome limitations of and complement more traditional sampling approaches. For example, Aubert *et al.* (2022) reported a pioneering drone survey of a West African crocodilian assemblage. They found that although they were less effective than nocturnal visual (on-the-ground) surveys, drone surveys were better at detecting crocodilians than were diurnal visual surveys, in large part because their aerial perspective overcomes on-the-ground visual obstructions caused by plants and other forms of habitat complexity. Moreover, drones alleviated many of the considerable logistical constraints imposed by both traditional techniques. This marked efficiency advantage is critical in the system studied by Aubert *et al.* (2022), and many others, where focal taxa are simultaneously imperilled and difficult to monitor. Sudholz *et al.* (2022) pushed a different research boundary, showing that drone surveys are an effective means of monitoring invasive species, in their case Rusa deer (*Rusa timorensis*) in Queensland, Australia, particularly when paired with automated detection via machine learning. Finally, Ejrnæs and Sprogis (2022) used drones off the coast of Western Australia to establish patterns of resting behaviour and energy expenditure in humpback whale (*Megaptera novaeangliae*) mother–calf pairs (Fig. 1*a*), providing crucial baselines from an undisturbed population for understanding anthropogenic impacts.

Just as importantly, this special issue also showcases cutting-edge methods and methodological caveats that should further improve the breadth and rigour of drone research and may also catalyse development of new applications. For example, Saunders *et al.* (2022) demonstrated that, across a range of landscapes, drone-based radio-tracking allows for much greater spatial coverage than does tracking from the ground. The viewshed analyses Saunders *et al.* (2022) used to quantify spatial coverage also enabled them to identify telemetry 'blind spots' that would need to be surveyed in a more targeted fashion to avoid missing or losing tagged animals. Both Howell *et al.* (2022) and McMahon *et al.* (2022) illustrated the effectiveness of drones equipped with thermal sensors, in contrast to more conventional wildlife monitoring approaches. Namely, Howell *et al.* (2022) showed that thermal imaging drones outperform the two more conventional field-based approaches of spotlighting and diurnal radial searches for detecting the koala (*Phascolarctos cinereus*), a cryptic forest-dwelling species. Similarly, McMahon *et al.* (2022) demonstrated that drone surveys estimate white-tailed deer (*Odocoileus virginianus*) densities as well as conventional pellet counts, while also allowing for greater efficiency and temporal coverage (Fig. 1*b*). Finally, using decoys to stand in for green sea turtles (*Chelonia mydas*), Odzer *et al.* (2022) showed that factors impeding visibility (glare, water depth, substrate vegetation) can markedly degrade subsurface drone detection performance in marine systems, leading them to caution that identifying and accounting for environmental limitations on detection efficacy are crucial components of drone survey design.

Looking ahead

As the role of drones in wildlife research continues to expand, we envision the insights they provide pushing biology and conservation in many exciting new directions. Here, while acknowledging that a full accounting of these future drone research directions is beyond the scope of this foreword, we highlight four such frontiers, namely: (1) individual behaviour for species that challenge focal observation and tracking via more conventional means; (2) monitoring the health of free-ranging animals; (3) assessing the conflicts between wildlife and humans; and (4) enhanced habitat characterisation.

Focal observation has long been a staple in animal behaviour research, merging detailed data collection capacity with the flexibility to monitor individuals or groups and to record spontaneous and unforeseen events (Altmann 1974). Although emerging biologging and tracking technology increasingly enables researchers to infer patterns of animal behaviour without direct visual observation (Smith and Pinter-Wollman 2021), a growing literature cautions of the disturbance responses that can bias drone surveys for some species. In this issue, for example, Landeo-Yauri *et al.* (2022) show that drone flights elicit persistent changes to respiration rates and activity budgets in captive Antillean manatees (*Trichechus manatus manatus*). For species without such effects, drones have the potential to address an important data gap. The unparalleled insights that can stem from continuously viewing an individual as it moves through its environment have thus far been largely restricted to species that can be watched (or filmed) directly and circumstances where more cryptic taxa are captured remotely on video (e.g. by motion-activated cameras). UAVs are being used increasingly to conduct focal and collective animal observations (Rieucau *et al.* 2018; Smith and Pinter-Wollman 2021), although typically while being operated manually (e.g. cetaceans, Torres *et al.* 2018, 2020; Ejrnæs and Sprogis 2022; rays, Oleksyn *et al.* 2021). Accordingly, the next advance is to program drones to automatically follow individual animals, or even groups of animals, as they move within and across habitats. Using drones aided by

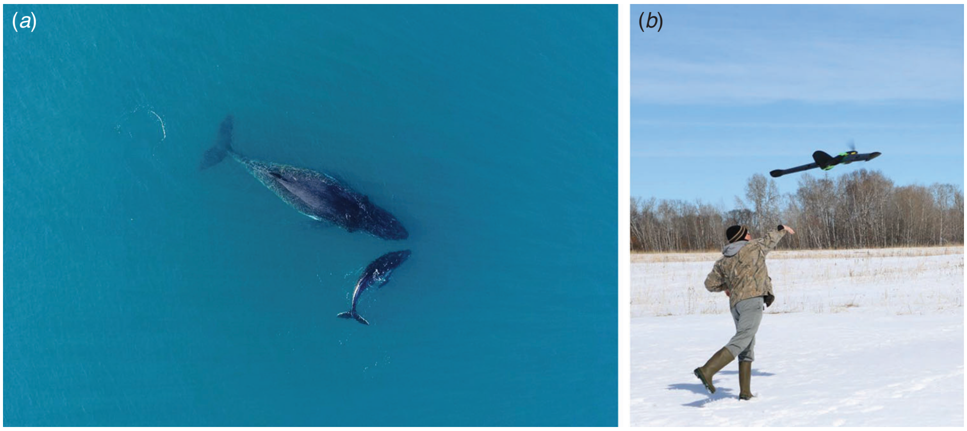

Fig. 1. (*a*) Aerial photograph of a humpback whale (*Megaptera novaeangliae*) mother–calf pair taken during a drone-based focal observation. Ejrnæs and Sprogis (2022) used these drone focal follows to explore patterns of resting behaviour and energy expenditure on a breeding ground off the coast of Western Australia. Photo credit: Kate Sprogis. (*b*) McMahon *et al.* (2022) launched a fixed-wing drone equipped with a thermal infrared sensor to estimate white-tailed deer (*Odocoileus virginianus*) population density. Photo credit: Michael McMahon.

artificial neural networks for image processing, such follows (of individual animals at least) have been conducted successfully in laboratory environments, but automated tracking under field conditions has yet to be attempted (Straw 2021). Drone deployments of this nature offer many exciting research possibilities, including identification of spatiotemporal patterns of cryptic behaviours (e.g. reproduction), exploration of inter- and intraspecific interactions involving cryptic taxa or in inaccessible environments, and comparisons of animal behaviour with and without human observers or other forms of disturbance.

Over the past few years, drones have also proved their value as a tool for investigating individual body condition and size by using photogrammetric methods, and for assessing (and potentially monitoring) individual- and population-level health status (e.g. nutritional status) of a range of species, particularly in marine environments (e.g. Pirotta *et al.* 2017; Allan *et al.* 2019; Stewart *et al.* 2021*a*). Recent advances have shown that the precision of photogrammetric methods can be dramatically improved using deep learning, reducing the amount of time spent inputting information manually, which will facilitate expansion and development of photogrammetric methods to automatically measure individual animals with the greatest precision (Gray *et al.* 2019). By implication, drone-based assessments of individual animal condition and size offer a new means of understanding impacts of environmental conditions and degradation associated with human activities on the health, nutritional status, and population dynamics of a range of species, in both aquatic and terrestrial ecosystems. Furthermore, continuous monitoring of changes to body condition and size of individual animals within populations using drones may allow researchers to evaluate long-term trends in associations between these measures and human activities and impacts (e.g. Stewart *et al.* 2021*b*).

Another potential area of research involves the use of drones to assess and monitor spatial and temporal patterns of conflicts between humans and wildlife. Both on land and in coastal marine environments, interactions between human activities (e.g. agriculture, tourism, urbanisation) and wildlife may lead to a diversity of challenges (e.g. crop destruction, aggressive interactions between wildlife and tourism), which drones could be employed to monitor at multiple spatial and temporal scales, including in real time. For example, Rutten *et al.* (2018) used drones to assess the spatial extent of and therefore identify the factors affecting damage to plantations caused by wild boars (*Sus scrofa*) across multiple habitats with considerable accuracy (Rutten *et al.* 2018). Such drone monitoring could help shape adaptive management policy aimed at reducing human–wildlife conflict and promoting coexistence.

In addition to animal observations, drones can advance understanding of animal distributions and improve habitat prioritisation for wildlife conservation through enriched spatiotemporal characterisation of wildlife habitat from local to landscape scales. Spatially extensive maps of vegetation, topography and other landscape features are powerful tools that support analyses of habitat selection and suitability mapping for wildlife to investigate innumerable research questions about their habitat requirements and responses to environmental perturbations such as anthropogenic development and climate change. However, vegetation maps are often inadequate in their specificity and accuracy for fine-scale wildlife applications. Drones can provide accurate, high-resolution maps of specific vegetation types or species in focal areas or across a network of sites, which, when combined with other remote-sensing imagery, enables the development of more extensive maps (Kattenborn *et al.* 2019; Rigge *et al.* 2020; Bhatnagar *et al.* 2021). Research has shown that many traditional field measures of vegetation can be replicated from drone imagery (Alonzo *et al.* 2018; Räsänen and Virtanen 2019; Sankey *et al.* 2021), which can provide spatially continuous measures over much larger areas to improve accuracy of training data for broad-scale mapping. Inclusion of drones in vegetation monitoring programs that are used to develop vegetation maps from satellite imagery (e.g. Allred *et al.* 2021) has high potential for improving these mapping efforts but requires extensive research on the capabilities of drone imagery to identify vegetation species and assessment of practical limits to sampling effort and equipment. For example, species identification can be enhanced with data from drone flights, including three-dimensional information from LiDAR or structure-from-motion, hyperspectral imagery, and plant phenology measured from multiple flights. In addition, each of these data types can directly describe important habitat attributes for many wildlife species, such as forest canopy complexity for arboreal species (e.g. Johnston and Moskal 2017) or timing of green-up for migratory species (e.g. Aikens *et al.* 2017). Finally, the flexibility and cost effectiveness of drones for frequent, targeted deployment with several sensor types allow researchers to test and optimise acquisitions of remotely sensed data to explore new approaches for characterising habitat that explain animal distributions.

Undoubtedly, drones have emerged as powerful and exciting tools for wildlife research with much potential that remains unrealised. As researchers continue to evaluate the capabilities of this technology, we need to consider how drones fit into a broader vision for wildlife research and conservation, including as a means for collecting citizen-science data (Preece 2016). Integration of drones into multi-scale management programs with diverse objectives to provide complete research, monitoring and assessment capabilities will be a challenging but worthwhile endeavour. This new aerial perspective, along with advancing sensors, analytical software, and animal tracking techniques, is inspiring researchers to think creatively about how to answer questions about wildlife, and we look forward to the discoveries that lie ahead.

Data availability

No data were used as part of this paper.

Conflicts of interest

Aaron Wirsing is an Editor-in-Chief for *Wildlife Research* and served as Editor-in-Chief for this special issue. Aaron Johnston and Jeremy Kiszka were also guest editors for this special issue. The authors have no further conflicts of interest to declare.

Declaration of funding

This research did not receive any specific funding.

Acknowledgements

We thank the journal for supporting this special issue. We are also grateful to the authors who contributed their research to this special issue and the reviewers of those papers. The research reported within this issue was supported by many organisations, which are described in each paper. D. Wood, T. Graves and A. Taylor provided helpful comments that improved this foreword. Any use of trade, firm or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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