ARTICLE

A standardized protocol for reporting methods when using drones for wildlife research

Andrew F. Barnas, Dominque Chabot, Amanda J. Hodgson, David W. Johnston, David M. Bird, and Susan N. Ellis-Felege

Abstract: Drones are increasingly popular tools for wildlife research, but it is important that the use of these tools does not overshadow reporting of methodological details required for evaluation of study designs. The diversity in drone platforms, sensors, and applications necessitates the reporting of specific details for replication, but there is little guidance available on how to detail drone use in peer-reviewed articles. Here, we present a standardized protocol to assist researchers in reporting of their drone use in wildlife research. The protocol is delivered in six sections: Project Overview; Drone System and Operation Details; Payload, Sensor, and Data Collection; Field Operation Details; Data Post-Processing; and Permits, Regulations, Training, and Logistics. Each section outlines the details that should be included, along with justifications for their inclusion. To facilitate ease of use, we have provided two example protocols, retroactively produced for published drone-based studies by the authors of this protocol. Our hopes are that the current version of this protocol should assist with the communication, dissemination, and adoption of drone technology for wildlife research and management.

Key words: drones, unmanned aircraft systems, unmanned aircraft vehicle, science communication, remote sensing, peer review.

Résumé : Les drones sont de plus en plus populaires au niveau de la recherche sur la faune, mais il est important que l'utilisation de ces outils ne prennent pas plus d'importance que les détails méthodologiques requis pour l'évaluation des plans d'étude. La diversité des plateformes de drones, des capteurs et des applications nécessite la communication de détails précis pour la répétition, mais il existe peu de directives sur la façon de détailler l'utilisation de drones dans les articles évalués par les pairs. Nous présentons ici un protocole normalisé pour aider les chercheurs à signaler l'utilisation de leurs drones dans la recherche sur la faune. Le protocole comporte six sections : aperçu du projet; détails sur le système de drones et son exploitation; charge utile, capteur et collecte de données; détails sur l'exploitation sur le terrain; post-traitement des données; et permis, règlements, formation et logistique. Chaque section décrit les détails qui devraient être inclus, ainsi

Received 7 June 2019. Accepted 22 January 2020.

A.F. Barnas and S.N. Ellis-Felege. Department of Biology, University of North Dakota, 10 Cornell Street, Stop 9019, Grand Forks, ND 58201, USA.
D. Chabot.* droneMetrics, 7 Tauvette Street, Ottawa, ON K1B 3A1, Canada.
A.J. Hodgson.* Aquatic Megafauna Research Unit, Centre for Sustainable Aquatic Ecosystems, Harry Butler Institute, Murdoch University, Murdoch 6150, Australia; Environmental and Conservation Sciences, Murdoch University, Murdoch 6150, Australia.
D.W. Johnston.* Marine Robotics and Remote Sensing Lab, Duke University Marine Laboratory, Division of Marine Science and Conservation, Nicholas School of the Environment, Duke University, Beaufort, NC 28516, USA.
D.M. Bird.* Department of Natural Resource Sciences, McGill University, Ste-Anne-de-Bellevue, QC H9X 3V9, Canada.
Corresponding author: Andrew F. Barnas (e-mail: andrew.f.barnas@gmail.com).

*Dominique Chabot currently serves as Editor-in-Chief, David Bird is the retired Editor-in-Chief, and Amanda Hodgson and David Johnston currently serve as Associate Editors; peer review and editorial decisions regarding this manuscript were handled by Juan José Negro

que les justifications de leur inclusion. Afin de faciliter l'utilisation de protocole, nous avons fourni deux exemples de protocoles produits rétroactivement par les auteurs de ce protocole pour des études publiées sur les drones. Nous espérons que la version actuelle de ce protocole contribuera à la communication, à la diffusion et à l'adoption de la technologie des drones pour la recherche et la gestion de la faune. [Traduit par la Rédaction]

Mots-clés : drones, systèmes d'aéronefs sans pilote, véhicules d'aéronefs sans pilote, communication scientifique, télédétection, examen par les pairs.

1. Introduction

Drones (Chapman 2014) are increasingly popular tools in the natural sciences and are notably being used for a growing variety of wildlife-related applications, including: monitoring of birds (Chabot et al. 2015; Ratcliffe et al. 2015; Weissensteiner et al. 2015; Hodgson et al. 2016; McEvoy et al. 2016), marine mammals (Hodgson et al. 2013, 2017; Koski et al. 2015; Moreland et al. 2015; Adame et al. 2017; Pirotta et al. 2017; Barnas et al. 2018*b*), large terrestrial mammals (Vermeulen et al. 2013; Guo et al. 2018; Su et al. 2018; Hu et al. 2020), primates (Van Andel et al. 2015; Wich et al. 2016; Bonnin et al. 2018), and reptiles (Elsey and Trosclair 2016; Schofield et al. 2017; Thapa et al. 2018); wildlife habitat assessment and modeling (Chabot et al. 2014; Puttock et al. 2015; Fraser et al. 2016; Marcaccio et al. 2016; Olsoy et al. 2018); and wildlife conflict management (Israel 2011; Mulero-Pázmány et al. 2013, 2014; Olivares-Mendez et al. 2015; Michez et al. 2016). The steady progression of drones into the toolkits of wildlife researchers and managers has been documented through a growing number of literature reviews (Anderson and Gaston 2013; Chabot and Bird 2015; Linchant et al. 2015; Christie et al. 2016; Borrelle and Fletcher 2017; Fiori et al. 2017; Mulero-Pázmány et al. 2017; Mustafa et al. 2018; Rees et al. 2018; Johnston 2019) and the publication of methodological synthesis and "best practice" articles (Junda et al. 2015; Hodgson and Koh 2016; Baxter and Hamilton 2018; Brack et al. 2018; Duffy et al. 2018).

The success of drones in this wide variety of wildlife applications is in part a result of the diversity of drone platforms, sensors, payloads, and specific ways they can be operated in the field. As drones become more popular, we expect there to be gradually fewer new proof-of-concept studies focused on drone operation, data collection, and post-processing methods; instead, future articles will increasingly focus on hypothesis testing and scientific inference based on drone-collected data. Nevertheless, it is important to efficiently document the details of drone equipment specifications and operational methods so they can be evaluated by readers and reviewers and replicated or adapted for future use. This documentation will become increasingly important as drone technology and applications continue to diversify. Determining which details to include and how to present them can be a difficult task, with many articles devoting large sections of text to describing drone-related specifications and methods or conversely omitting certain details that are of crucial importance for proper replication. This can be complicated by the varied experience levels of article reviewers and journal editors, leading to inconsistent reporting in the literature. Thus, there is a need for guidance on reporting these details for wildlife-related drone applications (Crutsinger et al. 2016; Hodgson and Koh 2016; Buters et al. 2019).

Other fields of research have overcome similar problems by outsourcing the description of technologies or methods to standardized reporting protocols (agent-based modelling (Grimm et al. 2006, 2010), bioscience research featuring laboratory animals (Kilkenny et al. 2010), statistical methods featuring regression analyses (Zuur and Ieno 2016)), which offer a framework for authors to ensure that methodological details are thoroughly documented (Meek et al. 2014; Fidler et al. 2017). These protocols are often provided as supplementary material and are used to provide details of interest to a specialized readership. Such practices are already commonplace for complex statistical modeling methods that require the availability of data and code via online public repositories or supplementary material (Mislan et al. 2016). As wildlife research methods become increasingly reliant on novel technologies, data collection methods need to be transparent so readers can evaluate and reproduce the study design (Ellison 2010; Fidler et al. 2017).

Although various best practices for drone operations have been recommended in the literature, there are currently no recommendations for methodological reporting requirements for wildlife studies involving drones. Since drones are being increasingly used in wildlife sciences, with papers published in a wide variety of journals, a standardized reporting protocol would be of great benefit to the communication and dissemination of drone-related methods (Crutsinger et al. 2016; Buters et al. 2019). Such a protocol would benefit journals and reviewers in the peer-review process and assist authors by clearly stipulating the required information for publication. Ultimately, it would benefit readers who wish to pursue similar applications, as using drones can be a complicated endeavor and many practitioners may be surprised by the amount of work required before, during, and after drone operation.

In the following sections, we outline a proposed protocol for reporting methodological details of drone-based data collection in the wildlife sciences. For each section, we provide a brief description of the information to be included along with justifications for why certain details are important to report. The protocol is written in the language and context of aerial drones, as these are the most commonly used, but could also be adapted to terrestrial or aquatic robotic vehicles.

2. The drone reporting protocol

2.1. Project overview

In this section the researcher should provide a brief description of the project and describe what type of data the drone was used to collect. It should include the research questions or data collection objectives that are being addressed by using drone technology. Briefly, what is the nature of the data collected by the drone (e.g., still images, video, biological samples)? The purpose of this section is to orient the reader and put the remainder of the document into context.

2.2. Drone system and operation details

2.2.1. Platform specifications

For commercial off-the-shelf systems, identify the make and model of the drone used in the study. If the drone is aerial, identify whether it is a fixed-wing or rotary-wing model. Provide a basic description of the drone, including weight, dimensions, number of rotors (if applicable), as well as any features of distinct importance to the study. This might include flight endurance, power source (including battery specifications), environmental or weather limitations, or special navigational instruments and capabilities. Describe the battery type or energy source used to power the drone. The reporting of such endurance characteristics is clearly relevant to evaluating the effectiveness of a drone for a particular purpose. If the drone was custom-built, provide an adequate description of the system comparable to the specifications typically provided by commercial manufacturers, and optionally include a photo or diagram of the drone, or of any specific custom components. The overall purpose of this section is to inform readers on the main physical, performance, and feature details of the drone that was used to meet the requirements of the study.

2.2.2. Takeoff and retrieval

Requirements and limitations relating to takeoff and retrieval can be crucial determinants of the suitability of a drone for a given application in a specific location, particularly for wildlife-related work that often takes place in remote, undeveloped, or otherwise challenging areas. Describe the method and requirements of takeoff for the drone used in the study. This is more relevant for fixed-wing platforms but may still be reported for vertical-takeoff-and-landing models (i.e., "no specialized launching equipment was required"). Report details of how the drone was retrieved following flight completion and what the retrieval requirements were in terms of space, surface, and equipment needed. A photo of any specialized launching or retrieval equipment should be included (see fig. 2 in Hodgson et al. 2017). One of the most challenging situations is deploying a drone from a boat, where the "home location" and "ground level" do not remain fixed, so these studies should provide details on special procedures or adaptations (e.g., inertial measurement unit initialization) required for launching or retrieval from a moving "home base".

2.2.3. Flight planning and method of operation

Describe the general approach used to perform drone flights in your study, whether manual, autonomous, or semi-autonomous. In the case of preprogrammed flights, state the flight planning software used. Authors are encouraged to use graphics or figures to describe flight plans, for example, a figure with a sample flight plan overlaid on a map or satellite image (e.g., Google Earth) including a scale reference. Such figures are especially helpful for studies involving wildlife surveys, as readers can better assess the survey design. Describe any relevant use of ground control station or other remote control equipment to control or monitor the aircraft during flight. State how many people were required to operate the system and describe their roles. State whether any special provisions were required during operation, such as internet access, that could be difficult to implement in remote ecological work. Any additional, nonstandard equipment that was required for drone operations should be detailed and documented.

3. Payload, sensor, and data collection

This section will vary considerably among studies depending on the payload or the type of data collected. As such, the recommendations in this section are only meant as general guidelines for authors, as it is not possible to give reporting requirements for all types of sensors or payloads. The following recommendations focus primarily on image collection, which is the most common application of drones. However, authors should carefully consider which details are necessary to make the study repeatable given the payload, data collection, and manipulation methods.

3.1. Data overview

While many applications of drones involve the acquisition of imagery, other payloads also have been used for wildlife-related applications, including acoustic sensors (Wilson et al. 2017; Fu et al. 2018), biological sample collectors (Pirotta et al. 2017), radio telemetry receivers (Cliff et al. 2018; Desrochers et al. 2018), and bait dispensers (Johnston et al. 2016). Use this section to briefly describe the type(s) of data collected with the drone or the main function of the payload. Authors are encouraged to include sample raw data (with appropriate captions and annotations) if they feel it can assist readers in evaluating the characteristics and quality of the data, and assessing their suitability for other similar applications (e.g., identifying similar species from mosaics, spectrograms, etc.). This may be especially important if examples of drone imagery are not provided in the main manuscript.

3.2. Payload or sensor description and data collection methods

Describe the onboard payload(s) or sensor(s) used in the study. Report the make and model and basic specifications (e.g., number of megapixels for standard cameras, number of bands for multi- or hyperspectral cameras, etc.) of any commercially available payloads or sensors, or provide an adequate description of custom-made payloads (including photos if appropriate). In the case of multi- or hyperspectral and other specialized cameras, report band wavelengths and widths as well as any accessories for performing radiometric calibration of the imagery (e.g., downwelling incident light sensor, calibration panel). In the case of standard RGB still images, camera shooting parameters and settings can have a major impact on image quality and characteristics. Therefore, it is important to include settings for focal length, shooting mode, shutter speed, aperture, ISO, metering mode, focus, etc. If payloads, sensors, or settings were changed for different objectives, clarify this here. If applicable, provide information on any sensor mounting or stabilization system used. Describe how the sensor or payload was operated during flight: e.g., fixed or operator-controlled camera orientation and zoom, manual or automated camera triggering, etc. State whether the data were downloaded or viewed in real time or stored onboard the drone (or both), and in the latter case, by what means (e.g., onboard SD cards). If applicable, describe how the imagery was georeferenced: e.g., direct geotagging of photos and use of ground control points (GCPs) (including the number and layout of GCPs, along with the make and model of the GPS receiver used to survey them). In the case of imagery that was subsequently mosaicked, state the percentage of forward and lateral overlap between photos. Finally, it is of key importance to state the spatial resolution of aerial imagery, e.g., the size of the pixels on the ground or ground sampling distance.

4. Field operation details

Provide a summary of the operational details of the drone work conducted in the study. In cases of relatively simple or straightforward operations such as those involving a single flight or multiple flights with the same general parameters, details in this section may be limited to a level comparable to the information typically provided in the main body of a manuscript. For example, include date(s) and time(s) of operations (can be given as ranges), weather conditions (e.g., range of temperatures and wind speeds), total number of flights, flight duration(s) (average and range), and flight altitude(s) (usually expressed as above ground level except for marine operations). However, for more complex operations such as those involving numerous flights, many flight days, more than one drone, multiple different locations or focal wildlife species, varying flight or sensor parameters, or particular dependency on precise timing or environmental conditions, authors should provide sufficient detail for readers to be able to properly follow and assess these specifics. More detailed operational summaries may be provided, for example, in table format. State whether the operational range (area surveyed) was limited by the vehicle or due to regulations or permissions restricting beyond-line-of-sight surveys.

5. Data post-processing

Describe any post-processing that was performed to prepare the raw data for formal analysis. For georeferenced imagery, this commonly involves photogrammetric processing to produce orthomosaics or digital surface models, in which case authors should state which software was used and any processing templates or presets that were applied or any special settings that were used at various stages to optimize results. Mention any special processing steps taken with regard to radiometric calibration or georeferencing of the imagery and, if relevant and possible, provide estimates of the error associated with these processes. State the spatial resolution of the various final outputs if it differs from that of the raw imagery. Authors are encouraged to include any software-generated processing logs and quality reports in an appendix to provide full details of processing parameters and results. If any integrated automated detection features are employed, provide any relevant details that are used to prepare the data for analysis.

6. Permits, regulations, training, and logistics

Public opinion of drone use remains apprehensive, and potential users may be surprised to learn of conflict between researchers and the public when it comes to drones (Markowitz et al. 2017). As such, responsible use is imperative to the continued use and acceptance of drones in natural sciences. This section is intended to demonstrate regulatory compliance, provide a primer for the amount of preparatory work and considerations required prior to drone operation, and emphasize the extent of operator training that may be required for the specific system used in the study. All permits directly relevant to the use of a drone in the study should be listed here (e.g., government permits, approved animal care protocols, etc.). As drone technology continues to become more accessible, regulations governing their use are likely to change and readers will benefit from current information on permitting requirements (Duffy et al. 2018). Authors are also encouraged to mention if any aspects of the work they had originally set out to accomplish with the drone were precluded by regulatory restrictions, or if the drone's potential contributions to the study were otherwise limited in any significant way by regulations. If any special training courses or pilot certifications were required, these should be reported as well. Finally, mention any other significant logistical issues or considerations that arose from the drone use in the study, such as challenges transporting high-capacity batteries to the study location onboard commercial airplanes.

7. Discussion

Until very recently, drones were viewed as an interesting novelty in place of more established remote sensing technologies (Chabot 2018). However, the rapid integration of drones into the wildlife sciences, along with their breadth of applications, has secured their place among the toolkit of wildlife researchers. Here we have provided a standardized approach for reporting drone methodological details for the process of peer review and replication. As technology changes so will considerations for reporting requirements; therefore, future studies will likely need to provide additional information not covered by this protocol. As such, our goal here is not to provide an all-encompassing protocol, but rather create a set of basic standards of reporting in ecological studies involving drones. Ultimately, the onus is upon authors to provide the relevant information that is required to evaluate and replicate the data collection by drones in their research.

Increasingly, larger-scale drone research is being conducted by third parties, alleviating financial costs of drone models capable of long-distance surveys for single principal investigators or small laboratories. In these cases, the use of drone data for ecological research becomes analogous to the acquisition of satellite imagery, whereby a third party collects data, and researchers are supplied with the data for analysis and interpretation. However, the commercial acquisition of drone imagery does not release authors from the responsibility of providing the technical details of the original data collection required to replicate study design. If third-party drone operators are employed for ecological studies, researchers will have to work closely with operators to provide the relevant information when producing manuscripts for peer review.

Standardization of a reporting structure is key to improving communication and dissemination of research. This protocol has been designed so that no specialized equipment or extraneous effort is needed for its production. Indeed, all of the information listed within the protocol should already be possessed by the researcher(s), and could reasonably be requested by an informed reviewer or editor. We hope this provides authors with a method by which they can readily organize their information for readers. To facilitate the uptake and ease of use of this protocol, we have included two example protocols (example protocol #1 for Hodgson et al. (2017) and example protocol #2 for Barnas et al. (2018*a*)) as Supplementary Material[1] retroactively produced by the authors of this protocol. We hope that in doing so, we have sufficiently covered a diversity of applications and pre-emptively addressed common questions or scenarios.

Authors will still have to provide a general overview for the method of data collection in the manuscript, but this protocol will ultimately save the reader from the minutia of drone and sensor detail that would otherwise be embodied in the methods section of manuscripts. In cases where information may be repeated in the main manuscript, we encourage authors to also include this information in the supplemental drone protocol, thereby allowing the protocol to be assessed independently.

Note it is not intended that this protocol include any details on the statistical or spatial analyses of data, unless such analyses were used in informing flight design and data collection. Our hopes are that the current version of this protocol should assist with the communication, dissemination, and adoption of drone technology for wildlife research and management.

Acknowledgements

AFB was supported by North Dakota EPSCoR Infrastructure Improvement Program-Doctoral Dissertation Assistantship #OIA-1355466. SNE and AFB were supported by the Department of Biology, University of North Dakota. The authors wish to thank the funding support of the Kenneth Molson Foundation and general support of the *Journal of Unmanned Vehicle Systems*. We are greatly appreciative for the constructive feedback provided by the Associate Editor and anonymous reviewer, as well as assistance from Donna Hartson during the peer-review process. Any funders had no role in the conception, preparation, or the decision to publish for this manuscript.

References

Adame, K., Pardo, M.A., Salvadeo, C., Beier, E., and Elorriaga-Verplancken, F.R. 2017. Detectability and categorization of California sea lions using an unmanned aerial vehicle. Mar. Mammal Sci. **33**(3): 913–925. doi: 10.1111/mms.12403.

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

Barnas, A.F., Newman, R., Felege, C.J., Corcoran, M.P., Hervey, S.D., Stechmann, et al. 2018*a*. Evaluating behavioral responses of nesting lesser snow geese to unmanned aircraft surveys. Ecol. Evol. **8**(2): 1328–1338. doi: 10.1002/ece3.3731.

Barnas, A.F., Felege, C.J., Rockwell, R.F., and Ellis-Felege, S.N. 2018*b*. A pilot(less) study on the use of an unmanned aircraft system for studying polar bears (*Ursus maritimus*). Polar Biol. **41**: 1055–1062. doi: 10.1007/s00300-018-2270-0.

Baxter, P.W., and Hamilton, G. 2018. Learning to fly: Integrating spatial ecology with unmanned aerial vehicle surveys. Ecosphere, **9**(4): 1–17. doi: 10.1002/ecs2.2194.

Bonnin, N., Van Andel, A., Kerby, J., Piel, A., Pintea, L., and Wich, S. 2018. Assessment of chimpanzee nest detectability in drone-acquired images. Drones, **2**(2): 17. doi: 10.3390/drones2020017.

Borrelle, S.B., and Fletcher, A.T. 2017. Will drones reduce investigator disturbance to surface-nesting seabirds? Mar. Ornithol. **45**: 89–94.

Brack, I.V., Kindel, A., and Oliveira, L.F.B. 2018. Detection errors in wildlife abundance estimates from unmanned aerial systems (UAS) surveys: Synthesis, solutions, and challenges. Methods Ecol. Evol. **9**(8): 1864–1873. doi: 10.1111/2041-210X.13026.

[1]Supplementary material is available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/juvs-2019-0011.

Buters, T.M., Bateman, P.W., Robinson, T., Belton, D., Dixon, K.W., and Cross, A.T. 2019. Methodological ambiguity and inconsistency constrain unmanned aerial vehicles as a silver bullet for monitoring ecological restoration. Remote Sens. **11**(10): 1180. doi: 10.3390/rs11101180.

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

Chabot, D., and Bird, D.M. 2015. Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in? J. Unmanned Veh. Syst. **3**(4): 137–155. doi: 10.1139/juvs-2015-0021.

Chabot, D., Carignan, V., and Bird, D.M. 2014. Measuring habitat quality for least bitterns in a created wetland with use of a small unmanned aircraft. Wetlands, **34**(3): 527–533. doi: 10.1007/s13157-014-0518-1.

Chabot, D., Craik, S.R., and Bird, D.M. 2015. Population census of a large common tern colony with a small unmanned aircraft. PLoS ONE, **10**(4): e0122588. doi: 10.1371/journal.pone.0122588. PMID: 25874997.

Chapman, A. 2014. It's okay to call them drones. J. Unmanned Veh. Syst. **2**(2): iii–v. doi: 10.1139/juvs-2014-0009.

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

Cliff, O.M., Saunders, D.L., and Fitch, R. 2018. Robotic ecology: Tracking small dynamic animals with an autonomous aerial vehicle. Sci. Robot. **3**(23): eaat8409. doi: 10.1126/scirobotics.aat8409.

Crutsinger, G.M., Short, J., and Sollenberger, R. 2016. The future of UAVs in ecology: An insider perspective from the Silicon Valley drone industry. J. Unmanned Veh. Syst. **4**(3): 161–168. doi: 10.1139/juvs-2016-0008.

Desrochers, A., Tremblay, J., Aubry, Y., Chabot, D., Pace, P., and Bird, D. 2018. Estimating wildlife tag location errors from a VHF receiver mounted on a drone. Drones, **2**(4): 44. doi: 10.3390/drones2040044.

Duffy, J.P., Cunliffe, A.M., DeBell, L., Sandbrook, C., Wich, S.A., Shutler, J.D., et al. 2018. Location, location, location: Considerations when using lightweight drones in challenging environments. Remote Sens. Ecol. Conserv. **4**(1): 7–19. doi: 10.1002/rse2.58.

Ellison, A.M. 2010. Repeatability and transparency in ecological research. Ecology, **91**(9): 2536–2539. doi: 10.1890/09-0032.1. PMID: 20957944.

Elsey, R.M., and Trosclair, P.L., III. 2016. The use of an unmanned aerial vehicle to locate alligator nests. Southeast. Nat. **15**(1): 76–82. doi: 10.1656/058.015.0106.

Fidler, F., Chee, Y.E., Wintle, B.C., Burgman, M.A., McCarthy, M.A., and Gordon, A. 2017. Metaresearch for evaluating reproducibility in ecology and evolution. BioScience, **67**(3): 282–289. doi: 10.1093/biosci/biw159. PMID: 28596617.

Fiori, L., Doshi, A., Martinez, E., Orams, M.B., and Bollard-Breen, B. 2017. The use of unmanned aerial systems in marine mammal research. Remote Sens. **9**(6): 543. doi: 10.3390/rs9060543.

Fraser, R.H., Olthof, I., Lantz, T.C., and Schmitt, C. 2016. UAV photogrammetry for mapping vegetation in the low-Arctic. Arct. Sci. **2**(3): 79–102. doi: 10.1139/as-2016-0008.

Fu, Y., Kinniry, M., and Kloepper, L.N. 2018. The Chirocopter: A UAV for recording sound and video of bats at altitude. Methods Ecol. Evol. **9**(6): 1531–1535. doi: 10.1111/2041-210X.12992.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., et al. 2006. A standard protocol for describing individual-based and agent-based models. Ecol. Model. **198**(1–2): 115–126. doi: 10.1016/j.ecolmodel.2006.04.023.

Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., and Railsback, S.F. 2010. The ODD protocol: A review and first update. Ecol. Model. **221**(23): 2760–2768. doi: 10.1016/j.ecolmodel.2010.08.019.

Guo, X., Shao, Q., Li, Y., Wang, Y., Wang, D., Liu, J., et al. 2018. Application of UAV remote sensing for a population census of large wild herbivores — Taking the headwater region of the Yellow River as an example. Remote Sens. **10**(7): 1041. doi: 10.3390/rs10071041.

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

Hodgson, A., Peel, D., and Kelly, N. 2017. Unmanned aerial vehicles for surveying marine fauna: Assessing detection probability. Ecol. Appl. **27**(4): 1253–1267. doi: 10.1002/eap.1519. PMID: 28178755.

Hodgson, J.C., and Koh, L.P. 2016. Best practice for minimising unmanned aerial vehicle disturbance to wildlife in biological field research. Curr. Biol. **26**(10): R404–R405. doi: 10.1016/j.cub.2016.04.001. PMID: 27218843.

Hodgson, J.C., Baylis, S.M., Mott, R., Herrod, A., and Clarke, R.H. 2016. Precision wildlife monitoring using unmanned aerial vehicles. Sci. Rep. **6**: 22574. doi: 10.1038/srep22574. PMID: 26986721.

Hu, J., Wu, X., and Dai, M. 2020. Estimating the population size of migrating Tibetan antelopes Pantholops hodgsonii with unmanned aerial vehicles. Oryx, **54**(1): 101–109. doi: 10.1017/S0030605317001673.

Israel, M. 2011. A UAV-based roe deer fawn detection system. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **38**(1/C22): 51–55. doi: 10.5194/isprsarchives-XXXVIII-1-C22-51-2011.

Johnston, D.W. 2019. Unoccupied aircraft systems in marine science and conservation. Annu. Rev. Mar. Sci. **11**: 439–463. doi: 10.1146/annurev-marine-010318-095323.

Johnston, M., McCaldin, G., and Rieker, A. 2016. Assessing the availability of aerially delivered baits to feral cats through rainforest canopy using unmanned aircraft. J. Unmanned Veh. Syst. **4**(4): 276–281. doi: 10.1139/juvs-2016-0012.

Junda, J., Greene, E., and Bird, D.M. 2015. Proper flight technique for using a small rotary-winged drone aircraft to safely, quickly, and accurately survey raptor nests. J. Unmanned Veh. Syst. **3**(4): 222–236. doi: 10.1139/juvs-2015-0003.

Kilkenny, C., Browne, W.J., Cuthill, I.C., Emerson, M., and Altman, D.G. 2010. Improving bioscience research reporting: The ARRIVE guidelines for reporting animal research. PLoS Biol. **8**(6): e1000412. doi: 10.1371/journal.pbio.1000412. PMID: 20613859.

Koski, W.R., Gamage, G., Davis, A.R., Mathews, T., LeBlanc, B., and Ferguson, S.H. 2015. Evaluation of UAS for photographic re-identification of bowhead whales, *Balaena mysticetus*. J. Unmanned Veh. Syst. **3**(1): 22–29. doi: 10.1139/juvs-2014-0014.

Linchant, J., Lisein, J., Semeki, J., Lejeune, P., and Vermeulen, C. 2015. Are unmanned aircraft systems (UASs) the future of wildlife monitoring? A review of accomplishments and challenges. Mammal Rev. **45**(4): 239–252. doi: 10.1111/mam.12046.

Marcaccio, J.V., Markle, C.E., and Chow-Fraser, P. 2016. Use of fixed-wing and multi-rotor unmanned aerial vehicles to map dynamic changes in a freshwater marsh. J. Unmanned Veh. Syst. **4**(3): 193–202. doi: 10.1139/juvs-2015-0016.

Markowitz, E.M., Nisbet, M.C., Danylchuk, A.J., and Engelbourg, S.I. 2017. What's that buzzing noise? Public opinion on the use of drones for conservation science. BioScience, **67**(4): 382–385. doi: 10.1093/biosci/bix003.

McEvoy, J.F., Hall, G.P., and McDonald, P.G. 2016. Evaluation of unmanned aerial vehicle shape, flight path and camera type for waterfowl surveys: Disturbance effects and species recognition. PeerJ, **4**: e1831. doi: 10.7717/peerj.1831. PMID: 27020132.

Meek, P., Ballard, G., Claridge, A., Kays, R., Moseby, K., O'Brien, T., et al. 2014. Recommended guiding principles for reporting on camera trapping research. Biodivers. Conserv. **23**(9): 2321–2343. doi: 10.1007/s10531-014-0712-8.

Michez, A., Morelle, K., Lehaire, F., Widar, J., Authelet, M., Vermeulen, C., and Lejeune, P. 2016. Use of unmanned aerial system to assess wildlife (*Sus scrofa*) damage to crops (*Zea mays*). J. Unmanned Veh. Syst. **4**(4): 266–275. doi: 10.1139/juvs-2016-0014.

Mislan, K., Heer, J.M., and White, E.P. 2016. Elevating the status of code in ecology. Trends Ecol. Evol. **31**(1): 4–7. doi: 10.1016/j.tree.2015.11.006. PMID: 26704455.

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

Mulero-Pázmány, M., Negro, J.J., and Ferrer, M. 2013. A low cost way for assessing bird risk hazards in power lines: Fixed-wing small unmanned aircraft systems. J. Unmanned Veh. Syst. **2**(1): 5–15. doi: 10.1139/juvs-2013-0012.

Mulero-Pázmány, M., Stolper, R., Van Essen, L., Negro, J.J., and Sassen, T. 2014. Remotely piloted aircraft systems as a rhinoceros anti-poaching tool in Africa. PLoS ONE, **9**(1): e83873. doi: 10.1371/journal.pone.0083873. PMID: 24416177.

Mulero-Pázmány, M., Jenni-Eiermann, S., Strebel, N., Sattler, T., Negro, J.J., and Tablado, Z. 2017. Unmanned aircraft systems as a new source of disturbance for wildlife: A systematic review. PLoS ONE, **12**(6): e0178448. doi: 10.1371/journal.pone.0178448. PMID: 28636611.

Mustafa, O., Barbosa, A., Krause, D.J., Peter, H.-U., Vieira, G., and Rümmler, M.-C. 2018. State of knowledge: Antarctic wildlife response to unmanned aerial systems. Polar Biol. **41**: 2387–2398. doi: 10.1007/s00300-018-2363-9.

Olivares-Mendez, M., Fu, C., Ludivig, P., Bissyandé, T., Kannan, S., Zurad, M., et al. 2015. Towards an autonomous vision-based unmanned aerial system against wildlife poachers. Sensors, **15**(12): 31362–31391. doi: 10.3390/s151229861. PMID: 26703597.

Olsoy, P.J., Shipley, L.A., Rachlow, J.L., Forbey, J.S., Glenn, N.F., Burgess, M.A., and Thornton, D.H. 2018. Unmanned aerial systems measure structural habitat features for wildlife across multiple scales. Methods Ecol. Evol. **9**(3): 594–604. doi: 10.1111/2041-210X.12919.

Pirotta, V., Smith, A., Ostrowski, M., Russell, D., Jonsen, I.D., Grech, A., and Harcourt, R. 2017. An economical custom-built drone for assessing whale health. Front. Mar. Sci. **4**: 425. doi: 10.3389/fmars.2017.00425.

Puttock, A., Cunliffe, A., Anderson, K., and Brazier, R.E. 2015. Aerial photography collected with a multirotor drone reveals impact of Eurasian beaver reintroduction on ecosystem structure. J. Unmanned Veh. Syst. **3**(3): 123–130. doi: 10.1139/juvs-2015-0005.

Ratcliffe, N., Guihen, D., Robst, J., Crofts, S., Stanworth, A., and Enderlein, P. 2015. A protocol for the aerial survey of penguin colonies using UAVs. J. Unmanned Veh. Syst. **3**(3): 95–101. doi: 10.1139/juvs-2015-0006.

Rees, Al.F., Avens, L., Ballorain, K., Bevan, E., Broderick, A.C., Carthy, R.R., et al. 2018. The potential of unmanned aerial systems for sea turtle research and conservation: A review and future directions. Endanger. Species Res. **35**: 81–100. doi: 10.3354/esr00877.

Schofield, G., Katselidis, K.A., Lilley, M.K., Reina, R.D., and Hays, G.C. 2017. Detecting elusive aspects of wildlife ecology using drones: New insights on the mating dynamics and operational sex ratios of sea turtles. Funct. Ecol. **31**(12): 2310–2319. doi: 10.1111/1365-2435.12930.

Su, X., Dong, S., Liu, S., Cracknell, A.P., Zhang, Y., Wang, X., and Liu, G. 2018. Using an unmanned aerial vehicle (UAV) to study wild yak in the highest desert in the world. Int. J. Remote Sens. **39**(15–16): 5490–5503. doi: 10.1080/01431161.2018.1441570.

Thapa, G.J., Thapa, K., Thapa, R., Jnawali, S.R., Wich, S.A., Poudyal, L.P., and Karki, S. 2018. Counting crocodiles from the sky: Monitoring the critically endangered gharial (*Gavialis gangeticus*) population with an unmanned aerial vehicle (UAV). J. Unmanned Veh. Syst. **6**(2): 71–82. doi: 10.1139/juvs-2017-0026.

Van Andel, A.C., Wich, S.A., Boesch, C., Koh, L.P., Robbins, M.M., Kelly, J., and Kuehl, H.S. 2015. Locating chimpanzee nests and identifying fruiting trees with an unmanned aerial vehicle. Am. J. Primatol. **77**(10): 1122–1134. doi: 10.1002/ajp.22446. PMID: 26179423.

Vermeulen, C., Lejeune, P., Lisein, J., Sawadogo, P., and Bouché, P. 2013. Unmanned aerial survey of elephants. PLoS ONE, **8**(2): e54700. doi: 10.1371/journal.pone.0054700. PMID: 23405088.

Weissensteiner, M.H., Poelstra, J.W., and Wolf, J.B. 2015. Low-budget ready-to-fly unmanned aerial vehicles: An effective tool for evaluating the nesting status of canopy-breeding bird species. J. Avian Biol. **46**(4): 425–430. doi: 10.1111/jav.00619.
Wich, S., Dellatore, D., Houghton, M., Ardi, R., and Koh, L.P. 2016. A preliminary assessment of using conservation drones for Sumatran orang-utan (*Pongo abelii*) distribution and density. J. Unmanned Veh. Syst. **4**(1): 45–52. doi: 10.1139/juvs-2015-0015.
Wilson, A.M., Barr, J., and Zagorski, M. 2017. The feasibility of counting songbirds using unmanned aerial vehicles. Auk, **134**(2): 350–362. doi: 10.1642/AUK-16-216.1.
Zuur, A.F., and Ieno, E.N. 2016. A protocol for conducting and presenting results of regression-type analyses. Methods Ecol. Evol. **7**(6): 636–645. doi: 10.1111/2041-210X.12577.