**Contribution of RPAS in research and conservation in protected areas: present and future**

Park managers demands practical, cost-effective and innovative solutions to handle an overwhelming amount of environmental issues requiring appropriate data-driven decision making. While RPAS have been called upon to revolutionize conservation, bottlenecks for integrating them into PAs come from different fronts, ranging from legal and social issues to operational challenges. A bibliographic survey was conducted to value the current state and prospects of RPAS, and how they can strengthen effective management in the scope of protected areas. We discuss multiple facets of applications, provide specific examples and suggest plausible scenarios to help achieve conservation goals in PAs, highlighting some trends, drawbacks and opportunities that apparently have not yet been adequately exploited.

Keywords: protected areas, RPAS, conservation, review, effective management, threats, pressures, wildlife, ecosystems, environmental assessment, emergency response, ecotourism

# Introduction

As defined by UICN, "a protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). Despite such praiseworthy intentions, PAs are still subject to a wide variety of unforeseen challenges requiring rapid and effective solutions (Watson et al. 2014). Habitat change and fragmentation, pollution, overexploitation of natural resources, climate change and invasive species have been identified as main global threats to biodiversity (Groom, Meffe, and Caroll 2006). To curb the loss of biodiversity while attending other inherent activities, PAs have benefit from a wide range of technological advances, methods or innovative application of existing technologies (Pimm et al. 2015) to assess, monitor and predict the state and pressures of PAs. More recently, remotely piloted aircraft systems (RPAS, also known as unmanned aerial systems, UAS, drones) have been the subject of a growing interest in both the civilian and scientific sphere and indeed avowed as a new distinct era of remote sensing for the study of environment (Melesse et al. 2007). RPAS offer a relatively risk-free and low-cost manner to rapidly and autonomously observe natural phenomes at high spatiotemporal resolution. Not surprisingly, RPAS have become a major trend in conservation according to the bibliography (Koh and Wich 2012; Anderson and Gaston 2013; Linchant et al. 2015a; Christie et al. 2016; Torresan et al. 2017). To date, however, it has not been adequately weighted how the full range of RPAS applications can help decision-makers to effectively attend management and face threats to PAs. To shed light on this question, we carried out an extensive literature revision to get a snapshot of the current state and perspectives of RPAS within PAs. We found that RPAS applications for wildlife research and habitat monitoring are suitable to track species and ecosystems responses to management at local scale, but potential disturbance effects and technological shortcomings should be carefully considered. Other facets, such enforcement have ostensibly received minor attention from the academia, despite the fact that poaching and other forms of illicit biological resource use are a major threat to biodiversity (Leverington et al. 2010). In addition, RPAS have been applied to support emergency response and hazard risk management, wildfires, pollution monitoring and ecotourism, representing a set of conceivable operational scenarios claiming a place on the PAs management toolset.

# Methods

A bibliographical review (see PRISMA Flowchart) of scientific articles, gray literature, postgraduate theses and websites was carried out, following a similar line to other related studies (Linchant et al. 2015b; Christie et al. 2016; Mulero-Pázmány et al. 2017). Last reference revised was published on October 2017. The main tool for selecting bibliography was Google Scholar. Key search criteria, primarily in English, encompass RPAS in their various meanings and acronyms, reflecting the varied terminology used. Keywords were combined with terms referring to topics related to RPAS, threats and common conservation measurements in PAs (see table 1) using logical disjunctions. A total of 47 search terms and combinations were applied. A sweep of bibliographical citations and related articles was performed and further complemented with some other recent references found elsewhere (Research Gate, Mendeley Desktop, Review articles, Internet search engines), resulting in more than 500 articles. After removing duplicated, review articles and spurious results, the remaining publications (377) were revised at different levels of depth and grouped according to the following interrelated categories: “wildlife research and management” (102), for those projects aimed at observing wildlife, estimate population parameters such abundance and distribution, and devising management measures to mitigate human-wildlife conflicts; “habitat research and management" (114), with regards to applications for the study and mapping of natural habitats; “Law enforcement” encompasses poaching, and other illicit activities; "Ecotourism" (4) is restricted to recreational activities and visitors management; “Environmental management and emergency response" (84) span from environmental monitoring and protection, search and rescue activities, natural risk assessment and similar issues. We briefly tackled legal and ethical issues, including potential impact on wildlife and habitats, but also economic and technological factors, since all shape the feasibility of RPAS to approach conservation and environmental issues. To guide the study, we identify common threats and essential management measures in PAs from the “Management effectiveness evaluation in protected areas – a global study” (Leverington et al. 2010) report and other alternatives sources. Examples are provided (table 2) and plausible scenarios to help achieve conservation goals in PAs are suggested, highlighting some trends, drawbacks and opportunities that apparently have not yet been adequately exploited.

# Results and discussion

## Wildlife research and management

Ecological monitoring is essential to track the response of wildlife to management and environmental factors, and assess whether distinct or further measurements are required to maintain viable populations (Gibbs et al. 1999). Compared with other methodologies, remotely sensed capabilities of RPAS offer a less invasive, non-hazardous and reliable monitoring technique (Jewell 2013) to collect abundance, distributional, behavioural, life-history and environmental data. Recent examples target large and medium size terrestrial mammals (Chrétien et al. 2016; Wich et al. 2016), marine mammals (Sweeney et al. 2016; Seymour et al. 2017; Hodgson et al. 2017), birds (Weissensteiner et al. 2015; Christie et al. 2016; J. C. Hodgson et al. 2016; Sardà-Palomera et al. 2017), reptiles (Evans et al. 2015; Elsey et al. 2016; Schofield et al. 2017), and fishes (Groves et al. 2016; Kiszka et al. 2016). While most surveys opted for both optical and thermal cameras, others implement acoustic sensors (Wilson et al. 2017) and RPAS based wildlife tracking systems (Mulero-Pázmány et al. 2015; Bayram et al. 2016; Xu et al. 2016).

On the other hand, human-wildlife conflicts are also present both in PAs and nearby locations as result of increasingly pressures on natural habitats. Within this topic, RPAS have been used to move elephants out of human settlements (Hahn et al. 2017), calculate compensation costs for wildlife damage on crops (Michez, Morelle, et al. 2016), select suitable locations to install ecological corridors in populations impacted by roadkill (Gülci and Akay 2016) or dropping fake baits targeting feral species (McCaldin, Johnston, and Rieker 2015). RPAS also constitute an attainable low-cost alternative to assess and reduce the risk that hazardous facilities (Mulero-Pázmány, Negro, and Ferrer 2014; Lobermeier et al. 2015) and mechanical harvesting (Israel 2012; Christiansen et al. 2014; Israel and Reinhard 2017) pose to wildlife. Finally, direct observation and mapping of environmental correlates have been applied for epidemiological and zoonotic studies threatening wildlife and humans (Fornace et al. 2014; Barasona et al. 2014; Hardy et al. 2017), providing a rapid manner to inform prevention and reinforce biosecurity programmes.

### Impact of RPAS on wildlife and ecosystems

Animal welfare and perturbation of sensitive habitat in wildlife management and ecological research is source of strong debate (F. Dormann et al. 2007; Wilson et al. 2006). RPAS are not exempt of discussion and consequently disturbance effects of RPAS on birds (Duriez et al. 2015; McEvoy et al. 2016; Fletcher 2017; Scobie et al. 2016; Weissensteiner et al. 2015; Lyons et al. 2017) and mammals (Ditmer et al. 2015; Pomeroy et al. 2015) were mainly documented. Despite a greater degree of awareness reflected in a emergent set of guidelines (Hodgson et al. 2016; Mulero-Pázmány et al. 2017; Gonzalez et al. 2017), most of studies marginally inform reactions and further trials aimed at quantifying changes in behavioural patterns and physiological effects targeting a broader group of wildlife is recommended. Also, we believe that development of RPAS platforms suited to wildlife projects remain fundamentally unexplored. Furthermore, a trade-off between benefits and environmental costs should be weighted (Grémillet et al. 2012; Sepúlveda et al. 2010). By designing quieter, non-polluting and safer components, the impact on wildlife and ecosystems could be reduced and its objective observation facilitated (Jewell 2013; Wilson et al. 2006), reducing sources of bias. Nonetheless, RPAS has great potential to evolve, replacing more invasive monitoring techniques. This should be consciously considered by those reluctant to integrate RPAS in research and conservation activities. Step by step, a code of best practice and recommendations could be continuously updated based on lessons learned (McEvoy et al. 2016), forming the basis for wildlife certified RPAS operators.

## Habitat research and management

Remote sensing environmental changes on threatened ecosystems from RPAS has the potential to surpass spatio-temporal scale challenges from aerial and satellite earth observation (Whitehead et al .2014), at affordable cost and providing rapid, flexible and precise in-situ measurements (Gross et al. 2009) in a regular basis, and without being affected by cloud coverage (Ballari et al. 2016). Similarly, mapping and quantifying ecosystem services from RPAS constitute an efficient mean to inform site design and planning in PAs where otherwise data is scarce or based on coarse environmental correlates. RPAS can also serve to assess whether higher rates of ecosystem degradation (land cover clearing, habitat loss and fragmentation) occur on surroundings areas (Mas 2005; Ewers and Rodrigues 2008), providing a mean to inform effectiveness of PAs designation and management. Experimental monitoring projects using RPAS have increased notoriously both by governmental institutions (U.S. Geological Survey National 2017) and research groups, where RPAS have been used to inform on the distribution (Puliti et al. 2015), health (Näsi et al. 2015; Michez et al. 2016) , productivity (Tian et al. 2017) , composition (Franklin et al. 2017) , structure and biomass (Messinger, Asner, and Silman 2016; Bedell et al. 2017; Rödig et al. 2017) of forests using both passive and active sensors (Sankey et al. 2017). As a result, RPAS forestry applications to inventory, characterization and habitat restoration are maturing fast, but scaling-up and linking the information collected at local scales to relatively coarse remote sensing data covering greater extensions remain a knowledge gap (Adam M. Wilson et al. 2011). RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014), providing a novel mean to engage developing countries within the carbon market (Reducing Emissions from Deforestation and forest Degradation, REDD). Other contributions focus on measuring the spread of invasive species (Michez, Piégay, Jonathan, et al. 2016; Müllerová et al. 2017; Perroy, et al. 2017), mapping coastal marine habitats (Ventura et al. 2016), wetlands (Pande-Chhetri et al. 2017; Marcaccio, Markle et al. 2015), grasslands (Lu and He 2017; Wang et al. 2017), polar (Fraser et al. 2016; Malenovský et al. 2017) and riparian ecosystems (Husson 2016), representing a non-exhaustive list of different environments where RPAS have successfully operated.

## Law enforcement

Effective control and surveillance of illicit activities is considered an essential management measurement to maintain the integrity of threatened species and ecosystems (Hilborn et al. 2006). But difficulty of enforcement is especially patent in large PAs, where many species are on the verge of extinction due to illegal hunting, fishing, encroachment or habitat loss. RPAS constitute a technological advance to complement insufficient staff and resourcing in anti-poaching (Mulero-Pázmány et al. 2014; Franco et al. 2016; M. A. Olivares-Mendez et al. 2014; Shaffer and Bishop 2016) and other less contentious acts (Sabella et al. 2017; Weber and Knaus 2017). However, the lack of scientific articles proving the use of RPAS to combat poaching might be explained by technological shortcomings and legal constraints, in spite of attract considerable attention from environmental organizations and media. Relative low endurance of affordable platforms limits the area under surveillance, a major obstacle to cover large natural areas. Technical and operational deployment is a complex undertaking and issues concerning recognition of suspicious activity or flying in adverse weather conditions have not yet been completely resolved. Notwithstanding, meeting the optimal specifications can be considered costly, especially in developing countries (Banzi 2014). However, as technology increasingly will become more accessible and sophisticated, it is expected that main barriers will appear in the legislative and sociopolitical sphere. For instance, flying beyond the visual line of sight (BVLOS) or above a certain altitude is often forbidden, restricting the usefulness of the inspection. This highlights the urgent need to seek consensus among countries and adapt legislation to distinguish amongst the purpose of leisure, research and management. But ethical and social issues are also factors to bear in mind. Detractors are skeptical about the ability of RPAS to persuade offenders, who in many cases go through a situation of great need. (Duffy 2014) analyzed the consequences of the militarization of conservation practices as an increasing trend in PAs around the world and illustrates how RPAS and other technologies can contribute to human right breaching, compromising effective conservation through the lack of commitment of the communities (Sandbrook 2015). However, some studies have remarked that the effectiveness of antipoaching depends on a greater allocation of resources (Hilborn et al. 2006). For instance, vessel patrol are considered difficult and expensive, but the record of illegal fishing within the boundaries of marine protected areas may be considered a reliable evidence for the court, even when offenders are seized outside the no catchment area. Probably the success of such initiatives requires a greater consensus among the parties involved and the development of strategies that seek to solve the causes of poaching.

## Ecotourism

Well-managed ecotourism serves conservation and brings socioeconomic benefits to local communities, stressing the need for environmental stewardship. On the contrary, it can also negatively affect animal welfare and their habitats (Samia et al. 2017). In the midst of the dilemma, RPAS have been proposed for recreational and educational purposes (King 2014; Chamata and King 2017), social research and visitor surveillance (Hansen 2016; Park and Ewing 2017). However, RPAS can also disturb wildlife, compromise tourist experience or lead to unexpected hazardous events in case of accidents, like water pollution or wildfires in sensitive areas due to the presence of toxic and flammable components. Subsequently, to restrain the uncontrolled presence of RPAS in PAs, stakeholders agreed on a set of policies to establish permitted activities in Antarctica (Leary 2017), opted for simpler rules and recommendations (OEH 2017) or, not without founded reasons, completely banned RPAS arguing safety reasons and wildlife impact (Peyer 2015). Even when the economic benefits and leisure possibilities are promising, undesirable events and a lack of ethical practise can fuel the low popularity of RPAS in detriment of the advantages they bring. Thus, it would be advisable to be cautious in the face of the demand of the ecotourism industry to incorporate RPAS within their promoted services and learn from others experience to evaluate the trade-off between the benefits and drawbacks they bring to PAs.

# Environmental management and emergency response

Anthropogenic disturbances, worsened by natural hazards are amid the most prevalent threats to maintain healthy and resilient ecosystem. Effectively managing PAs requires continuous monitoring of environmental indicators and physical parameters to ensure that potential sources of contamination are controlled or remain below a safety threshold and, if necessary, take corrective and restoration measures. In other cases, a rapid response is crucial to diminish the effects that natural and man-made disasters pose to natural resources and human being. Hazard risk assessment, planning and response are therefore essential measures to prevent and respond adequately to such circumstances. Although these actions are conventionally carried out in a combination of field work , airborne and satellite remote sensing , RPAS capabilities provide a valid alternative to remotely assist water, soil and air pollution sampling (Schwarzbach et al. 2014; Zang et al. 2012; Ore et al. 2015) and enable rapid image acquisition to monitor erosion (D’Oleire-Oltmanns et al. 2012), sediments dynamics (Casella et al. 2016), landslides (Jaukovic 2017), flood events (Izumida et al. 2016) oil spills (Messinger and Silman 2016) and wildfires (Wing et al. 2014; Cruz et al. 2016) at different stages. RPAS are also a valuable tool for rangers in search and rescue missions in the face of catastrophic scenarios (Cui et al. 2015), but also in remote mountainous (Karaca et al. 2017; Van Tilburg et al. 2017) and coastal marine regions. Such applications have operational requirements which eventually are costly. For instance, sophisticated on-board instruments, environmental sensors, advanced communications system, gas powered engines for longer endurance and heavier payloads or gear designed to assist sampling, hold cargo or deliver assistance. Besides, there are a variety of plausible scenarios where RPAS can demonstrate their usefulness, such assess damage in trails and amenities after natural hazard events, inspect facilities posing a risk to the environment (Gómez and Green 2017), or support plant invasion control by means of aerially deployed herbicide on target species (Rodriguez, Jenkins, and Leary 2017).

## Economic and technological factors

Expenses derived from the operation with RPAS are hardly quantifiable (AUVSI 2013) and depend on a confluence of factors. Although RPAS are relatively easy to operate, investment on technical and analytical expertise is not often adequately weighted. Computational requirements are demanding, big data storage options remain overpriced and certain phases of data processing requires the acquisition of commercial software or alternatively the recruitment of high-level specialized services. Also, operations with RPAS are not exempt from accidents thus having a negative impact on the budget originally planned. This is especially true with payload onboard, which is often the most expensive but also breakable part of the platform. Moreover, park rangers should be aware that there is no single solution covering all the conservation purposes (Koski 2010) and a trade-off analysis among available platforms should be pondered. While do-it-yourself (DIY) RPAS are often considered more versatile than commercial alternatives, further time is required for proper assembling and lack of experience could affect reliability. Suppliers often provide support, training and companion software, albeit services could be occasionally charged. On the other hand, environmental sensors and cameras deployed on RPAS collect massive amount of information, resulting in processing and methodological bottlenecks. When used for wildlife census, recurring to manual counting and identifying individuals is time consuming. Progress in computer vision and machine learning algorithms are intended to automate such procedures (Andrew and Shephard 2017; Chabot and Francis 2016; L. F. Gonzalez et al. 2016; Lhoest et al. 2015; van Gemert et al. 2015; Christiansen et al. 2014; Martin et al. 2012; Abd-Elrahman, Pearlstine, and Percival 2005; Longmore et al. 2017; Seymour et al. 2017). Despite encouraging results, these methods should be adapted to a broader range of species and probably implemented in more user-friendly packages. Also, further research should be encompassed to assess the overall performance of RPAS data collection techniques compared to more mature options where statistical and sampling methods to address the analysis and modelling of species distribution are available (J. C. Hodgson et al. 2016). Additionally, traditional pixel-based remote sensing algorithms for land-cover and vegetation classification are ineffective for ultra-high spatial resolution data from RPAS. As a result, machine learning techniques and object-based image analysis (OBIA) are likely to cope the next generation of classification methods (Whitehead and Hugenholtz 2014). The expected the arrival of hyperspectral miniaturized sensors (Pande-Chhetri et al. 2017), will bring more complexity to the matter, requiring novel analytical approaches not currently implemented. Conversely, the photogrammetric process is well documented and supported by a myriad of commercial software and emerging open source alternatives (Colomina and Molina 2014), probably at expense of major complexity.

# Conclusions

RPAS have remarkably demonstrated their adequacy to environmental monitoring and better inform management. Their versatility, portability and rapid deployment will probably make them attractive for many distinct PAs in the world. It would be desirable to conduct cost-benefit analysis when using RPAS instead of other conventional techniques. This require ponder socioeconomic and legal factors, technological restrictions, wildlife impact, planning management, adequate resourcing and staff training. Moreover, unlike satellite remote sensing where global facilities exist, establishing a management framework for easy integration and exploitation of the data gathered from the platform remain fundamentally unexplored and implies a technological barrier for those remote PAs lacking an adequate infrastructure. Still, it is likely that in the next decade RPAS will make a definitive leap to position themselves as a perfect complement to manage PAs.

Abd-Elrahman, Amr, Leonard Pearlstine, and Franklin Percival. 2005. “Development of Pattern Recognition Algorithm for Automatic Bird Detection from Unmanned Aerial Vehicle Imagery.” *Surveying and Land Information Science* 65 (1): 37.

Alvarez-taboada, Flor, Claudio Paredes, and Julia Julián-Pelaz. 2017. “Mapping of the Invasive Species Hakea Sericea Using Unmanned Aerial Vehicle ( UAV ) and WorldView-2 Imagery and an Object-Oriented Approach.” *Remote Sensing* 9 (913): 1–17. doi:10.3390/rs9090913.

Anderson, Karen, and Kevin J Gaston. 2013. “Lightweight Unmanned Aerial Vehicles Will Revolutionize Spatial Ecology.” *Frontiers in Ecology and the Environment* 11 (3): 138–46. doi:10.1890/120150.

Andrew, Margaret E, and Jill M Shephard. 2017. “Semi-Automated Detection of Eagle Nests: An Application of Very High-Resolution Image Data and Advanced Image Analyses to Wildlife Surveys.” doi:10.1002/rse2.38.

AUVSI. 2013. “Are UAS More Cost Effective than Manned Flights? | Association for Unmanned Vehicle Systems International.” *AUVSI*. http://www.auvsi.org/are-uas-more-cost-effective-manned-flights.

Ballari, D., D. Orellana, E. Acosta, A. Espinoza, and V. Morocho. 2016. “Uav Monitoring for Enviromental Management in Galapagos Islands.” *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*. doi:10.5194/isprsarchives-XLI-B1-1105-2016.

Banzi, Jamali Firmat. 2014. “A Sensor Based Anti-Poaching System in Tanzania.” *International Journal of Scientific and Research Publications* 4 (4): 1–7.

Barasona, José A., Margarita Mulero-Pázmány, Pelayo Acevedo, Juan J. Negro, María J. Torres, Christian Gortázar, and Joaquín Vicente. 2014. “Unmanned Aircraft Systems for Studying Spatial Abundance of Ungulates: Relevance to Spatial Epidemiology.” *PLoS ONE* 9 (12): 1–17. doi:10.1371/journal.pone.0115608.

Bayram, Haluk, Krishna Doddapaneni, Nikolaos Stefas, and Volkan Isler. 2016. “Active Localization of VHF Collared Animals with Aerial Robots,” no. 13: 74–75. doi:10.1109/COASE.2016.7743503.

Bedell, Emily, Monique Leslie, Katie Fankhauser, Jonathan Burnett, Michael G. Wing, and Evan A. Thomas. 2017. “Unmanned Aerial Vehicle-Based Structure from Motion Biomass Inventory Estimates.” *Journal of Applied Remote Sensing* 11 (2): 26026. doi:10.1117/1.JRS.11.026026.

Casella, Elisa, Antoine Collin, Daniel Harris, Sebastian Ferse, Sonia Bejarano, Valeriano Parravicini, James L. Hench, and Alessio Rovere. 2017. “Mapping Coral Reefs Using Consumer-Grade Drones and Structure from Motion Photogrammetry Techniques.” *Coral Reefs* 36 (1). Springer Berlin Heidelberg: 269–75. doi:10.1007/s00338-016-1522-0.

Casella, Elisa, Alessio Rovere, Andrea Pedroncini, Luigi Mucerino, Marco Casella, Luis Alberto Cusati, Matteo Vacchi, Marco Ferrari, and Marco Firpo. 2014. “Study of Wave Runup Using Numerical Models and Low-Altitude Aerial Photogrammetry: A Tool for Coastal Management.” *Estuarine, Coastal and Shelf Science* 149. Elsevier Ltd: 160–67. doi:10.1016/j.ecss.2014.08.012.

Casella, Elisa, Alessio Rovere, Andrea Pedroncini, Colin P. Stark, Marco Casella, Marco Ferrari, and Marco Firpo. 2016. “Drones as Tools for Monitoring Beach Topography Changes in the Ligurian Sea (NW Mediterranean).” *Geo-Marine Letters* 36 (2): 151–63. doi:10.1007/s00367-016-0435-9.

Chabot, Dominique, and Charles M. Francis. 2016. “Computer-Automated Bird Detection and Counts in High-Resolution Aerial Images: A Review.” *Journal of Field Ornithology* 87 (4): 343–59. doi:10.1111/jofo.12171.

Chamata, Johnny Elie, and Lisa Marie King. 2017. “The Commercial Use of Drones in U.S. National Parks.” *The International Technology Management Review* 6 (4): 158–64.

Chrétien, Louis-Philippe, Jérôme Théau, and Patrick Ménard. 2016. “Visible and Thermal Infrared Remote Sensing for the Detection of White-Tailed Deer Using an Unmanned Aerial System.” *Wildlife Society Bulletin* 40 (1): 181–91. doi:10.1002/wsb.629.

Christiansen, Peter, Kim Arild Steen, Rasmus Nyholm Jørgensen, and Henrik Karstoft. 2014. “Automated Detection and Recognition of Wildlife Using Thermal Cameras.” *Sensors (Switzerland)* 14 (8): 13778–93. doi:10.3390/s140813778.

Christie, Katherine S., Sophie L. Gilbert, Casey L. Brown, Michael Hatfield, and Leanne Hanson. 2016. “Unmanned Aircraft Systems in Wildlife Research: Current and Future Applications of a Transformative Technology.” *Frontiers in Ecology and the Environment* 14 (5): 241–51. doi:10.1002/fee.1281.

Colomina, I., and P. Molina. 2014. “Unmanned Aerial Systems for Photogrammetry and Remote Sensing: A Review.” *ISPRS Journal of Photogrammetry and Remote Sensing* 92. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS): 79–97. doi:10.1016/j.isprsjprs.2014.02.013.

Cruz, Henry, Martina Eckert, Juan Meneses, and José Fernán Martínez. 2016. “Efficient Forest Fire Detection Index for Application in Unmanned Aerial Systems (UASs).” *Sensors (Switzerland)* 16 (6). doi:10.3390/s16060893.

Cui, Jin Q., Swee King Phang, Kevin Z.Y. Ang, Fei Wang, Xiangxu Dong, Yijie Ke, Shupeng Lai, et al. 2015. “Drones for Cooperative Search and Rescue in Post-Disaster Situation.” In *Proceedings of the 2015 7th IEEE International Conference on Cybernetics and Intelligent Systems, CIS 2015 and Robotics, Automation and Mechatronics, RAM 2015*, 167–74. doi:10.1109/ICCIS.2015.7274615.

D’Oleire-Oltmanns, Sebastian, Irene Marzolff, Klaus Daniel Peter, and Johannes B. Ries. 2012. “Unmanned Aerial Vehicle (UAV) for Monitoring Soil Erosion in Morocco.” *Remote Sensing* 4 (11): 3390–3416. doi:10.3390/rs4113390.

Ditmer, Mark A., John B. Vincent, Leland K. Werden, Jessie C. Tanner, Timothy G. Laske, Paul A. Iaizzo, David L. Garshelis, and John R. Fieberg. 2015. “Bears Show a Physiological but Limited Behavioral Response to Unmanned Aerial Vehicles.” *Current Biology* 25 (17). Elsevier Ltd: 2278–83. doi:10.1016/j.cub.2015.07.024.

Dudley, Nigel. 2008. *Guidelines for Protected Area Management Categories*. *System*. Vol. 3. doi:10.2305/IUCN.CH.2008.PAPS.2.en.

Duffy, Rosaleen. 2014. “Waging a War to Save Biodiversity: The Rise of Militarized Conservation.” *International Affairs* 90 (4): 819–34. doi:10.1111/1468-2346.12142.

Duriez, Olivier, Guillaume Boguszewski, Elisabeth Vas, and David Gre. 2015. “Approaching Birds with Drones: First Experiments and Ethical Guidelines ´,” 2015–18.

Elsey, Ruth M., and Phillip L Trosclair III. 2016. “The Use of an Unmanned Aerial Vehicle to Locate Alligator Nests.” *SOUTHEASTERN NATURALIST* 15 (151): 76–82. doi:10.1656/058.015.0106.

Evans, Luke J., T. Hefin Jones, Keeyen Pang, Meaghan N. Evans, Silvester Saimin, and Benoit Goossens. 2015. “Use of Drone Technology as a Tool for Behavioral Research: A Case Study of Crocodilian Nesting.” *Herpetological Conservation and Biology* 10 (1): 90–98. doi:10.3233/978-1-61499-432-9-895.

Ewers, Robert M., and Ana S.L. Rodrigues. 2008. “Estimates of Reserve Effectiveness Are Confounded by Leakage.” *Trends in Ecology and Evolution*. doi:10.1016/j.tree.2007.11.008.

F. Dormann, Carsten, Jana M. McPherson, Miguel B. Araújo, Roger Bivand, Janine Bolliger, Gudrun Carl, Richard G. Davies, et al. 2007. “Methods to Account for Spatial Autocorrelation in the Analysis of Species Distributional Data: A Review.” *Ecography* 30 (5): 609–28. doi:10.1111/j.2007.0906-7590.05171.x.

Fletcher, Stephanie B. Borrelle; Andrew T. 2017. “Will Drones Reduce Investigator Disturbance to Surface-Nesting Birds?” *Marine Ornithology* 45 (January): 89–94.

Fornace, Kimberly M., Chris J. Drakeley, Timothy William, Fe Espino, and Jonathan Cox. 2014. “Mapping Infectious Disease Landscapes: Unmanned Aerial Vehicles and Epidemiology.” *Trends in Parasitology*. doi:10.1016/j.pt.2014.09.001.

Franco, Antonio Di, Pierre Thiriet, Giuseppe Di Carlo, Charalampos Dimitriadis, Patrice Francour, Nicolas L Gutiérrez, Alain Jeudy De Grissac, et al. 2016. “Five Key Attributes Can Increase Marine Protected Areas Performance for Small-Scale Fisheries Management.” *Nature Publishing Group*, no. November. Nature Publishing Group: 1–9. doi:10.1038/srep38135.

Franklin, Steven E., and Oumer S. Ahmed. 2017. “Deciduous Tree Species Classification Using Object-Based Analysis and Machine Learning with Unmanned Aerial Vehicle Multispectral Data.” *International Journal of Remote Sensing*. doi:10.1080/01431161.2017.1363442.

Fraser, Robert H., Ian Olthof, Trevor C. Lantz, and Carla Schmitt. 2016. “UAV Photogrammetry for Mapping Vegetation in the Low-Arctic.” *Arctic Science* 2 (3): 79–102. doi:10.1139/as-2016-0008.

Gemert, Jan C van, Camiel R Verschoor, Pascal Mettes, Kitso Epema, Lian Pin Koh, and Serge Wich. 2015. “Nature Conservation Drones for Automatic Localization and Counting of Animals.” *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* 8925: 255–70. doi:10.1007/978-3-319-16178-5\_17.

Gibbs, J P, H L Snell, and C E Causton. 1999. “Effective Monitoring for Adaptive Wildlife Management: Lessons from the Galapagos Islands.” *JOURNAL OF WILDLIFE MANAGEMENT* 63 (4): 1055–65. doi:10.2307/3802825.

Gómez, Cristina, and David R. Green. 2017. “Small Unmanned Airborne Systems to Support Oil and Gas Pipeline Monitoring and Mapping.” *Arabian Journal of Geosciences* 10 (9). doi:10.1007/s12517-017-2989-x.

Gonzalez, Felipe, and Sandra Johnson. 2017. “Standard Operating Procedures for UAV or Drone Based Monitoring of Wildlife,” 1–8.

Gonzalez, Luis F., Glen A. Montes, Eduard Puig, Sandra Johnson, Kerrie Mengersen, and Kevin J. Gaston. 2016. “Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation.” *Sensors (Switzerland)* 16 (1). doi:10.3390/s16010097.

Grémillet, David, William Puech, Véronique Garçon, Thierry Boulinier, and Yvon Le Maho. 2012. “Robots in Ecology: Welcome to the Machine.” *Open Journal of Ecology* 2 (2): 49–57. doi:10.4236/oje.2012.22006.

Groom, Martha J, Gary Meffe, and C Ronald Caroll. 2006. “Principles of Conservation Biology” 3 (779): 63–109.

Gross, John E., Scott J. Goetz, and Josef Cihlar. 2009. “Application of Remote Sensing to Parks and Protected Area Monitoring: Introduction to the Special Issue.” *Remote Sensing of Environment* 113 (7). Elsevier B.V.: 1343–45. doi:10.1016/j.rse.2008.12.013.

Groves, Phillip A, Brad Alcorn, Michelle M Wiest, Jacek M Maselko, and William P Connor. 2016. “Testing Unmanned Aircraft Systems for Salmon Spawning Surveys.” *Facets* 1 (1): 187–204. doi:10.1139/facets-2016-0019.

Gülci, Sercan, and Abdullah Emin Akay. 2016. “Using Thermal Infrared Imagery Produced by Unmanned Air Vehicles to Evaluate Locations of Ecological Road Structures.” *Journal of the Faculty of Forestry Istambul University* 66 (2): 698–709. doi:10.17099/jffiu.76461.

Habel, Jan Christian, Mike Teucher, Werner Ulrich, Markus Bauer, and Dennis Rödder. 2016. “Drones for Butterfly Conservation: Larval Habitat Assessment with an Unmanned Aerial Vehicle.” *Landscape Ecology* 31 (10): 2385–95. doi:10.1007/s10980-016-0409-3.

Hahn, Nathan, Angela Mwakatobe, Jonathan Konuche, Nadia de Souza, Julius Keyyu, Marc Goss, Alex Chang’a, Suzanne Palminteri, Eric Dinerstein, and David Olson. 2017. “Unmanned Aerial Vehicles Mitigate Human–elephant Conflict on the Borders of Tanzanian Parks: A Case Study.” *Oryx* 51 (3): 513–16. doi:10.1017/S0030605316000946.

Hansen, Andreas Skriver. 2016. “Applying Visitor Monitoring Methods in Coastal and Marine Areas – Some Learnings and Critical Reflections from Sweden.” *Scandinavian Journal of Hospitality and Tourism* 2250 (June): 1–18. doi:10.1080/15022250.2016.1155481.

Hardy, Andy, Makame Makame, Dónall Cross, Silas Majambere, and Mwinyi Msellem. 2017. “Using Low-Cost Drones to Map Malaria Vector Habitats.” *Parasites & Vectors* 10 (1): 29. doi:10.1186/s13071-017-1973-3.

Hilborn, Ray, Peter Arcese, Markus Borner, Justin Hando, Grant Hopcraft, Martin Loibooki, Simon Mduma, and Anthony R E Sinclair. 2006. “Effective Enforcement in a Conservation Area.” *Science* 314 (5803): 1266–1266. doi:10.1126/science.1132780.

Hodgson, Amanda, David Peel, and Natalie Kelly. 2017. “Unmanned Aerial Vehicles for Surveying Marine Fauna: Assessing Detection Probability.” *Ecological Applications* 27 (4): 1253–67. doi:10.1002/eap.1519.

Hodgson, Jarrod C., and Lian Pin Koh. 2016. “Best Practice for Minimising Unmanned Aerial Vehicle Disturbance to Wildlife in Biological Field Research.” *Current Biology* 26 (10). doi:10.1016/j.cub.2016.04.001.

Hodgson, Jarrod C, Shane M Baylis, Rowan Mott, Ashley Herrod, and Rohan H Clarke. 2016. “Precision Wildlife Monitoring Using Unmanned Aerial Vehicles.” *Scientific Reports* 6 (March). Nature Publishing Group: 22574. doi:10.1038/srep22574.

Husson, Eva. 2016. “Images from Unmanned Aircraft Systems for Surveying Aquatic and Riparian Vegetation.” Uppsala.

Israel, Martin. 2012. “A UAV-Based Roe Deer Fawm Detection System.” *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 38 (1): 1–5. doi:10.5194/isprsarchives-XXXVIII-1-C22-51-2011.

Israel, Martin, and Aline Reinhard. 2017. “Detecting Nests of Lapwing Birds with the Aid of a Small Unmanned Aerial Vehicle with Thermal Camera.”

Izumida, Atsuto, Shoichiro Uchiyama, and Toshihiko Sugai. 2016. “Application of UAV-SfM Photogrammetry and Aerial LiDAR to a Disastrous Flood: Multitemporal Topographic Measurement of a Newly Formed Crevasse Splay of the Kinu River, Central Japan.” *Natural Hazards and Earth System Sciences Discussions*, no. 2013: 1–22. doi:10.5194/nhess-2017-42.

Jaukovic, Isabella. 2017. “Unmanned Aerial Vehicles : A New Tool for Landslide Risk Assessment,” no. October 2016: 1–7.

Jewell, Zoe. 2013. “Effect of Monitoring Technique on Quality of Conservation Science.” *Conservation Biology* 27 (3): 501–8. doi:10.1111/cobi.12066.

Karaca, Yunus, Mustafa Cicek, Ozgur Tatli, Aynur Sahin, Sinan Pasli, Muhammed Fatih Beser, and Suleyman Turedi. 2017. “The Potential Use of Unmanned Aircraft Systems (Drones) in Mountain Search and Rescue Operations.” *The American Journal of Emergency Medicine*. Elsevier Inc. doi:10.1016/j.ajem.2017.09.025.

King, Lisa M. 2014. “Will Drones Revolutionise Ecotourism?” *Journal of Ecotourism* 13 (1): 85–92. doi:10.1080/14724049.2014.948448.

Kiszka, Jeremy J., Johann Mourier, Kirk Gastrich, and Michael R. Heithaus. 2016. “Using Unmanned Aerial Vehicles (UAVs) to Investigate Shark and Ray Densities in a Shallow Coral Lagoon.” *Marine Ecology Progress Series* 560: 237–42. doi:10.3354/meps11945.

Koh, Lian Pin, and Serge A. Wich. 2012. “Dawn of Drone Ecology: Low-Cost Autonomous Aerial Vehicles for Conservation.” *Tropical Conservation Science* 5 (2): 121–32. doi:WOS:000310846600002.

Koski, William. 2010. “An Inventory and Evaluation of Unmanned Aerial Systems for Offshore Surveys of Marine Mammals An Inventory and Evaluation of Unmanned Aerial Systems for Offshore Surveys of Marine Mammals,” no. March.

Leary, David. 2017. “Drones on Ice: An Assessment of the Legal Implications of the Use of Unmanned Aerial Vehicles in Scientific Research and by the Tourist Industry in Antarctica.” *Polar Record*, no. May: 1–15. doi:10.1017/S0032247417000262.

Leverington, Fiona, Katia Lemos Costa, Jose Courrau, Helena Pavese, Christoph Nolte, Melitta Marr, Lauren Coad, et al. 2010. “Management Effectiveness Evaluation in Protected Areas – a Global Study. Second Edition 2010.” *Environmental Management* 46 (5): 685–98. doi:10.1007/s00267-010-9564-5.

Lhoest, S, J Linchant, S Quevauvillers, C Vermeulen, and P Lejeune. 2015. “How Many Hippos (Homhip): Algorithm for Automatic Counts of Animals with Infra-Red Thermal Imagery from UAV.” *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* 40 (3W3): 355–62. doi:10.5194/isprsarchives-XL-3-W3-355-2015.

Linchant, Julie, Jonathan Lisein, Jean Semeki, Philippe Lejeune, and Cédric Vermeulen. 2015a. “Are Unmanned Aircraft Systems (UASs) the Future of Wildlife Monitoring? A Review of Accomplishments and Challenges.” *Mammal Review* 45 (4): 239–52. doi:10.1111/mam.12046.

———. 2015b. “Are Unmanned Aircraft Systems (UASs) the Future of Wildlife Monitoring? A Review of Accomplishments and Challenges.” *Mammal Review* 45 (4): 239–52. doi:10.1111/mam.12046.

Lobermeier, Scott, Matthew Moldenhauer, Christopher Peter, Luke Slominski, Richard Tedesco, Marcus Meer, James Dwyer, Richard Harness, and Andrew Stewart. 2015. “Mitigating Avian Collision with Power Lines: A Proof of Concept for Installation of Line Markers via Unmanned Aerial Vehicle.” *Journal of Unmanned Vehicle Systems* 3 (4): 252–58. doi:10.1139/juvs-2015-0009.

Longmore, S. N., R. P. Collins, S. Pfeifer, S. E. Fox, M. Mulero-P??zm??ny, F. Bezombes, A. Goodwin, M. De Juan Ovelar, J. H. Knapen, and S. A. Wich. 2017. “Adapting Astronomical Source Detection Software to Help Detect Animals in Thermal Images Obtained by Unmanned Aerial Systems.” *International Journal of Remote Sensing* 38 (8–10): 2623–38. doi:10.1080/01431161.2017.1280639.

Lu, Bing, and Yuhong He. 2017. “Species Classification Using Unmanned Aerial Vehicle (UAV)-Acquired High Spatial Resolution Imagery in a Heterogeneous Grassland.” *ISPRS Journal of Photogrammetry and Remote Sensing* 128. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS): 73–85. doi:10.1016/j.isprsjprs.2017.03.011.

Lyons, Mitchell, Kate Brandis, Corey Callaghan, Justin Mccann, Charlotte Mills, Sharon Ryall, and Richard Kingsford. 2017. “Bird Interactions with Drones from Individuals to Large Colonies.” *bioRxiv*, 1–10. doi:10.1101/109926.

Malenovský, Zbyněk, Arko Lucieer, Diana H. King, Johanna D. Turnbull, and Sharon A. Robinson. 2017. “Unmanned Aircraft System Advances Health Mapping of Fragile Polar Vegetation.” *Methods in Ecology and Evolution*. doi:10.1111/2041-210X.12833.

Marcaccio, James V., Chantel E. Markle, and Patricia Chow-Fraser. 2015. “Unmanned Aerial Vehicles Produce High-Resolution, Seasonally-Relevant Imagery for Classifying Wetland Vegetation.” In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 40:249–56. doi:10.5194/isprsarchives-XL-1-W4-249-2015.

Martin, Julien, Holly H. Edwards, Matthew A. Burgess, H. Franklin Percival, Daniel E. Fagan, Beth E. Gardner, Joel G. Ortega-Ortiz, Peter G. Ifju, Brandon S. Evers, and Thomas J. Rambo. 2012. “Estimating Distribution of Hidden Objects with Drones: From Tennis Balls to Manatees.” *PLoS ONE* 7 (6): 1–8. doi:10.1371/journal.pone.0038882.

Mas, Jean François. 2005. “Assessing Protected Area Effectiveness Using Surrounding (Buffer) Areas Environmentally Similar to the Target Area.” *Environmental Monitoring and Assessment* 105 (1–3): 69–80. doi:10.1007/s10661-005-3156-5.

McCaldin, Guy, Michael Johnston, and Andrew Rieker. 2015. “Use of Unmanned Aircraft Systems to Assist with Decision Support for Land Managers on Christmas Island (Indian Ocean).” Australia.

McEvoy, John F., Graham P. Hall, and Paul G. McDonald. 2016. “Evaluation of Unmanned Aerial Vehicle Shape, Flight Path and Camera Type for Waterfowl Surveys: Disturbance Effects and Species Recognition.” *PeerJ* 4. doi:10.7717/peerj.1831.

Melesse, A, Q Weng, S Prasad, and G Senay. 2007. “Remote Sensing Sensors and Applications in Environmental Resources Mapping and Modelling.” *Sensors* 7: 3209–41. doi:10.3390/s7123209.

Messinger, Max, Gregory P. Asner, and Miles Silman. 2016. “Rapid Assessments of Amazon Forest Structure and Biomass Using Small Unmanned Aerial Systems.” *Remote Sensing* 8 (8). doi:10.3390/rs8080615.

Messinger, Max, and Miles Silman. 2016. “Unmanned Aerial Vehicles for the Assessment and Monitoring of Environmental Contamination: An Example from Coal Ash Spills.” *Environmental Pollution* 218: 889–94. doi:10.1016/j.envpol.2016.08.019.

Michez, Adrien, Kevin Morelle, François Lehaire, Jérome Widar, Manon Authelet, Cédric Vermeulen, Philippe Lejeune, et al. 2016. “Use of Unmanned Aerial System to Assess Wildlife (Sus Scrofa) Damage to Crops (Zea Mays).” *J. Unmanned Veh. Sys* 4: 266–75. doi:10.1139/juvs-2016-0014.

Michez, Adrien, Hervé Piégay, Lisein Jonathan, Hugues Claessens, and Philippe Lejeune. 2016. “Mapping of Riparian Invasive Species with Supervised Classification of Unmanned Aerial System (UAS) Imagery.” *International Journal of Applied Earth Observation and Geoinformation* 44. Elsevier B.V.: 88–94. doi:10.1016/j.jag.2015.06.014.

Michez, Adrien, Hervé Piégay, Jonathan Lisein, Hugues Claessens, and Philippe Lejeune. 2016. “Classification of Riparian Forest Species and Health Condition Using Multi-Temporal and Hyperspatial Imagery from Unmanned Aerial System.” *Environmental Monitoring and Assessment* 188 (3): 1–19. doi:10.1007/s10661-015-4996-2.

Mulero-Pázmány, Margarita, Jose Ángel Barasona, Pelayo Acevedo, Joaquín Vicente, and Juan José Negro. 2015. “Unmanned Aircraft Systems Complement Biologging in Spatial Ecology Studies.” *Ecology and Evolution* 5 (21): 4808–18. doi:10.1002/ece3.1744.

Mulero-Pázmány, Margarita, Susanne Jenni-Eiermann, Nicolas Strebel, Thomas Sattler, Juan Jose Negro, and Z. Tablado. 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.

Mulero-Pázmány, Margarita, Juan José Negro, and Miguel Ferrer. 2014. “A Low Cost Way for Assessing Bird Risk Hazards in Power Lines: Fixed-Wing Small Unmanned Aircraft Systems.” *Journal of Unmanned Vehicle Systems* 2 (1): 5–15. doi:10.1139/juvs-2013-0012.

Mulero-Pázmány, Margarita, Roel Stolper, L D Van Essen, Juan J Negro, and Tyrell Sassen. 2014. “Remotely Piloted Aircraft Systems as a Rhinoceros Anti-Poaching Tool in Africa.” *PLoS ONE* 9 (1): 1–10. doi:10.1371/journal.pone.0083873.

Müllerová, Jana, Tomáš Bartaloš, Josef Brůna, Petr Dvořák, and Michaela Vítková. 2017. “Unmanned Aircraft in Nature Conservation: An Example from Plant Invasions.” *International Journal of Remote Sensing* 38 (8–10): 2177–98. doi:10.1080/01431161.2016.1275059.

Murfitt, Sarah L., Blake M. Allan, Alecia Bellgrove, Alex Rattray, Mary A. Young, and Daniel Ierodiaconou. 2017. “Applications of Unmanned Aerial Vehicles in Intertidal Reef Monitoring.” *Scientific Reports* 7 (1). Springer US: 10259. doi:10.1038/s41598-017-10818-9.

Näsi, Roope, Eija Honkavaara, Päivi Lyytikäinen-Saarenmaa, Minna Blomqvist, Paula Litkey, Teemu Hakala, Niko Viljanen, Tuula Kantola, Topi Tanhuanpää, and Markus Holopainen. 2015. “Using UAV-Based Photogrammetry and Hyperspectral Imaging for Mapping Bark Beetle Damage at Tree-Level.” *Remote Sensing* 7 (11): 15467–93. doi:10.3390/rs71115467.

OEH. 2017. “Drones in Parks Policy.” *NSW Environment & Heritage*. Accessed October 19. http://www.environment.nsw.gov.au/topics/parks-reserves-and-protected-areas/park-policies/drones-in-parks.

Olivares-Mendez, Miguel A, Tegawendé F Bissyandé, Kannan Somasundar, Jacques Klein, Holger Voos, and Yves Le Traon. 2014. “The NOAH Project: Giving a Chance to Threatened Species in Africa with UAVs.” *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST* 135 LNICST: 198–208. doi:10.1007/978-3-319-08368-1\_24.

Olivares-Mendez, Miguel, Changhong Fu, Philippe Ludivig, Tegawendé Bissyandé, Somasundar Kannan, Maciej Zurad, Arun Annaiyan, Holger Voos, and Pascual Campoy. 2015. “Towards an Autonomous Vision-Based Unmanned Aerial System against Wildlife Poachers.” *Sensors* 15 (12): 31362–91. doi:10.3390/s151229861.

Ore, John Paul, Sebastian Elbaum, Amy Burgin, and Carrick Detweiler. 2015. “Autonomous Aerial Water Sampling.” *Journal of Field Robotics* 32 (8): 1095–1113. doi:10.1002/rob.21591.

Pande-Chhetri, Roshan, Amr Abd-Elrahman, Tao Liu, Jon Morton, and Victor L Wilhelm. 2017. “Object-Based Classification of Wetland Vegetation Using Very High-Resolution Unmanned Air System Imagery.” *European Journal of Remote Sensing ISSNOnline) Journal European Journal of Remote Sensing* 50 (1). Taylor & Francis: 2279–7254. doi:10.1080/22797254.2017.1373602.

Paneque-Gálvez, Jaime, Michael K. McCall, Brian M. Napoletano, Serge A. Wich, and Lian Pin Koh. 2014. “Small Drones for Community-Based Forest Monitoring: An Assessment of Their Feasibility and Potential in Tropical Areas.” *Forests* 5 (6): 1481–1507. doi:10.3390/f5061481.

Park, Keunhyun, and Reid Ewing. 2017. “The Usability of Unmanned Aerial Vehicles (UAVs) for Measuring Park-Based Physical Activity.” *Landscape and Urban Planning* 167 (January). Elsevier: 157–64. doi:10.1016/j.landurbplan.2017.06.010.

Perroy, Ryan L., Timo Sullivan, and Nathan Stephenson. 2017. “Assessing the Impacts of Canopy Openness and Flight Parameters on Detecting a Sub-Canopy Tropical Invasive Plant Using a Small Unmanned Aerial System.” *ISPRS Journal of Photogrammetry and Remote Sensing* 125. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS): 174–83. doi:10.1016/j.isprsjprs.2017.01.018.

Peyer, Robin de. 2015. “Drones Are Banned from Royal Parks amid ‘Fears over Impact on Wildlife and Visitor Safety.’” *London Evening Standard*, no. March: 1–4.

Pimm, Stuart L, Sky Alibhai, Richard Bergl, Alex Dehgan, Chandra Giri, Zoë Jewell, Lucas Joppa, Roland Kays, and Scott Loarie. 2015. “Emerging Technologies to Conserve Biodiversity.” *Trends in Ecology & Evolution* 30 (11). Elsevier Ltd: 685–96. doi:10.1016/j.tree.2015.08.008.

Pomeroy, P, L O Connor, and P Davies. 2015. “Assessing Use of and Reaction to Unmanned Aerial Systems in Gray and Harbor Seals during Breeding and Molt in the UK.” *Journal of Unmanned Vehicle Systems* 113 (September): 102–13.

Puliti, Stefano, Hans Olerka, Terje Gobakken, and Erik Næsset. 2015. “Inventory of Small Forest Areas Using an Unmanned Aerial System.” *Remote Sensing* 7 (8): 9632–54. doi:10.3390/rs70809632.

Rödig, Edna, Matthias Cuntz, Jens Heinke, Anja Rammig, and Andreas Huth. 2017. “Spatial Heterogeneity of Biomass and Forest Structure of the Amazon Rainforest: Linking Remote Sensing, Forest Modeling and Field Inventory.” *Global Ecology & Biogeography*, no. August. doi:10.1111/geb.12639.

Rodríguez, Airam, Juan J. Negro, Mara Mulero, Carlos Rodríguez, Jesús Hernández-Pliego, and Javier Bustamante. 2012. “The Eye in the Sky: Combined Use of Unmanned Aerial Systems and GPS Data Loggers for Ecological Research and Conservation of Small Birds.” *PLoS ONE* 7 (12). doi:10.1371/journal.pone.0050336.

Rodriguez, Roberto, Daniel Jenkins, and James Leary. 2017. Enhancing Invasive Species Control with Unmanned Aerial Systems and Herbicide Ballistic Technology.

Sabella, Giorgio, Fabio Massimo Viglianisi, Sergio Rotondi, and Filadelfo Brogna. 2017. “Preliminary Observations on the Use of Drones in the Environmental Monitoring and in the Management of Protected Areas. The Case Study of ‘R.N.O. Vendicari’, Syracuse (Italy)” 8 (1): 79–86.

Samia, Diogo S.M., Lisa M. Angeloni, Maddalena Bearzi, Eduardo Bessa, Kevin R. Crooks, Marcello D’Amico, Ursula Ellenberg, et al. 2017. “Best Practices Toward Sustainable Ecotourism,” no. October: 153–78. doi:10.1007/978-3-319-58331-0.

Sandbrook, Chris. 2015. “The Social Implications of Using Drones for Biodiversity Conservation.” *Ambio* 44 (S4): 636–47. doi:10.1007/s13280-015-0714-0.

Sankey, Temuulen, Jonathon Donager, Jason McVay, and Joel B. Sankey. 2017. “UAV Lidar and Hyperspectral Fusion for Forest Monitoring in the Southwestern USA.” *Remote Sensing of Environment* 195. Elsevier Inc.: 30–43. doi:10.1016/j.rse.2017.04.007.

Sardà-Palomera, Francesc, Gerard Bota, Núria Padilla, Lluis Brotons, and Francesc Sardà. 2017. “Unmanned Aircraft Systems to Unravel Spatial and Temporal Factors Affecting Dynamics of Colony Formation and Nesting Success in Birds.” *Journal of Avian Biology*. doi:10.1111/jav.01535.

Schofield, Gail, Kostas A. Katselidis, Martin K. S. Lilley, Richard D. Reina, and Graeme C. Hays. 2017. “Detecting Elusive Aspects of Wildlife Ecology Using Drones: New Insights on the Mating Dynamics and Operational Sex Ratios of Sea Turtles.” *Functional Ecology* 38 (1): 42–49. doi:10.1111/1365-2435.12930.

Schwarzbach, Marc, Maximilian Laiacker, Margarita Mulero-Pazmany, and Konstantin Kondak. 2014. “Remote Water Sampling Using Flying Robots.” *2014 International Conference on Unmanned Aircraft Systems, ICUAS 2014 - Conference Proceedings*, 72–76. doi:10.1109/ICUAS.2014.6842240.

Scobie, Corey A., and Chris H. Hugenholtz. 2016. “Wildlife Monitoring with Unmanned Aerial Vehicles: Quantifying Distance to Auditory Detection.” *Wildlife Society Bulletin* 40 (4): 781–85. doi:10.1002/wsb.700.

Sepúlveda, Alejandra, Mathias Schluep, Fabrice G Renaud, Martin Streicher, Ruediger Kuehr, Christian Hagelüken, and Andreas C Gerecke. 2010. “A Review of the Environmental Fate and Effects of Hazardous Substances Released from Electrical and Electronic Equipments during Recycling: Examples from China and India.” *Environmental Impact Assessment Review* 30 (1). Elsevier Inc.: 28–41. doi:10.1016/j.eiar.2009.04.001.

Seymour, A. C., J. Dale, M. Hammill, P. N. Halpin, and D. W. Johnston. 2017. “Automated Detection and Enumeration of Marine Wildlife Using Unmanned Aircraft Systems (UAS) and Thermal Imagery.” *Scientific Reports* 7: 45127. doi:10.1038/srep45127.

Shaffer, Michael J, and Joseph A Bishop. 2016. “Predicting and Preventing Elephant Poaching Incidents through Statistical Analysis, GIS-Based Risk Analysis, and Aerial Surveillance Flight Path Modeling.” *Tropical Conservation Science* 9 (1): 525–48. doi:10.1177/194008291600900127.

Sweeney, Kathryn L, Van T Helker, Wayne L Perryman, Donald J LeRoi, Lowell W Fritz, Tom S Gelatt, and Robyn P. Angliss. 2016. “Flying beneath the Clouds at the Edge of the World: Using a Hexacopter to Supplement Abundance Surveys of Steller Sea Lions (Eumetopias Jubatus) in Alaska.” *Journal of Unmanned Vehicle Systems* 4 (1): 70–81. doi:10.1139/juvs-2015-0010.

Tian, Jinyan, Le Wang, Xiaojuan Li, Huili Gong, Chen Shi, Ruofei Zhong, and Xiaomeng Liu. 2017. “Comparison of UAV and WorldView-2 Imagery for Mapping Leaf Area Index of Mangrove Forest.” *International Journal of Applied Earth Observation and Geoinformation* 61: 22–31. doi:10.1016/j.jag.2017.05.002.

Tilburg, Christopher Van, S.T. Brown, M. Ferguson, and et al. 2017. “First Report of Using Portable Unmanned Aircraft Systems (Drones) for Search and Rescue.” *Wilderness & Environmental Medicine* 15 (0). Elsevier Inc.: 12. doi:10.1016/j.wem.2016.12.010.

Torresan, Chiara, Andrea Berton, Federico Carotenuto, Salvatore Filippo Di Gennaro, Beniamino Gioli, Alessandro Matese, Franco Miglietta, Carolina Vagnoli, Alessandro Zaldei, and Luke Wallace. 2017. “Forestry Applications of UAVs in Europe: A Review.” *International Journal of Remote Sensing* 38 (8–10). Taylor & Francis: 2427–47. doi:10.1080/01431161.2016.1252477.

U.S. Geological Survey National. 2017. “U.S. Geological Survey National Unmanned Aircraft Systems (UAS) Project.” Accessed September 20. https://uas.usgs.gov/.

Ventura, Daniele, Michele Bruno, Giovanna Jona Lasinio, Andrea Belluscio, and Giandomenico Ardizzone. 2016. “A Low-Cost Drone Based Application for Identifying and Mapping of Coastal Fish Nursery Grounds.” *Estuarine, Coastal and Shelf Science* 171. doi:10.1016/j.ecss.2016.01.030.

Wang, Dongliang, Xiaoping Xin, Quanqin Shao, Matthew Brolly, Zhiliang Zhu, and Jin Chen. 2017. “Modeling Aboveground Biomass in Hulunber Grassland Ecosystem by Using Unmanned Aerial Vehicle Discrete Lidar.” *Sensors (Switzerland)* 17 (1): 1–19. doi:10.3390/s17010180.

Watson, James E. M., Nigel Dudley, Daniel B. Segan, and Marc Hockings. 2014. “The Performance and Potential of Protected Areas.” *Nature* 515 (7525): 67–73. doi:10.1038/nature13947.

Weber, Stefan, and Florian Knaus. 2017. “Using Drones as a Monitoring Tool to Detect Evidence of Winter Sports Activities in a Protected Mountain Area.” *Eco.mont* 9 (1): 30–34. doi:10.1553/eco.mont-9-1s30.

Weissensteiner, M H, J W Poelstra, and J B W Wolf. 2015. “Low-Budget Ready-to-Fly Unmanned Aerial Vehicles: An Effective Tool for Evaluating the Nesting Status of Canopy-Breeding Bird Species.” *Journal of Avian Biology* 46 (4): 425–30. doi:10.1111/jav.00619.

Whitehead, Ken, and Chris H. Hugenholtz. 2014. “Remote Sensing of the Environment with Small Unmanned Aircraft Systems (UASs), Part 1: A Review of Progress and Challenges 1.” *Journal of Unmanned Vehicle Systems* 2 (3): 69–85. doi:10.1139/juvs-2014-0006.

Wich, Serge, David Dellatore, Max Houghton, Rio Ardi, and Lian Pin Koh. 2016. “A Preliminary Assessment of Using Conservation Drones for Sumatran Orangutan (Pongo Abelii) Distribution and Density.” *Journal of Unmanned Vehicle Systems* 4 (1): 45–52. doi:10.1139/juvs-2015-0015.

Wilson, Adam M., John A. Silander, Alan Gelfand, and Jonathan H. Glenn. 2011. “Scaling up: Linking Field Data and Remote Sensing with a Hierarchical Model.” *International Journal of Geographical Information Science* 25 (3): 509–21. doi:10.1080/13658816.2010.522779.

Wilson, Andrew M., Janine Barr, and Megan Zagorski. 2017. “The Feasibility of Counting Songbirds Using Unmanned Aerial Vehicles.” *The Auk* 134 (2): 350–62. doi:10.1642/AUK-16-216.1.

Wilson, Rory P, and and Clive R McMahon. 2006. “Measuring Devices on Wild Animals: What Constitutes Acceptable Practice?” *Frontiers in Ecology and the Environment* 4 (3): 147–54. doi:10.1890/1540-9295(2006)004.

Wing, M.G., Jonathan D. Burnett, and J. Sessions. 2014. “Remote Sensing and Unmanned Aerial System Technology for Monitoring and Quantifying Forest Fire Impacts.” *International Journal of Remote Sensing Applications* 4 (1): 18. doi:10.14355/ijrsa.2014.0401.02.

Xu, Jun, Gurkan Solmaz, Rouhollah Rahmatizadeh, Damla Turgut, and Ladislau Boloni. 2016. “Internet of Things Applications: Animal Monitoring with Unmanned Aerial Vehicle,” 1–12.

Zang, Wenqian, Jiayuan Lin, Yangchun Wang, and Heping Tao. 2012. “Investigating Small-Scale Water Pollution with UAV Remote Sensing Technology.” *World Automation Congress*, no. Puerto Vallarta, Mexico, 2012: 1–4.

Table 1 Search terms

|  |
| --- |
| **Search Terms** |
| protected area, conservation, ecology, ecosystem, habitat, ecosystem, vegetation, forest, wetland, reforestation, monitoring, survey, sampling, inventory, wildlife, fauna, bird, mammal, fish, amphibian, reptile, wildfire, landslide, remote sensing, tourism, ecotourism, law enforcement, poaching, anti-poaching, logging, risk management, pollution, search and rescue, landslide, flood, erosion, multispectral, hyperspectral unmanned aircraft systems, UAS, remotely piloted aerial system, RPAS, drone, model aircraft, unmanned aerial vehicle, UAV, unmanned aircraft system |
| **Search example** |
| "vegetation drone" OR "vegetation UAS" OR "vegetation UAV" OR "vegetation unmanned aircraft system" OR "vegetation unmanned aircraft" OR "vegetation RPAS" OR "vegetation radio control aircraft" |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Publication | Category | Aim | Target | Location | RPAS type | RPAS model | Payload |
| (A. Hodgson, Peel, and Kelly 2017) | Wildlife Research and Management | Assess proportion of whales detected | Humpback whale *Megaptera novaeangliae* | North Stradbroke Island (Australia) | Fixed-Wing | ScanEagle | Nikon D90, Standard Definition Electro- Optical Camera |
| (Kiszka et al. 2016) | Wildlife Research and Management | Estimate elasmobranchs density in coral-reef ecosystems | Blacktip reef shark *Carcharhinus melanopterus*, Pink whipray *Himantura fai* | Moorea (French Polynesia) | Rotor-wing | DJI Phantom II | GoPro Hero 3+ |
| (Habel et al. 2016) | Wildlife Research and Management | Aerial pictures to help identify micro-habitat | Common blue butterfly *Polyommatus icarus*, Adonis blue butterfly *Polyommatus bellargus* | Dietersheimer Brenne (Germany) | Rotor-wing | DJI Phantom II | GoPro Hero 4 Black |
| (Michez, Morelle, et al. 2016) | Wildlife Research and Management | Assess wildlife damage to crops | Wild boar *Sus scrofa* | Wallonia (Belgium) | Fixed-Wing | Gatewing X100 | Ricoh GR3 |
| (Lobermeier et al. 2015) | Wildlife Research and Management | Mitigate avian collision with power lines using markers | Birds | USA | Rotor-wing | Mikrokopter Hexa XL | BirdMark BM-AG |
| (Alvarez-taboada, Paredes, and Julián-Pelaz 2017) | Ecosystem monitoring | Mapping invasive plant using RPAS / RS following an object-oriented image analysis approach. | Needlebush *Hakea sericea* | Viana de Castelo, Portugal | Fixed-Wing | Ebee SenseFly | Canon IXUS 220 HS; Canon ELPH 300HS |
| (Messinger, Asner, and Silman 2016) | Ecosystem monitoring | Monitoring of aboveground carbon density for ecological studies and payment for ecosystem services ventures. | Lowland Tropical Forest | Los Amigos Biological Station, Peru | Fixed-Wing | Kestrel | Canon S110 |
| (Murfitt et al. 2017) | Ecosystem monitoring | Compares UAV remote sensing / on-ground monitoring surveys; explain observed intertidal algal and invertebrate assemblages from geomorphological features. | Intertidal reefs | Pickering Point, Shelly Beach, Point Lonsdale, Point Lonsdale, Australia | Rotor-wing | Swellpro Splashdrone | Canon D30 |
| (Weber and Knaus 2017) | Law enforcement | Detect human winter activities in threatened wildlife in sensitive mountain areas | capercaillie (Tetrao urogallus) | Entlebuch Biosphere Reserve, Switzerland | Fixed-wing | Maja-D | Canon SX260HS, GoPro 3 |
| (Mulero-Pázmány et al. 2014) | Law enforcement | Monitor poaching activities | Black rhinocero (Diceros bicornis), white rhinocero (Ceratotherium simum) | KwaZulu-Nata (Africa) | Fixed-wing | Easy Fly St-330 | Panasonic Lumix LX-3, GoPro Hero2; Thermoteknix Micro CAM |
| (M. Olivares-Mendez et al. 2015) | Law enforcement | Detection and tracking of animals and poachers | White rhinocero (Ceratotherium simum), elephant (Loxodonta africana), human (Homo sapiens) | Africa | Rotor-wing | AscTec Firefly | UEye UI-1240ML-C-HQ |
| (Shaffer and Bishop 2016) | Law enforcement | Methods for identifying high risk elephant poaching areas and modeling drone surveillance capabilities | African elephant (Loxodonta africana), | Tsavo NP, Kenya | Fixed-wing | RQ-84Z AeroHawk | FLIR Tau 2 640 |
| (Park and Ewing 2017) | Ecotourism | Measure park-based physical activity | Park users | Neighborhood parks Lake City, Utah, USA | Rotor-wing | DJI Phantom 3 Advanced | Built-in Sony EXMOR |
| (Van Tilburg et al. 2017) | Enviromental management and emergency response | Search and Rescue | Park users | Columbia Gorge National Scenic Area, Oregon, USA | Rotor-wing | DJI Phantom 3 | Built-in Sony EXMOR |
| Messinger and Silman 2016 | Enviromental management and emergency response |  |  | Dan River in Eden, North Carolina, USA | Fixed-wing | Deacon Airborne Observatory (DAO) | Canon SX260HS |
|  |  |  |  |  |  |  |  |

Table 1. Threats to Protected Areas. Adapted from (Leverington et al. 2010; Safety 2016)

|  |
| --- |
| **Threats** |
| **Residency and commercial development in the protected area** |
| Dwelling and human settlement |
| Commercial and industrial areas |
| Tourism and recreation |
| Agriculture and aquaculture in the protected area |
| Annual and other crop cultivation |
| Animal husbandry |
| Aquaculture – fishing, fish farming, and farming of other river organisms |
| **Mining and energy production in the protected area** |
| Extraction of coal, oil, and gas |
| Exploitation of mineral raw materials |
| Energy production, including hydropower stations |
| **Transportation network, roads, communication infrastructure, and service network in the protected area** |
| Roads and railroads |
| Communication infrastructure and services (e.g. power lines, telephone lines, etc.) |
| Numerous canals and locks |
| Air traffic |
| Roadkill |
| **Use of biological resources and resulting damage in the protected area** |
| Hunting, killing, and collection of land animals (includes killing of animals due to conflicts between humans and wild animals) |
| Collection of land plant species and related products |
| Deforestation and woodsmanship |
| Fishing and exploiting aquatic wildlife |
| **Impact of humans and disturbance in the protected area** |
| Tourism and recreational activities |
| War activities, military exercises, etc. |
| Research, educational, and other activities in the protected area |
| Activities of the protected area manager (e.g. construction, use of vehicles, artificial dams, etc.) |
| Vandalism and other forms of destructive activity affecting the protected area, the managing structure, or the visitors |
| **Natural system modifications in protected area** |
| Fires and fire prevention |
| Dams, modifications of water surfaces, water management, and water use |
| Increased fragmentation within the protected area |
| Isolation from other natural habitats (e.g. deforestation, dams without proper passages for aquatic life, etc.) |
| Other “borderline” effects on the area’s values |
| Loss of keystone species (e.g. apex predators, pollinators, etc.) |
| **Invasive and other problematic species and genera in protected area** |
| Invasive introduced plant species or their seed |
| Invasive introduced animal species |
| Pathogenic microorganisms (introduced or native, but causing new problems / increased detrimental effect) |
| Introduced genetic material (e.g. genetically modified organisms) Pollution |
| **Pollution reaching the protected area or generated within it** |
| Household and urban waste water |
| Sewage and waste water from buildings in the protected area (e.g. hotels, public restrooms, administrative buildings, etc.) |
| Waste water and waste material from industry, mines, and other commercial facilities and buildings (e.g. water from hydropower stations, which can be thermally contaminated, deoxygenated, or contaminated in another way) |
| Waste water and other pollutants from agriculture and forestry (e.g. fertilizer and pesticide contamination) |
| Municipal solid waste Air |
| Air pollution |
| Other types of pollution, such as thermal pollution, light pollution, etc. |
| **Geological events in protected area** |
| Volcanic activities |
| Earthquakes (tsunami) |
| Landslides |
| Soil erosion |
| **Climate change and extreme weather conditions in protected area** |
| Changes in habitat composition |
| Droughts |
| Extreme temperatures |
| Storms and floods |
| **Specific cultural and social threats in protected area** |
| Loss of connection with the tradition and disappearance of traditional knowledge and skills for protected area management |
| Natural decay of locations with high cultural value |
| Degradation of cultural heritage buildings, special areas, etc. |

