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

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

During the past two decades, we have witnessed a growing interest in projects aimed to evaluate the feasibility of RPAS for conservation purposes, including environmental and wildlife monitoring or law enforcement. Beyond ethical, legal, technical and methodological challenges hindering the potential of RPAS to deliver a wide range of benefits to protected areas, it remains to be seen whether research investment is driven to meet the needs demanded by natural park managers. A bibliographic survey was carried out to value the usefulness of RPAS in PAs by searching for possible applications aimed to reduce threats to biodiversity and reinforce effective management. We found multiple facets of application, but common factors impeding the smoother consolidation of RPAS within protected areas remain.

Keywords: protected areas, RPAS, conservation

# 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). Protected areas (PAs) have been declared under different reasons and circumstances but there is a consensus on its importance in safeguarding biodiversity, preserving ecosystem services and ensure persistence of the natural heritage (Watson et al. 2014; Chape, Spalding, and Jenkins 2008). Despite such praiseworthy intentions, PAs are 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 the main global threats to biodiversity (Groom, Meffe, and Caroll 2006) . To curb the loss of biodiversity while attending other inherent activities, financial allocations have targeted, among others, staff recruitment and training, infrastructure and equipment, communication programs, tourism and recreational activities, law enforcement, support decision-making and disaster management, biodiversity monitoring, environmental assessment or actions aimed at strengthening educational and research programs. Moreover, conservation in PAs have benefit from a wide range of technological advances, methods or innovative application of existing technologies, including remote sensors, field-based monitoring stations, manned surveys, camera traps, wildlife tracking devices and computing resources (Pimm et al. 2015). More recently, applications of 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 (Rodríguez et al. 2012; Koh and Wich 2012; Anderson and Gaston 2013; Linchant et al. 2015a; Christie et al. 2016; Torresan et al. 2017). While obstacles remain, the use of RPAS for conservation purposes have receive a major emphasis and its feasibility reasonably proven. To date, however, it has not been adequately weighted whether RPAS meet the demands of decision-makers, which often face daunting decisions affected by budgetary constraints and under-resourcing, limiting the accomplishment of management objectives (Watson et al. 2014).

(Leverington et al. 2010) compiled and systematically reviewed outcomes from performance assessments of PAs across the world and revealed that “adequacy of infrastructure, equipment and facilities” was the closest management indicator related to overall effectiveness. Within this study, conservation practitioners identified threats requiring appropriate management measurements. As a result, “biological resources use”, including hunting, logging and fishing, was pointed out as a major concern, scoring high globally. Nevertheless, RPAS for wildlife and habitat monitoring account for most of studies, while law enforcement has ostensibly received minor attention from the academia, despite the relevance. To bridge the gap between science and conservation priorities, we carried out an extensive literature revision to set the current state of RPAS for conservation purposes and shed light on how effective management in PAs can benefit from a RPAS perspective. We primarily relied on the “Management effectiveness evaluation in protected areas – a global study” (Leverington et al. 2010) to match threats and managements measures within the scope of RPAS studies. Also, pausible scenarios to help achieve conservation goals in PAs are suggested, highlighting some trends and opportunities that apparently have not yet been adequately exploited.

# 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 X, 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 threats and common conservation measurements in PAs (see table 1) using logical disjunctions. A total of X search terms and X 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). After removing duplicated results, more than 500 articles were collected. The remaining publications (x) were grouped according to the following interrelated categories: “wildlife monitoring”, for feasibility studies facing alternative fauna population surveys and tracking methods; “wildlife risk assessment and management”; broadly focus on measures to mitigate human-wildlife conflicts; “terrestrial and aquatic ecosystems monitoring", with regards to applications for the study and mapping of natural habitats; “Law enforcement” encompasses poaching, illegal logging and other illicit activities surveillance; "Ecotourism" is restricted to recreational activities and visitors management; “Environmental management and emergency response" span from environmental monitoring and assessment, response to natural and man-made disasters to search and rescue activities. Common challenges to above categories are summarize within legal constraints and concerns to minimize impact on wildlife / ecosystems, but also operational costs and technological issues, since all shape the feasibility of RPAS to approach conservation and environmental issues. Recent and representative examples in PAs are presented in tabular format (see table 2), identifying where the study was conducted, the expected accomplishments and technical specifications of the aerial platform.

# Results and discussion

## Wildlife Monitoring

Wildlife surveys are considered essential for effective management of PAs. RPAS have mostly been applied for surveying large and medium size terrestrial mammals (Jain 2013; Barasona et al. 2014; Stark et al. 2017; Chrétien, Théau, and Ménard 2016), birds (A. M. Wilson, Barr, and Zagorski 2017; J. C. Hodgson et al. 2016; Christie et al. 2016; Sardà-Palomera et al. 2012; Chabot and Bird 2012; Ratcliffe et al. 2015) , species relying on coastal and marine ecosystems (Colefax, Butcher, and Kelaher 2017; A. Hodgson, Peel, and Kelly 2017; W. R. Koski et al. 2015; Dulava, Bean, and Richmond 2015; Durban et al. 2015; W. R. Koski et al. 2009), to inspect breeding and nesting areas at inaccessible sites (Szantoi et al. 2017; Wich et al. 2016; Puttock et al. 2015; van Andel et al. 2015; Weissensteiner, Poelstra, and Wolf 2015) or as a complement for wildlife telemetry tracking methods (Christie et al. 2016; Bayram et al. 2016; Mulero-Pázmány et al. 2015; Körner et al. 2010; Cliff et al. 2015; Ordóñez-Delgado et al. 2016; Soriano, Caballero, and Ollero 2009). Summing up, authors mostly coincide on the broad potential of RPAS to complement census campaigns, traditionally carried out by ground-based crews, terrestrial vehicles, manned aircrafts or vessels. As becoming easier to operate, there are sufficient grounds to instruct rangers on the use of RPAS, who are often subject to time-consuming and often dangerous raids. If appropriate safety measures are taken, RPAS might be considered a less invasive, nonhazardous and reliable monitoring technique (Jewell 2013) compared with other methodologies requiring approaching, capturing or indirectly disturbing wildlife. Moreover, RPAS constitute a promising advance linking animal movement and remote sensing disciplines. For instance, wildlife and habitat interactions can be closely examine by having fine-scale and timely aerial images from places crossed by electronically tagged species.

## Wildlife risk assessment and Management

RPAS constitute an attainable low-cost alternative to manually inspecting hazardous facilities and detecting ground nest or vulnerable species at agricultural fields where mechanical harvesting pose risk of death (Barasona et al. 2014; Lobermeier et al. 2015; Christiansen et al. 2014; Israel and Reinhard 2017; Mulero-Pázmány, Negro, and Ferrer 2014). Human-wildlife conflicts are also present both in PAs and nearby locations as result of increasingly pressures. Within this topic, RPAs have been used to move elephants out of human settlements, 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 baits to eradicate feral species (McCaldin, Johnston, and Rieker 2015). Without going into debate, some park managers could contemplate the adoption of RPAS for wildlife capture procedures, through devices adapted to release tranquilizing darts where otherwise manual approaching free-range animals is often considered ineffective, biased or dangerous.

## Terrestrial and aquatic ecosystems monitoring

Operational deployment of RPAS to inform adaptive management has the potential to complement aerial remote sensing and earth observation (EO), surpassing spatio-temporal scale challenges at affordable cost and providing precise in-situ measurements (Gross, Goetz, and Cihlar 2009). Ecosystem mapping and monitoring projects using RPAS have increased notoriously both by governmental institutions (U.S. Geological Survey National 2017) and research groups. Studies on this topic range from quantifying the spread and detection rate of invasive species (Müllerová et al. 2016; Zaman, Jensen, and McKee 2011; Perroy, Sullivan, and Stephenson 2017; Müllerová et al. 2017; Michez, Piégay, et al. 2016), analyze the dynamic, structure and biophysical attributes of forest stands (Gini et al. 2012; Zahawi et al. 2015; Lisein et al. 2015; Kachamba et al. 2016; L. F. Gonzalez et al. 2016; Zhang et al. 2016; Getzin, Nuske, and Wiegand 2014; Getzin, Wiegand, and Schöning 2012; Ivosevic, Han, and Kwon 2017; Stark et al. 2017) or mapping sensitive shallow coastal habitats (Ventura et al. 2016; Casella et al. 2017) , wetlands (Chabot and Bird 2013) or riparian ecosystems (Husson 2016). Considering that “Involvement of communities and stakeholder” is moderately correlated to effective management in PAs, it is fortunate that RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014). Moreover, RPAS can play a fundamental role on actions aimed to assess effectiveness of PAs compared to buffer zones and surroundings where it is assume that higher rates of ecosystem degradation occur (Ewers and Rodrigues 2008). Despite undeniable progress, efforts to design standardized RPAS based surveying protocols remain fundamentally unexplored.

## Law enforcement

RPAS also have their place in the control and surveillance of PAs including 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 forbidden activities (Sabella et al. 2017). (Duffy 2014) analyzed the consequences of the militarization of conservation practices as an increasing trend in PAs around the world and illustrates the use of RPAS through several examples. Nevertheless, effective implementation of RPAS to the arsenal of antipoaching tools faces important technical and legal constraints that can explain the scarcity of scientific articles published. Low autonomy of RPAS is especially critical in large natural parks, limiting the area under surveillance, while issues concerning flying in bad weather conditions have not yet been completely resolved. In general, meeting the proper specifications can be costly, especially in developing countries (Banzi 2014). However, as technology increasingly becomes more accessible and sophisticated, it is expected that main barriers will appear in the legislative and social sphere. For instance, flying beyond the visual line of sight (BVLOS) or above a certain altitude is often forbidden, limiting the effectiveness of the inspection. RPAS applied to surveillance of PAs is also questioned arguing human right breaching (Duffy 2014). Some detractors are skeptical about the ability of RPAS to persuade offenders, who in many cases go through a situation of great need. However, some studies have remarked that the effectiveness of antipoaching depends to a large extent on a greater allocation of resources (Hilborn et al. 2006). Moreover, recording illegal and vandalism acts within the limits of PAs can prove to be valid evidence against offenders. 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

Within the still scarce literature (King 2014) summarized possible recreational activities and formulas for granting RPAS flight permits in designated areas. (Hansen 2016; Park and Ewing 2017) valued the effectiveness of RPAS to monitor visitors activities in PAs and (Chamata and King 2017) proposed possible profitable concession scenarios. Stakeholders agreed on a set of policies to establish permitted activities with RPAS within tourist locations in Antarctica (Leary 2017). Other PAs opted for simpler rules (OEH 2017) or, not without founded reasons, banned RPAS arguing safety reasons and wildlife impact (Peyer 2015). Accidents could also lead to unexpected hazardous events, like water supply pollution or wildfires in sensitive areas due to the presence of flammable and toxic components. Even when the economic benefits and leisure possibilities are promising, it would be advisable to be cautious in the face of the demand of the ecotourism industry to incorporate RPAS in their activities, as undesirable events can fuel the low popularity of RPAS in detriment of the advantages they bring.

# Environmental management and emergency response

RPAS has been adapted for remotely sensing pollution and air / water quality measurements (Schwarzbach et al. 2014; Zang et al. 2012; Ore et al. 2015), mapping environmental risk factors for predicting zoonotic diseases (Fornace et al. 2014), erosion and sediments dynamics (Casella et al. 2016, 2014), landslides, volcanic activity, flood events, mining and wildfires, and search and rescue missions (Van Tilburg et al. 2017). Such applications have operational requirements which eventually are costly. For instance, sophisticated on-board instruments, gas powered engines for longer endurance and higher payloads or gear designed to assist sampling, hold cargo or deliver assistance. Plausible and easy to implement scenarios include automate procedures to assess damage in trails and amenities after natural hazard events.

## Current Challenges

### Legal barriers and ethical constraints

RPAS operations faces important social and legal barriers that undermine their true potential in the civilian sphere (Stöcker et al. 2017; Sandbrook 2015). An overly restrictive regulatory framework is currently limiting the applications of RPAS in the field of conservation and their use has not been without problems, resulting in governments that have totally or partially prohibited RPAS operations in PAs. This highlights the urgent need to seek consensus among countries and adapt legislation to distinguish amongst the purpose of leisure, research and management.

### 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; R. P. Wilson and McMahon 2006). RPAS are not exempt of discussion and consequently disturbance effects of RPAS on birds (Duriez et al. 2015; McEvoy, Hall, and McDonald 2016; Fletcher 2017; Scobie and Hugenholtz 2016; Weissensteiner, Poelstra, and Wolf 2015; Lyons et al. 2017) and mammals (Ditmer et al. 2015; Pomeroy, Connor, and Davies 2015) were mainly documented. Despite a greater degree of awareness reflected in a emergent set of guidelines (Hodgson and Koh 2016; Mulero-Pázmány et al. 2017; Gonzalez and Johnson 2017), most of studies marginally inform reactions and further trials aimed at quantifying changes in behavioral 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, an optimal 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 and McMahon 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, Hall, and McDonald 2016), forming the basis for wildlife certified RPAS operators.

### Costs of RPAS operation

From the economic point of view, expenses derived from the operation with RPAS are hardly quantifiable (AUVSI 2013) .While 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 a challenge and certain phases of information processing requires the acquisition of pricey commercial software or alternatively the recruitment of high-level specialized services. Also, operations with RPAS are not exempt from accidents affecting both the structural components and captors, thus having a negative impact on the budget originally planned. Moreover, park rangers should be aware that there is no single solution covering all the conservation purposes (W. 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, 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 charged indirectly. Furthermore, coupled sensors are often the more expensive but also breakable parts of the platform. Despite these drawbacks, RPAS are increasingly being considered a cost-effective and safer alternative to manned aircraft and brings advantages to both ground surveys and satellite remote sensing.

### Technological issues

Massive amount of information is collected when remotely sensing ecosystems using ultra-high resolution sensors, resulting in storage, 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 modeling of species distribution are available. On the contrary, the planning phase and photogrammetric process is guaranteed from both commercial software and emerging open source alternatives (Duarte et al. 2017), at expense of major complexity. On the other hand, traditional pixel-based remote sensing classification algorithms are ineffective for ultra-high resolution images of RPAS, and further investment on machine learning techniques would be desirable (Piragnolo, Masiero, and Pirotti 2017). In general, we found that a solid technical and analytical background is required. This may curb the applicability of RPAS in PAs, worsened by weakness of “adequacy of staff training” and although this category has been notably correlated to effective management.

# Conclusions

Park managers demands practical and cost-effective solutions to handle an overwhelming amount of environmental issues requiring appropriate decisions. Bridging the gap between science and conservation priorities require driving research to those critical aspects of management requiring realistic, cost-effective and innovative solutions. While RPAS have been called upon to revolutionize conservation, bottlenecks for integrating them into the PAs management toolset come from different fronts, ranging from legal and social issues to operational challenges. However, being a relatively young discipline, conservation RPAS have gone far and have great potential to evolve and raise better-informed decisionsto cope with underlying pressures protected areas face.

# References

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.

Andel, Alexander C. van, Serge A. Wich, Christophe Boesch, Lian Pin Koh, Martha M. Robbins, Joseph Kelly, and Hjalmar S. Kuehl. 2015. “Locating Chimpanzee Nests and Identifying Fruiting Trees with an Unmanned Aerial Vehicle.” *American Journal of Primatology* 77 (10): 1122–34. doi:10.1002/ajp.22446.

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.

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.

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 David M Bird. 2012. “Evaluation of an off-the-Shelf Unmanned Aircraft System for Surveying Flocks of Geese.” *Waterbirds* 35 (1): 170–74. doi:10.1675/063.035.0119.

———. 2013. “Small Unmanned Aircraft: Precise and Convenient New Tools for Surveying Wetlands” 24 (June): 15–24.

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.

Chape, Stuart, Mark Spalding, and Martin Jenkins. 2008. *The World’s Protected Areas: Status, Values and Prospects in the 21st Century*. *Prospects*. doi:10.1007/s10728-009-0140-1.

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 A rild Steen, Rasmus N yholm Jørgensen, and Henrik Karstoft. 2014. “Automated Detection and Recognition of Wildlife Using Thermal Cameras.” *Sensors (Basel, 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.

Cliff, Oliver M, Robert Fitch, Salah Sukkarieh, Debra L Saunders, and Robert Heinsohn. 2015. “Online Localization of Radio-Tagged Wildlife with an Autonomous Aerial Robot System.” *Robotics Science and Systems*, no. November 2016: 1–9. doi:10.15607/RSS.2015.XI.042.

Colefax, Andrew P., Paul A. Butcher, and Brendan P. Kelaher. 2017. “The Potential for Unmanned Aerial Vehicles (UAVs) to Conduct Marine Fauna Surveys in Place of Manned Aircraft.” *ICES Journal of Marine Science*. doi:10.1093/icesjms/fsx100.

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.

Duarte, L., A. C. Teodoro, O. Moutinho, and J. A. Gon??alves. 2017. “Open-Source GIS Application for UAV Photogrammetry Based on MicMac.” *International Journal of Remote Sensing* 38 (8–10): 3181–3202. doi:10.1080/01431161.2016.1259685.

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.

Dulava, Sharon, William T. Bean, and Orien M. W. Richmond. 2015. “ENVIRONMENTAL REVIEWS AND CASE STUDIES: Applications of Unmanned Aircraft Systems (UAS) for Waterbird Surveys.” *Environmental Practice* 17 (3): 201–10. doi:10.1017/S1466046615000186.

Durban, J W, H Fearnbach, W L Perryman, and D J Leroi. 2015. “Photogrammetry of Killer Whales Using a Small Hexacopter Launched at Sea.” *Journal of Unmanned Vehicle Systems* 3 (June): 1–5. doi:dx.doi.org/10.1139/juvs-2015-0020.

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

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*, October. Elsevier Ltd, 1–6. 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.

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.

Getzin, Stephan, Robert S. Nuske, and Kerstin Wiegand. 2014. “Using Unmanned Aerial Vehicles (UAV) to Quantify Spatial Gap Patterns in Forests.” *Remote Sensing* 6 (8): 6988–7004. doi:10.3390/rs6086988.

Getzin, Stephan, Kerstin Wiegand, and Ingo Schöning. 2012. “Assessing Biodiversity in Forests Using Very High-Resolution Images and Unmanned Aerial Vehicles.” *Methods in Ecology and Evolution* 3 (2): 397–404. doi:10.1111/j.2041-210X.2011.00158.x.

Gini, R., D. Passoni, L. Pinto, and G. Sona. 2012. “Aerial Images From an Uav System: 3D Modeling and Tree Species Classification in a Park Area.” *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XXXIX-B1 (September): 361–66. doi:10.5194/isprsarchives-XXXIX-B1-361-2012.

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.

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.

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.

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, and Aline Reinhard. 2017. “Detecting Nests of Lapwing Birds with the Aid of a Small Unmanned Aerial Vehicle with Thermal Camera.” In *Unmanned Aircraft Systems (ICUAS), 2017 International Conference on*, 1199–1207.

Ivosevic, Bojana, Yong Gu Han, and Ohseok Kwon. 2017. “Calculating Coniferous Tree Coverage Using Unmanned Aerial Vehicle Photogrammetry.” *Journal of Ecology and Environment* 41 (1). Journal of Ecology and Environment: 4–11. doi:10.1186/s41610-017-0029-0.

Jain, Mukesh. 2013. “Unmanned Aerial Survey of Elephants.” *PLoS ONE*. doi:10.1371/ journal.pone.0054700.

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

Kachamba, Daud Jones, Hans Ole Ørka, Terje Gobakken, Tron Eid, and Weston Mwase. 2016. “Biomass Estimation Using 3D Data from Unmanned Aerial Vehicle Imagery in a Tropical Woodland.” *Remote Sensing* 8 (11): 1–18. doi:10.3390/rs8110968.

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.

Körner, Fabian, Raphael Speck, Ali Haydar, and Salah Sukkarieh. 2010. “Autonomous Airborne Wildlife Tracking Using Radio Signal Strength,” 107–12.

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.

Koski, William R., Travis Allen, Darren Ireland, Greg Buck, Paul R. Smith, a. Michael Macrander, Melissa a. Halick, Chris Rushing, David J. Sliwa, and Trent L. McDonald. 2009. “Evaluation of an Unmanned Airborne System for Monitoring Marine Mammals.” *Aquatic Mammals* 35 (3): 347–57. doi:10.1578/AM.35.3.2009.347.

Koski, William R., Gayan Gamage, Andrew R. Davis, Tony Mathews, Bernard LeBlanc, and Steven H. Ferguson. 2015. “Evaluation of UAS for Photographic Re-Identification of Bowhead Whales, Balaena Mysticetus.” *Journal of Unmanned Vehicle Systems* 3 (1): 22–29. doi:10.1139/juvs-2014-0014.

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.

Lisein, Jonathan, Adrien Michez, Hugues Claessens, and Philippe Lejeune. 2015. “Discrimination of Deciduous Tree Species from Time Series of Unmanned Aerial System Imagery.” *PLoS ONE* 10 (11). doi:10.1371/journal.pone.0141006.

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.

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.

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.

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.

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.

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 José Negro, and Zulima Tablado. 2017. “Unmanned Aircraft Systems as a New Source of Disturbance for Wildlife: A Systematic Review.” *PLoS ONE* 12 (6). 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, Josef Brůna, Tomáš Bartaloš, Petr Dvořák, Michaela Vítková, and Petr Pyšek. 2017. “Timing Is Important: Unmanned Aircraft vs. Satellite Imagery in Plant Invasion Monitoring.” *Frontiers in Plant Science* 8 (May). doi:10.3389/fpls.2017.00887.

Müllerová, Jana, Josef Brůna, Petr Dvořák, Tomáš Bartaloš, and Michaela Vítková. 2016. “Does the Data Resolution/origin Matter? Satellite, Airborne and UAV Imagery to Tackle Plant Invasions.” *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* 41 (July): 903–8. doi:10.5194/isprsarchives-XLI-B7-903-2016.

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.

Ordóñez-Delgado, Leonardo, Gustavo Tomás, Diego Armijos-Ojeda, Andrea Jara-Guerrero, Rodrigo Cisneros, and Carlos Iván Espinosa. 2016. “New Contributions to the Knowledge of Birds in Tumbesian Region; Conservation Implications of the Dry Forest Biosphere Reserve, Zapotillo, Ecuador.” *Ecosistemas* 25 (2): 13–23. doi:10.7818/ECOS.2016.25-2.03.

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.

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 (June). 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.

Piragnolo, Marco, Andrea Masiero, and Francesco Pirotti. 2017. “Open Source R for Applying Machine Learning to RPAS Remote Sensing Images.” *Open Geospatial Data, Software and Standards* 2 (1): 16. doi:10.1186/s40965-017-0033-4.

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.

Puttock, A.K., A.M. Cunliffe, K. Anderson, and R.E. Brazier. 2015. “Aerial Photography Collected with a Multirotor Drone Reveals Impact of Eurasian Beaver Reintroduction on Ecosystem Structure 1.” *Journal of Unmanned Vehicle Systems* 3 (3): 123–30. doi:10.1139/juvs-2015-0005.

Ratcliffe, Norman, Damien Guihen, Jeremy Robst, Sarah Crofts, Andrew Stanworth, and Peter Enderlein. 2015. “A Protocol for the Aerial Survey of Penguin Colonies Using UAVs.” *Journal of Unmanned Vehicle Systems* 3 (3): 95–101. doi:10.1139/juvs-2015-0006.

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.

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.

Safety, Occupational. 2016. “Evaluation of Protected Area Management Effectiveness – an Overview of ...” 5 (November): 29–35. doi:10.7562/SE2016.6.01.05.

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

Sardà-Palomera, Francesc, Gerard Bota, Carlos Viñolo, Oriol Pallarés, Víctor Sazatornil, Lluís Brotons, Spartacus Gomáriz, and Francesc Sardà. 2012. “Fine-Scale Bird Monitoring from Light Unmanned Aircraft Systems.” *Ibis* 154 (1): 177–83. doi:10.1111/j.1474-919X.2011.01177.x.

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.

Soriano, P, F Caballero, and A Ollero. 2009. “RF-Based Particle Filter Localization for Wildlife Tracking by Using an UAV.” *40 Th International Symposium of Robotics*, 239–44.

Stark, Danica J., Ian P. Vaughan, Luke J. Evans, Harjinder Kler, and Benoit Goossens. 2017. “Combining Drones and Satellite Tracking as an Effective Tool for Informing Policy Change in Riparian Habitats: A Proboscis Monkey Case Study.” *Remote Sensing in Ecology and Conservation*, no. Manyangadze 2009: 1–9. doi:10.1002/rse2.51.

Stöcker, Claudia, Rohan Bennett, Francesco Nex, Markus Gerke, and Jaap Zevenbergen. 2017. “Review of the Current State of UAV Regulations.” *Remote Sensing* 9 (5): 459. doi:10.3390/rs9050459.

Szantoi, Zoltan, Scot E. Smith, Giovanni Strona, Lian Pin Koh, and Serge A. Wich. 2017. “Mapping Orangutan Habitat and Agricultural Areas Using Landsat OLI Imagery Augmented with Unmanned Aircraft System Aerial Photography.” *International Journal of Remote Sensing* 38 (8–10). Taylor & Francis: 1–15. doi:10.1080/01431161.2017.1280638.

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.

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.

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.

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, 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.

Zahawi, Rakan A, Jonathan P Dandois, Karen D Holl, Dana Nadwodny, J Leighton Reid, and Erle C Ellis. 2015. “Using Lightweight Unmanned Aerial Vehicles to Monitor Tropical Forest Recovery.” *Biological Conservation* 186 (June). Elsevier Ltd: 287–95. doi:10.1016/j.biocon.2015.03.031.

Zaman, Bushra, Austin M. Jensen, and Mac McKee. 2011. “Use of High-Resolution Multispectral Imagery Acquired with an Autonomous Unmanned Aerial Vehicle to Quantify the Spread of an Invasive Wetlands Species.” *International Geoscience and Remote Sensing Symposium (IGARSS)*, 803–6. doi:10.1109/IGARSS.2011.6049252.

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.

Zhang, Jian, Jianbo Hu, Juyu Lian, Zongji Fan, Xuejun Ouyang, and Wanhui Ye. 2016. “Seeing the Forest from Drones: Testing the Potential of Lightweight Drones as a Tool for Long-Term Forest Monitoring.” *Biological Conservation* 198: 60–69. doi:10.1016/j.biocon.2016.03.027.

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. |

Table 2. Management measurements

Table 3. Examples of studies reviewed classified according to goals

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Publication | Category | Aim | Target | Place | RPAS type | RPAS model | Captor |
| (A. Hodgson, Peel, and Kelly 2017) | Wildlife Monitoring | 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 Monitoring | 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 Monitoring | 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 Risk Assessment and Management | Assess wildlife damage to crops | Wild boar (Sus scrofa) | Wallonia (Belgium) | Fixed-Wing | Gatewing X100 | Ricoh GR3 |
| (Lobermeier et al. 2015) | Wildlife Risk Assessment and Management | Mitigating avian collision with power lines using markers | Birds | USA | Rotor-wing | Mikrokopter Hexa XL | - |
| (Alvarez-taboada, Paredes, and Julián-Pelaz 2017) | Monitoring of terrestrial and aquatic ecosystems | 20 | +4 |  |  |  |  |
| Universidad Olmo | Monitoring of terrestrial and aquatic ecosystems | 53 | -10 |  |  |  |  |
| Academia Arce | Monitoring of terrestrial and aquatic ecosystems | 11 | -8 |  |  |  |  |
| (Mulero-Pázmány et al. 2014) | Law enforcement |  | 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 for modeling drone surveillance capabilities | elephant (Loxodonta africana), | Tsavo National Park, Kenya | Fixed-wing | RQ-84Z AeroHawk | FLIR Tau 2 640 |
|  | Ecotourism |  |  |  |  |  |  |
|  | Ecotourism |  |  |  |  |  |  |