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

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In the last few decades, we have witnessed a growing interest in projects aimed to evaluate the feasibility of RPAS for conservation purposes. So far, RPAS have been proposed for a variety of research and management activities including environmental and wildlife monitoring or law enforcement. Beyond technical, ethical and legal barriers that compromise their effective implementation, it remains to be seen how well RPAS complement conservation actions in protected areas, particularly those claimed by natural park managers. We carried out a systematic review of the published literature to consider those conservation activities where RPAS might play a major role. After discussing results, we expose main drawbacks and identify those areas that requires further research investment, highlighting some trends and opportunities that apparently have not yet been adequately exploited.

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 have been declared under different reasons and circumstances but there is a consensus on its importance in safeguarding biodiversity, contribute to human well-being and ensure persistence of the natural heritage for the enjoyment of future generations. Despite such praiseworthy intentions, the reality faced by protected areas is subject to a wide variety of requirements and unforeseen challenges requiring rapid and effective solutions. To achieve both long-term and short-term conservation goals, protected areas have benefited from an extensive regulatory framework, effectively implemented by means of management plans. These plans aimed to establish the basic guidelines to protect the natural and socioeconomic values by which protected areas were declared. As a result, available human and material resources have mainly been allocated to regulate tourism and recreational activities, law enforcement including various forms of illegal resource extraction, wildfire prevention and fighting, monitoring campaigns to maintain up-to-date fauna and vegetation inventories, environmental assessment or actions aimed at strengthening educational and research programs.

As reference sites for monitoring and managing biodiversity, protected areas management and research activities have benefit from a wide range of technological advances, including remote sensors, field-based monitoring stations, manned surveys, camera traps, wildlife tracking devices or computational tools. 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 sphere and scientific community. Not surprisingly, there have been a significant amount of articles facing conservation issues using RPAS (Linchant et al. 2015; Chabot and Bird 2015; Christie et al. 2016; Koh and Wich 2012; Rodríguez et al. 2012; Wulder et al. 2004; Zahawi et al. 2015).

However, to date, it has not been adequately weighted whether RPAS meet the demands of conservation practitioners, which often face budgetary constraints. As noted in this study, wildlife and habitat monitoring have received major emphasis while there is a scarcity of research investment in other potential application areas. Moreover, legal barriers are currently limiting the usefulness of RPAS for conservation purposes. Filling this important gap is essential to move beyond the hype and consciously assess how RPAS could leverage protected areas management.

# Methods

To achieve the proposed objectives, a systematic bibliographical review (see PRISMA Flowchart) of scientific articles, gray literature, postgraduate theses, websites and specialized journals was carried out, following a similar line to other related studies (Linchant et al. 2015; Christie et al. 2016; Mulero-Pázmány et al. 2017). Last reference revised was published on June, 2017. The main tools for selecting bibliography include Google Schoolar, Research Gate and Mendeley Desktop, while the use of Internet search engines include other references outside the scientific scope. Key search criteria, primarily in English, include RPAS in their various meanings and acronyms, reflecting the varied terminology used: "remotely piloted aerial system (RPAS)", "drone", "unmanned aircraft system (UAS)" "unmanned aircraft", "model aircraft", "radio control aircraft" , "unmanned aerial vehicle (UAV)" combined with several terms referring to common activities carried out in protected areas, from the general to the particular: "conservation", "protected areas", "ecology" "ecosystem", "habitat", "vegetation", "forest", "wetland", "reforestation", "monitoring", "survey", "sampling", "inventory", "wildlife", "fauna", "bird", "mammal", "fish, "amphibian", "reptile", "wildfire", "remote sensing", "tourism", "ecotourism", "law enforcement", "poaching", "logging", "risk management", "pollution" and so on. A boolean search was carried out using AND logical statement. We also included references from those articles not indexed in research results but often cited.

From the total number of publications (x), we excluded duplicated results or those with no relevance for conservation, based on activities included in protected area management plans worldwide. The selected publications (x) were categorized according to the focus of the study. These categories include: "wildlife monitoring and management", for those feasibility studies facing alternative fauna population surveys and tracking methods. We also include recent advances in machine learning computer vision software, aimed to automatically detect and count animals; "monitoring and mapping of terrestrial and aquatic ecosystems", for habitat surveys; "Law enforcement" encompasses monitoring poaching, illegal logging and other illicit activities; "ecotourism" is restricted to recreational activities and visitors management; "Environmental management and decision support" span from environmental monitoring and assessment, disaster management to search and rescue activities. Finally, legal constraints and actions to minimize impact on fauna are also considered, as both shape the feasibility of RPAS to approach conservation and environmental issues.

The collected information is presented in tabular format, identifying where the study was conducted, the expected accomplishments and technical specifications of the aerial platform. After exposing main results, gaps are identified and possible scenarios for implementing RPAS as essential tools to help achieve conservation goals in protected areas are discussed.

# Results

## Wildlife Monitoring and Management

Several studies focused on testing survey methods aimed at locating, counting and characterizing wildlife communities and habitats, ranging from large and medium size terrestrial mammals (Jain 2013; Barasona et al. 2014), birds (A. M. Wilson, Barr, and Zagorski 2017; Hodgson et al. 2016; Christie et al. 2016; Sardà-Palomera et al. 2012; Chabot and Bird 2012), but also species relying on coastal and marine ecosystems (Colefax, Butcher, and Kelaher 2017; Hodgson, Amanda;Peel, David;Kelly 2017; Koski et al. 2015; Dulava, Bean, and Richmond 2015; Durban et al. 2015; Koski et al. 2009). RPAS have as well been applied as a means of inspecting and assess breeding and nesting areas at inaccessible sites in several species (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; Ord 2016; Soriano, Caballero, and Ollero 2009). Given the large amount of information generated, computer vision software have been developed to handle the automatic detection, recognition and counting of individuals captured in scenes acquired by visible and thermal-infrared sensors, replacing otherwise time-consuming manual tasks (Andrew and Shephard 2017; Chabot and Francis 2016; 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).

## Monitoring and mapping of terrestrial and aquatic ecosystems

So far RPAS have been used to a variety of research missions (U.S. Geological Survey National 2017), monitoring the spread and detection rate of invasive species (Müllerová et al. 2016, Zaman, Jensen, and McKee (2011), Perroy, Sullivan, and Stephenson (2017)), the characterization of forest stands (Gini et al. 2012), including the evaluation of the effectiveness of restoration actions (Zahawi et al. 2015) or multitemporal analysis of the spectral response to phenological variations in different species of deciduous trees (Lisein et al. 2015). Recently, shallow coastal habitats were also mapped using consumer grade RPAS (Casella et al. 2017, Ventura et al. (2016)), but also to monitor erosion dynamics in shorelines. (Casella et al. 2016). This momentum has been especially notable with the parallel development of affordable multispectral and hyperspectral sensors adapted to small aircraft (Bareth et al. 2015).

## Infrastructure and risk assessment

Other research projects highlight the convenience of RPAS in assessing the risk that linear electrical infrastructures posed for birds (Barasona et al. 2014; Lobermeier et al. 2015) or identify nests on the ground at risk of destruction by harvesting (Mulero-Pázmány M. 2011).

## Law enforcement

RPAS have also relevance in the control and surveillance of protected areas, including monitor poaching and illegal fishing activities (Mulero-Pázmány et al. 2014; Franco et al. 2016; Olivares-Mendez et al. 2014) but also other less contentious illegal activities (Sabella et al. 2017). (Duffy 2014) analyzed the consequences of the militarization of conservation practices as an increasing trend in natural protected areas around the world and illustrates the use of RPAS through several examples.

## Ecotourism

(King 2014) summarized possible recreational activities and formulas for granting RPAS flight permits in designated areas. Within the still scarce literature, (Hansen 2016) values the effectiveness of RPAS in monitoring visitors both in marine and coastal areas. More recent, (Chamata and King 2017) analyze the positive socioeconomic impact to US National Parks while proposing two possible profitable concession scenarios.

# Environmental management and decision support

(Cornell, Herman, and Ontiveros 2016) obtained ground truth data by adapting RPAS to take water samples for comparison with hyperspectral measurements of Landsat 8 Operational Land Imager (OLI). (Zang et al. 2012) identified several pollution agents in riparian areas using RPAS imagery. (Schwarzbach et al. 2014) goes further away by performing several aerial water sampling methods using an unmanned helicopter to monitor water pollution, while (Schmale, Dingus, and Reinholtz 2008) collected a broad spectrum of both prokaryotic and eukaryotic microorganisms using a fixed-wing aircraft equipped with a custom made aerial sampling device. (Fornace et al. 2014) considered mapping environmental risk factors for predicting zoonotic diseases as part of an extensive epidemiological study carried out in Philippines and so on. Literature citing RPAS for search and rescue activities is profuse and an in-depth revision is beyond the scope of this article, but a recent publication illustrate several examples where RPAS were successfully operated to assist rescue teams (Van Tilburg et al. 2017). A google scholar search sorted by relevance using disaster management and drones keywords throws at first place a complete report describing a complex framework for decision support using RPAS (Maza et al. 2011). RPAS have also been used to drop poised baits to eradicate feral cats disturbing threatened native species (McCaldin, Johnston, and Rieker 2015).

## Impact of RPAS on wildlife and ecosystems

Animal welfare in wildlife management practices and ecological research is a sensitive issue from which ethical issues arise (F. Dormann et al. 2007; R. P. Wilson and McMahon 2006). RPAS are not exempt of discussion and several trials measure the 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) and mammals (Ditmer et al. 2015; Pomeroy, Connor, and Davies 2015), while other studies marginally inform observed behavioral patterns (Jain 2013; Mulero-Pázmány et al. 2015). Finally, a code of good practice and recommendations is built upon the learned experiences.

## Legal barriers

RPAS operations faces important legal barriers that undermine their true potential in the civilian sphere (Stöcker et al. 2017). An overly restrictive regulatory framework could limit the possibilities of use of the RPAS in the field of conservation, which makes clear the urgent need to harmonize legislation. In the United States and in most of the European countries consulted, interim legislation has been adopted which, to a certain extent, equates the management of RPAS with that of traditional aircraft. In general terms, the situation in Latin America is uneven, however there is a general tendency to develop specific laws to cope with the rise of the RPAS in both the civil and military sectors (New America 2017). Africa is one of the continents where the impact of RPAS in conservation has had greater repercussions. However, in the opinion of some conservationists, their use has not been without problems, resulting in governments that have totally or partially prohibited drone operations, arguing national security problems in detriment of protection of natural areas (Andrews 2014). But RPAS have also been generally welcomed in several developing countries in Asia, where an array of related programs are being carried out (Nugraha, Jeyakodi, and Mahem 2016). The uncertainty of the users along the world has promoted the development of associations in order to advise on the legal aspects to be taken into account during the operation, with the International Association for Unmanned Vehicle Systems (AUVSI 2017) claiming to be the largest nonprofit organization in the world dedicated to advancing the community of unmanned aerial vehicles users.

# Discussion

Most of the analyzed sources focus on local-scale conservation projects and feasibility studies of RPAS methods to sampling distribution and abundance of wildlife populations.

Research investment is equally prolific in mapping and monitoring activities in both terrestrial and aquatic ecosystems, a niche until recently entirely occupied by aerial and space platforms for environmental remote sensing. RPAS has also replaced

Despite the low number of scientific articles addressing the use of RPAS in the control and surveillance of natural protected areas, RPAS for anti-poaching is a major trend, mainly promoted by government and environmental organizations.

From the economic point of view, expenses derived from the operation with RPAS are hardly quantifiable. While RPAS are considered easy to operate, not all studies assess the investment required to enhance the staff technical and analytical skills. Computational requirements are also demanding and certain phases of information processing requires the acquisition of commercial software whose price is generally high. Also, operations with RPAS are not exempt from accidents, thus having a negative impact on the budget originally planned. Nonetheless, we found evidence ~~in the reviewed literature~~ to support that RPAS operational cost are lower than those derived from manned aircraft and likely commercial high-resolution satellite images.

In addition, statistical and sampling methods approaching the analysis of data are mostly in its infancy and further research should be encompassed to assess the overall performance of these methods. Computer vision software is mainly on , while forest based applications are .

## Wildlife Monitoring and Management

Wildlife census campaigns, usually carried out by going in on foot, terrestrial vehicles or by vessel deployment in aquatic environments, could be supplemented or replaced by RPAS mapping and monitoring capabilities. As becoming easier to operate, there are sufficient grounds to encourage park rangers training in the use of RPAS, which are subject in many cases to time-consuming and often dangerous raids. If operated responsibly, it might be considered a non-invasive and reliable monitoring technique (Jewell 2013). RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014). From the technological point of view, "Follow-me" capabilities of RPAS constitute a promising advance in animal movement and remote sensing disciplines, by having high-resolution aerial imagery from places frequently visited or crossed by electronically tagged species.

## Infrastructure and risk assessment

Relative low operational cost of RPAS make them an attractive alternative to manual inspection. The literature citing RPAS for such purposes is limited, at least in the field of Protected Areas. To our best knowledge, we didn’t find studies aimed to test whether RPAS might help decreasing fatalities where terrestrial vehicles and vessels strike are frequent. By scheduling periodic flights monitoring facilities, roads crossing sensitive areas and coastal ecosystems, proper measurement could be taken. RPAS might also help to persuade birds from approaching power lines, wind turbines and other potential hazards, just as it has been applied to keep airports safe.

## Monitoring and mapping of terrestrial and aquatic ecosystems

Fusion of earth observation remote sensing techniques in the scope of RPAS opens new possibilities in the observation of environmental phenomena at local scale, complementing other systems of Earth observation. Protected area managers should be aware of the benefits of having information on demand.

## Law enforcement

The convenience of using RPAS in the fight against poaching and illegal fishing in protected areas faces important technical and legal constraints. First, the reviewed literature mentions the need to design more efficient live vision systems. Low autonomy of RPAS is especially critical in large natural parks, limiting the area under surveillance. Issues concerning atmospheric conditions have not yet been completely resolved. (Banzi 2014) proposed a sensor based economical feasible anti-poaching alternative, arguing that RPAS fulfilling suitable specifications are costly, especially in developing countries. However, as technology becomes more accessible, it is expected that main barriers will appear in the legislative and social sphere. In some countries, it is forbidden to fly beyond the visual range of the operator, limiting the effectiveness of the inspection in real time. RPAS applied to surveillance of protected areas 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. 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. Surveillance of illegal logging activities or bonfires detection in unauthorized areas have great potential and may be convenient to implement.

## Ecotourism

A permissive regularization of RPAS in ecotourism activities in natural parks could lead to unpredictable situations. On the one hand, the constant presence of sources of noise coming from propellers and engines, the sensation of invasion or lack of privacy, security issues and the visual impact of RPAS on the landscape could negatively affect the tourist experience. It is well known that the consequences triggered by RPAS disturbing wildlife have led to the ban on flying them in national parks in the United States and other protected areas of the world. As result of potential environmental impact due to the use of RPAS by tourist in Antarctica, (Leary 2017) reported the partial prohibition of recreational RPAS in coastal areas as part of a more extensive regulation promoted by stakeholders. Such regulation looks reasonable and could be the way forward for other protected areas to adapt the allowed activities with RPAS. It seems obvious to deduce that in the hands of non-skilled operators, the risk of accidents and losses would increase. This may lead to the aforementioned wildlife disturbance, but they also pose a risk for contamination of water supplies or the triggering of fires in sensitive areas due to the presence of flammable and toxic components, fueling the low popularity of RPAS to the detriment of the benefits they bring. It does not appear that feasibility studies or opinion polls have been published that respond to the issues raised and to the ethical and legal implications derived from their use. Even when the leisure possibilities are wide and recognized, it would be advisable to be cautious in the face of the demand of the ecotourism industry to incorporate RPAS in their activities.

## Impact of RPAS on wildlife and ecosystems

Ethical implications of RPAS in wildlife studies have not yet been adequately weighed since most studies only marginally address the presence or absence of reactions in species in the vicinity of RPAS. Despite the greater degree of awareness reflected in a emergent set of guidelines (Hodgson and Koh 2016; Mulero-Pázmány et al. 2017), we consider that further trials aimed at quantifying physiological and behavioral changes targeting a broader group of wild species should be carried out. The establishment of a best practices and recommendations manual could increase the chances of integrating the responsible use of RPAS in conservation and management activities in natural areas. Moreover, some authors mentioned the lack of commercial operators with sufficient expertise to carry out such activities (McEvoy, Hall, and McDonald 2016). Also, an optimal trade-off between benefits and environmental costs should be pursued (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. Nonetheless we trust that, as far as further testing be done, RPAS has great potential to replace more invasive monitoring techniques, whose reliability is challenged by the potential to induce conditions of unacceptable stress in wildlife that could ultimately invalidate the results of the research (Jewell 2013; R. P. Wilson and McMahon 2006). This should be consciously considered by those park managers reluctant to incorporate RPAS in research and conservation activities.

# Environmental monitoring and decision support

Protected areas are subject to periodic environmental quality control procedures where RPAS could play a major role. Also, RPAS are suitable to assist decision making where rapid response is crucial by offering valuable information at real time to handle natural and man-made disasters. Wildfires is a major concern in natural parks and is not rare that RPAS have been put forward to assist in prevention, fighting and evaluation phases. In most cases, 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 robotics arms and containers designed to assist sampling, hold cargo or deliver assistance. RPAS could leverage wildlife capture procedures by carrying dart guns for chemical immobilization where otherwise manual approaching free-ranging animals is considered inefficient or dangerous.

# Conclusions

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