**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**

In the past few 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 technical, ethical and legal barriers that compromise their effective implementation, it remains to be seen how well RPAS meet the requirements demanded by natural park managers. We carried out a RPAS related bibliographic survey to search for those articles facing ecologically remarkable protected area targets. After discussing results, we expose main gaps, highlighting some trends and opportunities that apparently have not yet been adequately exploited. We found that while the range of RPAS applications to complement management actions are diverse and may contribute to the overall performance of protected areas, linking research investment with conservation priorities was far from being evenly distributed. This could have implications for effectively addressing the most critical threats to biodiversity through RPAS.

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 (Watson et al. 2014). Despite such praiseworthy intentions, the reality faced by protected areas is subject to a wide variety of unforeseen challenges requiring rapid and effective solutions. Habitat change and fragmentation, severe pollution particularly in freshwater ecosystems, overexploitation of resources, climate change and the impact of invasive species on indigenous populations have been identified as the main global threats to biodiversity (Groom, Meffe, and Caroll 2006) . To curb the loss of biodiversity, protected areas have been reinforced from a broad regulatory framework, implemented through management plans. As a result, available human and material resources have 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. These conservation actions 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 describing the pros and cons of RPAS for conservation activities (Rodríguez et al. 2012; Koh and Wich 2012; Anderson and Gaston 2013; Linchant et al. 2015a; Christie et al. 2016; Torresan et al. 2017). However, to date, it has not been adequately weighted whether RPAS meet the demands of conservation practitioners, which often face budgetary constraints and under-resourcing limiting the accomplishment of management objectives (Watson et al. 2014). As noted in this study, wildlife and habitat monitoring have received major emphasis, while there is an apparent scarcity of scientific articles in other potential application areas. For example, law enforcement was clearly underrepresented, although as part of the Management Effectiveness Tracking Tool (METT) developed by WWF and the World Bank (Dudley et al. 2007), poaching and logging were identified as the main threats to protected areas. To explain this apparent lack of literature, we hypothesize two possible reasons. First, these projects are currently being carried out, but do not involve publication in journals. Second, technological, economical and legal barriers make this type of studies difficult to undertake, hindering the effective implementation of RPAS in protected areas. We consider relevant to fill these gaps to go beyond the hype and consciously drive research with RPAS to those critical aspects of conservation management that require realistic, cost-effective and innovative solutions.

## 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 (‘OR’ boolean expression) with terms referring to common biodiversity targets, threats, stresses and conservation actions carried out in protected areas (see table 1). A total of X search terms and X combinations were applied. From the X papers found, a second recursive scan was performed by following “cited by” links (x results). We then exclude duplicate or non-conservation results and complemented with some other references found elsewhere (Research Gate, Mendeley Desktop, Review articles, Internet search engines). The remaining publications (x) were grouped according to the following categories: "wildlife monitoring and management", for feasibility studies facing alternative fauna population surveys and tracking methods, but also 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. We then further classified the projects attending to a standard nomenclature for threats and conservation actions (Salafsky et al. 2008) and compared this compilation with those conservation actions ranking as critical within the “Management effectiveness evaluation in protected areas – a global study” report (Stoll-kleemann 2010) , as the main reference to guide this review. 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 and discussion

## Wildlife Monitoring and Management

Most of the reviewed studies focus on local-scale conservation projects and feasibility approaches of RPAS as instrument to sampling distribution and abundance of wildlife populations, 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; Ratcliffe et al. 2015) and 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 mean of inspecting 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; Ordóñez-Delgado et al. 2016; Soriano, Caballero, and Ollero 2009). Processing such volume of data require the development of computer vision algorithms aimed to the automatic detection, recognition and counting of individuals, 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; Longmore et al. 2017).

### Discussion

Not coincidentally, census campaigns, usually carried out by ground-based crews, terrestrial vehicles, manned aircrafts or vessels, may benefit from RPAS mapping and monitoring capabilities. As becoming easier to operate, there are sufficient grounds to instruct park rangers in the use of RPAS, which are often subject to time-consuming and often dangerous raids. If operated responsibly, RPAS might be considered a non-invasive and reliable monitoring technique (Jewell 2013). RPAS constitute a promising advance in animal movement and remote sensing disciplines, by having very high spatial and temporal resolution aerial images from places crossed by electronically tagged species.

## 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; Müllerová et al. 2017; Michez et al. 2016) and forest stands (Gini et al. 2012; Zahawi et al. 2015; Lisein et al. 2015; Kachamba et al. 2016; 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). Recently, shallow coastal habitats were also mapped using consumer grade RPAS (Ventura et al. 2016; Casella et al. 2017) but also to monitor shorelines erosion dynamics (Casella et al. 2016, 2014). This momentum has been especially notable with the parallel development of affordable multispectral and hyperspectral sensors adapted to small aircraft (Nebiker et al. 2008).

## 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) and 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 possible profitable concession scenarios.

# Environmental management and decision support

RPAS has been adapted to water (Cornell, Herman, and Ontiveros 2016; Schwarzbach et al. 2014) and air sampling (Villa et al. 2016), remote sensing pollution (Zang et al. 2012) or mapping environmental risk factors for predicting zoonotic diseases (Fornace et al. 2014). 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).

# Discussion

## Monitoring and mapping of terrestrial and aquatic ecosystems

Research investment is prolific in mapping and monitoring both terrestrial and aquatic ecosystems, a niche until recently entirely occupied by aerial and space platforms for environmental remote sensing. Forest applications of RPAS are among the most benefited disciplines. Fusion of 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. RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014).

## Law enforcement

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, but 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 line of sight (BVLOS), limiting the effectiveness of the inspection. 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. However, surveillance of illegal hunting, logging, fishing or bonfire detection in unauthorized areas can prove to be valid evidence against offenders.

## Infrastructure and risk assessment

Relative low operational cost of RPAS make them an attractive alternative to manually inspect infrastructures posing a risk to wildlife. 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.

## 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 at US National Parks and other protected areas of the world. As result of potential environmental impact of tourist flying RPAS 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 set of rules look reasonable and could be the way forward for other protected areas to adapt the allowed activities with RPAS. It seems obvious that in hands of non-skilled operators, the risk of accidents and losses would increase. This may also pose a risk of contamination of water supplies or triggering fires in sensitive areas due to the presence of flammable and toxic components, fueling the low popularity of RPAS in 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.

# Environmental monitoring and decision support

RPAS would ease periodic environmental quality control procedures, especially on remote places. But they also suitable to assist decision making where rapid response and real-time information is crucial 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. 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. Among other applications, 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.

## Current Challenges

### Legal barriers and ethical constraints

RPAS operations faces important legal barriers that undermine their true potential in the civilian sphere (Stöcker et al. 2017). An overly restrictive regulatory framework is currently limiting the applications of 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.

### 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; Lyons et al. 2017) 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). Despite a greater degree of awareness reflected in a emergent set of guidelines (Hodgson and Koh 2016; Mulero-Pázmány et al. 2017), further trials aimed at quantifying physiological and behavioral changes targeting a broader group of wild species should be carried out. Step by step, a code of best practice and recommendations would be continuously updated based on lessons learned, while filling the gap of trained operators (McEvoy, Hall, and McDonald 2016). Moreover, 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; R. P. Wilson and McMahon 2006). Nonetheless, RPAS has great potential to evolve, replacing invasive monitoring techniques. This should be consciously considered by those reluctant to integrate RPAS in research and conservation activities.

### Costs of RPAS operation

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 personnel 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 costs are lower than those derived from manned aircraft and likely commercial very high-resolution satellite images.

### Software and statistical methods

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 for species detection are complex to operate by end-users, while forest-based applications where biomass and structure is modeled from a digital terrain model are more mature.

# Conclusions

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