**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 technical, ethical and legal barriers impede their integration in protected areas, it remains to be seen whether RPAS meet the requirements demanded by natural park managers. A bibliographic survey was carried out to search for potential RPAS applications supporting conservation actions and those aimed to reduce threats to biodiversity. We found that linking research investment with conservation priorities was far from being evenly distributed. This could have implications for consolidating the use of RPAS in protected areas, despite their potential to deliver a wide range of benefits that can positively influence the effectiveness of management in protected areas.

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, preserving ecosystem services and ensure persistence of the natural heritage (Watson et al. 2014; Chape, Spalding, and Jenkins 2008). 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, pollution, 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 while attending other inherent activities, protected areas have been reinforced from a broad regulatory framework, implemented through management plans. As a result, human and material resources have been allocated to regulate tourism and recreational activities, law enforcement including various forms of illegal resource extraction, support decision-making and disaster management, monitoring campaigns to maintain up-to-date fauna and vegetation inventories, environmental assessment or actions aimed at strengthening educational and research programs. With different levels of success, these conservation actions have leveraged from a wide range of technological advances, including remote sensors, field-based monitoring stations, manned surveys, camera traps, wildlife tracking devices or computational tools (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). To date, however, 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). While obstacles remain, the use of RPAS in the scope of wildlife or habitat monitoring activities in protected areas have receive a major emphasis and its feasibility reasonably proven. However, there is a diverse typology of physical, biological and human threats to protected areas requiring further attention. Filling this gap is important to go beyond the hype and consciously drive research 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 expressions) 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 sweep of bibliographical citations and related articles was performed. 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; "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, risk mitigation, disaster response to search and rescue activities; “analytical and technological advances”, include both software, hardware and statistical methods. 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.

Recent examples are 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, highlighting some trends and opportunities that apparently have not yet been adequately exploited.

# Results and discussion

## Wildlife Monitoring and Management

Wildlife surveys are considered essential for effective management of protected areas. RPAS have mostly been applied for surveying large and medium size terrestrial mammals (Jain 2013; Barasona et al. 2014), 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). As result, authors mostly coincide on the broad potential of RPAS to complement census campaigns, usually carried out by ground-based crews, terrestrial vehicles, manned aircrafts or vessels. 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 the flight is performed responsibly, RPAS might be considered a less invasive and reliable monitoring technique (Jewell 2013), compared to other methodologies requiring approaching, capturing or indirectly disturbing wildlife. Moreover, RPAS constitute a promising advance in animal movement and remote sensing disciplines. Interactions between habitat and wildlife can be closely examine by having very high spatial and temporal resolution aerial images from places crossed by electronically tagged species. Finally, park rangers should be aware of RPAS requirements for wildlife monitoring (W. Koski 2017), as there is no single solution that covers all the purposes.

## Monitoring and mapping of terrestrial and aquatic ecosystems

Mapping and monitoring research projects using RPAS have increased notoriously, a niche until recently entirely occupied by aerial and satellite remote sensing. Ver paper remote sensing y protected areas USGS is currently deploying RPAS for different purposes, while RPAS are being currently deployed for different purposes by the USGS (U.S. Geological Survey National 2017). Researchers are using RPAS to quantify 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), analyze the biophysical attributes of forest stands from various perspectives (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) or mapping shallow coastal habitats using consumer grade RPAS (Ventura et al. 2016; Casella et al. 2017). While affordable multispectral and hyperspectral sensors adapted to small aircraft are currently under development (Nebiker et al. 2008), further investment should be accomplished to reach satellite remote sensing state of art. Forestry applications of RPAS are among the most benefited disciplines, where fusion of remote sensing techniques and recent advances in 3D modeling opens new possibilities in the observation of environmental phenomena at local scale, complementing current limitations for 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).

## Wildlife risk assessment

Relative low operational cost of RPAS make them an attractive alternative to manually inspecting infrastructures posing a risk to wildlife. (Barasona et al. 2014; Lobermeier et al. 2015) highlight the convenience of RPAS in assessing the risk that linear electrical infrastructures posed for birds, while (Mulero-Pázmány M. 2011; Israel and Reinhard 2017) proposed a workflow to remotely and timely detect vulnerable wildlife at risk of death through mechanical harvesting. To our best knowledge, we found no studies aimed at testing whether RPAS monitoring could help to reduce wildlife deaths due to impacts with land vehicles, vessels or facilities, especially in sensitive terrestrial and coastal areas where transit flow and human presence is frequent.

## 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. 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) argues 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.

## Ecotourism

(King 2014) summarized possible recreational activities and formulas for granting RPAS flight permits in designated areas. Within the still scarce literature, (Hansen 2016; Park and Ewing 2017) value the effectiveness of RPAS to monitor visitors activities in protected areas, while (Chamata and King 2017) analyze the positive socioeconomic impact to US National Parks and propose possible profitable concession scenarios. However, 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. In addition, the irresponsible use of RPAS has caused the perturbation of wildlife, reason why its use has been banned in several 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 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) , mapping environmental risk factors for predicting zoonotic diseases (Fornace et al. 2014). but also shorelines erosion dynamics (Casella et al. 2016, 2014). A recent publication illustrate several examples where RPAS were successfully operated to assist rescue teams (Van Tilburg et al. 2017). RPAS have also been used to drop poised baits to eradicate feral cats disturbing threatened native species (McCaldin, Johnston, and Rieker 2015). If carefully planned, 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. In addition, RPAS could automate the evaluation of the general conditions of trails and amenities after a natural hazard event. Manual approaching free-range animals is often considered ineffective or dangerous. Without going into discussion, some park managers may contemplate the use of RPAS for wildlife capture procedures through devices for the release of tranquilizing darts.

## Technological and analytical advances

RPAS gather high volume of data Processing to assist mosaic, modeling, etcsuch 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).

## 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 and their use has not been without problems, resulting in governments that have totally or partially prohibited drone operations in protected areas. This highlights the urgent need to seek consensus among countries and adapt legislation to distinguish amongst the purpose of leisure, research and management. Ethical impediments should focus on wildlife disturbance. 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 (J. C. 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 more 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 (AUVSI 2013) .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, bid data storage remains a challenge and certain phases of information processing requires the acquisition of pricey commercial software or recruitment of high-level specialized services. Also, operations with RPAS are not exempt from accidents, thus having a negative impact on the budget originally planned. Despite these drawbacks, RPAS is considered a cost-effective and often the unique viable alternative to manned aircraft, ground surveys and likely very high-resolution commercial satellite images.

### Software and statistical methods

When using RPAS for wildlife census, recurring to manual counting and identifying individuals is time consuming. While there are advances in computer vision software to automate such procedures, these methods are currently under development and mostly non- user-friendly. Statistical and sampling methods that address the analysis and modeling of species distribution are scarce and still in its infancy and further research should be encompassed to assess the overall performance of RPAS compared to other traditional techniques. RPAS forest-based applications are promising and leverage from satellite remote sensing analysis, with several studies implementing machines learning algorithms to yield tree species level inventories. Biomass quantification and tridimensional canopy reconstruction are currently modeled using structure from motion photogrammetry (SfM) software, with results similar to LIDAR techniques. While most studies use relative expensive commercial software, impulse to open source is increasing.

# Conclusions

Bottlenecks to integrate RPAS for complementing management in protected areas arise from several

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