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

Jiménez López, Jesús; Mulero-Pázmány, Margarita

Department, University of Loja, Loja, Ecuador

Provide full correspondence details here including e-mail for the corresponding author

Provide short biographical notes on all contributors here if the journal requires them.

**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 and legal barriers impeding 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 paired and technical / methodological challenges remain. This could hinder the potential of RPAS 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 (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. 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). While obstacles remain, the use of RPAS to monitor natural resources 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 park managers, which often face budgetary constraints and under-resourcing limiting the accomplishment of management objectives (Watson et al. 2014). Moreover, as a result of different methodologies to assess effectiveness of PAs, conservation practitioners identified a wide range of threats and pressures requiring appropriate management measurements. To define the current state of RPAS for conservation purposes, we carried out a extensive literature revision in the hope to consciously bridge the gap between science and conservation priorities, and fostering research to those critical aspects of management requiring 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 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-relevant conservation results and complemented with some other recent 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 emergency response" span from environmental monitoring, risk assessment, disaster response to search and rescue activities. Challenges common to above categories are summarize within legal constraints and actions to minimize impact on fauna, while operational costs and technological are also considered, since all shape the feasibility of RPAS to approach conservation and environmental issues.

Recent examples are presented in tabular format (see table 2), 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 suggested, 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 PAs. 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 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.

## Monitoring and mapping of terrestrial and aquatic ecosystems

Operational use 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 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; 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) and riparian (Husson 2016) ecosystems. RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014), encouraging engagement of local stakeholders. Remote sensing performance in PAs is feasible by periodically comparing human impact with buffer zones and regions beside their limits, where it is assume that rates of ecosystem degradation are higher (Ewers and Rodrigues 2008). With reference to the above, efforts to design a solid RPAS based surveying protocol remain fundamentally unexplored.

## Wildlife risk assessment

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 2013). A recent study registered wildlife night activity from a RPAS using a thermal camera to select suitable locations to install ecological corridors (Gülci and Akay 2016).

## Law enforcement

RPAS have also relevance in the control and surveillance of PAs including illegal encroachment, mining, poaching (Mulero-Pázmány et al. 2014; Franco et al. 2016; Olivares-Mendez et al. 2014) 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 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, while issues concerning flying in bad weather 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. Often flying beyond the visual line of sight (BVLOS) and above a certain altitude is 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. 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, some studies have shown that the effectiveness of antipoaching depends to a large extent on a greater allocation of resources (Hilborn et al. 2006). Moreover, recording illegal activities within the limits of PAs can prove to be valid evidence against offenders.

## 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), while others opted for simpler rules (OEH 2017) . Nevertheless, a permissive use of RPAS for recreational purposes could result in visual and acoustic impact on the landscape, causing discomfort and risk to visitors and wildlife. It seems obvious that in hands of non-skilled operators, the risk of accidents and losses would increase. This can also lead to hazardous events, like water supply pollution or wildfires 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. Even when the economical 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.

# Environmental management and emergency response

RPAS has been adapted for sampling water , air and remotely sensing pollution (Schwarzbach et al. 2014; Zang et al. 2012; Ore et al. 2015), used for mapping environmental risk factors for predicting zoonotic diseases (Fornace et al. 2014). but also coastal erosion dynamics (Casella et al. 2016, 2014), search and rescue missions (Van Tilburg et al. 2017), support eradication of feral species (McCaldin, Johnston, and Rieker 2015), and wildfires. 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. In addition, RPAS could automate the evaluation of the general conditions of trails and amenities after a natural hazard event. Without going into discussion, some park managers may contemplate the use 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.

## 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 RPAS 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. Social and ethical

### 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 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 and gaps on RPAS platforms suited to wildlife projects remain. 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; 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. Step by step, a code of best practice and recommendations could be continuously updated based on lessons learned, forming the basis for the certification and training of specialized operators (McEvoy, Hall, and McDonald 2016).

### 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 also demanding, big data storage remains 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 payload, 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 required for proper assembling and lack of experience could affect reliability. Suppliers often provide support, training and companion software, albeit services could be charged. 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 complement both ground surveys and satellite remote sensing.

### Technological advances

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; 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 photogrammetric process is guaranteed from commercial software and emerging open source alternatives are promoted by institutions, at expense of major complexity. Pixel-based classification algorithms at coarser satellite remote sensing images are not suitable for fine-scale RPAS , and further machine learning techniques (Piragnolo, Masiero, and Pirotti 2017) should be developed in the realm of computer vision software to improve the applicability of RPAS in conservation.

# Conclusions

Bottlenecks to integrate RPAS in PAs arise from different fronts.

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Table 1. habitat disturbances resulting from research