ARTICLE TEMPLATE

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

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ARTICLE HISTORY

Compiled June 18, 2017

ABSTRACT:

Protected areas management has historically benefited from a wide range of technological advances from remote sensing, camera traps or wildlife tracking devices to a continuous development of analytical techniques to cope with such amount of data collected. During the last decade, we have witnesessed a growing interest in projects aimed to evaluate the feasibility of RPAS for conservation purposes. So far, RPAS have been tested or directly applied for a variety of research and management activities including environmental and wildlife monitoring or anti-poaching strategies. But there are technical, ethical, and legal barriers that are currently limiting its effectiveness. However, as a result of efforts to improve the features of these systems, followed by a greater concern related to animal welfare and the parallel development of novel surveys and statistical methods, their presence as an essential tool for conservation in protected areas is increasingly justified.

KEYWORDS:

RPAS, UAV, drones, natural protected areas, conservation, biodiversity

1. Introduction

1.1. *Current context*

Civil applications of remotely piloted aircraft systems (RPAS, also known as unmanned aerial systems, UAS, drones) have been raised in an increasingly number of scientific

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articles. During the last few years there have been a significant amount of wildlife research projects in natural protected areas using RPAS (J. Linchant et al. 2015; Chabot and Bird 2015; Christie et al. 2016) and it is rapidly taking its place within the broad set of technological solutions that support conservation (Pimm et al. 2015). In most cases, feasibility studies were carried out, assessing the capacity of RPAS in relation to traditional conservation instruments by measuring the overall performance, delimiting their strenghts and weakness, and establishing guidelines and recommendations, resulting in new perspectives of application.

Although the potential of RPAS for mapping is tackled at the end of the seventies (**???**), we found some references dating back to the early 1980s, where first trials with RPAS on environmental issues began with the objective of acquiring aerial photographs and demonstrating their usefulness in forestry applications, the management of fish resources or the coupling of sensors for atmospheric studies among others (Tomlins and Lee 1983). Towards the end of the 20th century, the first mapping surveys of vegetation in threatened species appeared (Quilter, 1997), while with the arrival of the new millennium the number of publications began to increase significantly (Hardin and Jensen 2013). At present there are some initiatives that seek to determine the current state of the RPAS in the areas of ecology and conservation. Recently, the journals *Remote Sensing in Ecology and Conservation* and the *International Journal of Remote Sensing* made a call to the scientific community for the sending of proposals in order to update the current state of RPAS applied into the enviromental spere. As result, a significant production of RPAS related papers on the matter is expected. On the other hand, it is remarkable the greater presence of web portals that center their activity around civil applications with RPAS. In the field of research applied to conservation, the website http://conservationdrones.org/ is a worldwide reference, whose contents illustrate recent pioneering projects, so they are not always reflected in the scientific literature. The popularity of RPAS has transcended the scientific-technical field, giving rise to the emergence of user communities with a large presence on the Internet. One of the most active portals is http://diydrones.com/, which brings together fans of the do-it-yourself philosophy that encourages the use of open platforms versus the traditional closed systems offered by the traditional industry. This has unchained the reduction of costs of these equipment and, together with the development of specialized open source software, have led to the democratization of technology, bringing it closer to a broad number of users and organizations. The scientific community has probably benefited from this general trend. For some authors, the flexibility in the assembly of RPAS offers in principle a greater degree of customization, allowing to combine different sensors and control systems according to the particular needs of each project and within the research group itself (Koh and Wich 2012). In the commercial field, more companies offer RPAS of high performance and reliability along with professional services and software, so the sector benefits from great dynamism.

1.2. *Protected areas*

As defined by UICN, "a protected area is a clearly defined geographical space, recognised, 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). Despite the fact that the number of protected areas has increased considerably at a global level, with 15.4% of the land area and 8.4% of the marine areas under some protection figure (Juffe-Bignoli et al. 2014) the size of wildlife populations has been estimated to have decreased by 52% in the period 1970 to 2012. Habitat fragmentation, severe pollution particularly in freshwater ecosystems, overexploitation of resources, environmental impacts of climate change and the impact of invasive species on indigenous populations have been identified as the main threats to biodiversity (Barnosky et al. 2011; Conabio 2017). To address the current environmental crisis, the Convention on Biological Diversity (CBD), as part of the United Nations Environment Program (UNEP), established in Nagoya, Japan, a strategic plan for the period 2011-2020 which includes the so-called Aichi targets for biological diversity. Among the goals raised is the increase in protected area systems of special importance for biodiversity and ecosystem services (target 11) following governance, equity, management, representativeness and ecological connectivity criteria.

The Group on Earth Observations Biodiversity Observation Network (GEO BON) as part of the Group on Earth Observations (GEOSS), has identified a set of Essential Biodiversity Variables (Pereira et al. 2013) as key components for the collection of environmental information to monitor the global state of our ecosystems and support better decision-making on biodiversity conservation (Forum 2008). As part of the large array of observing systems monitoring biodiversity, RPAS can fill the gap at an intermediate spatial scale, surpassing the financial and technological constrains of remote sensing and ground / aerial manned vehicles based surveys (Koh and Wich 2012; A. Rodríguez et al. 2012; Chabot and Bird 2015). First, while it is possible to acquire satellite images at low or virtually zero cost (LandSat, MODIS, Sentinel, etc.), most of these platforms operate on a global or regional scale. The limited spatial and temporal resolution, along with the inconveniences of cloud presence, especially noticeable in tropical areas, reduces the effectiveness of remote sensing in the collection of data at fine-scale, according to the requirements of ecological studies at the level of species, habitats or populations (Wulder et al. 2004). Secondly, the large extent of these protected areas significantly increases the costs of field work, particularly in hadarzous and inaccessible areas. Finally, while manned aerial vehicles offers an optimal alternative for covering much larger areas, they suffer from excessively high operational costs and are also subject to observer bias. In addition, air accidents are ranking as the leading cause of death in wildlife specialists in the United States (Sasse 2003). As a consequence, RPAS have been positioned as an appropriate complement for conservation activities (Zahawi et al. 2015) avoiding to a certain extent some of the above-mentioned drawbacks. In developing countries, especially sensitive in terms of budgetary allocations and technical capacities, monitoring and surveillance programs are being successfully developed through the use of RPAS. For example, by capturing aerial images in the Volta delta, Ghana, a team of scientists measured the effects of climate change on coastal areas and evaluates the effectiveness of prevention and restoration measures against erosive processes (Gerster/Panos 2017).

1.3. *Legal barriers*

RPAS operations faces important legal barriers that undermine the 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 the 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 (America 2017). Africa is one of the continents where the impact of drones 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) http://www.auvsi.org being the largest nonprofit organization in the world dedicated to advancing the community of unmanned aerial vehicles users.

2. Methods

To achieve the proposed objectives, a bibliographical review of scientific articles, gray literature, postgraduate theses, websites and specialized journals was carried out, following a similar line to other studies (J. Linchant et al. 2015; Christie et al. 2016). The main tools for selection of the cited 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 for keywords included unmanned aerial vehicles in their various meanings and acronyms (RPAS, UAV, drones, etc.), along with a variety of terms referring to natural protected areas, primarily in English. Last references revised was published on June, 2017.

The selected information was categorized according to the role played by RPAS in direct or indirect relation to conservation in natural areas. It is presented in tabular format, identifying where the study was conducted, the expected accomplishments and technical specifications of the aerial platform. After posing main results obtained, gaps are indentified and possible scenarios for implementing RPAS as essential tools to help achieve conservation plans in protected areas are discussed, highlighting some trends and opportunities that apparently have not yet been adequately exploited.

3. Results

3.1. *Wildlife Monitoring and Management*

Manned aircraft have been traditional used to undertake a variety of ecological surveys. As remarked by most papers reviewed such techniques are risky, costly and despite several efforts to minimize error estimation (Cook and Jacobson 1979) are subject to visibility bias since a greater number of observers is required to guarantee an exhaustive count of populations. RPAS have emerged as a feasible alternative to surpass such drawbacks. Several studies addressed counting large terrestrial mammals with positive contributions (Jain 2013, Lancia et al. (2005), Mulero-Pázmány et al. (2015)). (Colefax, Butcher, and Kelaher 2017) reviewed the potential of RPAS as surveys tools in species relying on coastal and marine ecosystems . RPAS have as well been applied to study population dynamics in bird colonies (Sardà-Palomera et al. 2012), but also in the inspection and characterization of inaccessible nesting sites using multicopters (Weissensteiner, Poelstra, and Wolf 2015). In some cases, in order to overcome the barriers to directly detect the species of interest, the studies focused on locating and characterizing their breeding and nesting areas (Andel et al. 2015, Szantoi et al. (2017), Andrew and Shephard (2017), Serge Wich et al. (2016)).

One of the central themes in ecology is the development of surveys and statistical models for estimating abundance and distribution of animals in wild populations (Lancia et al. 2005; Mateo, Felicísimo, and Muñoz 2011). Such methods allow inferring the potential or suitable habitat of organisms by collecting environmental information and species presence data from different sources and techniques. Wildlife telemetry tracking is one of the most common methods used to gather movement data. (Mulero-Pázmány et al. 2015) compared the performance of RPAS as tools for data collection against biologgers in cattle (*Bos taurus*), easily identifiable by high-resolution aerial images obtained by photographic sensors on board. The authors obtained similar results regarding the performance of the models, but they emphasized the cost-benefit factor of RPAS as the main advantage. In general, the relatively expensive purchase of electronic tracking devices limits their availability for research purposes, reducing sample size. Added to the risk of marking individuals under non-random criteria, the robustness of the analysis can be seriously affected. However, main advantage of wildlife telemetry is its ability to provide a large amount of data for longer periods of time.

Nevertheless, the authors pointed out that both methodologies have the potential to complement each other throughout all phases of the study. Other innovative techniques have recently been illustrated in scientific papers evaluating the feasibility of pairing radio locators in RPAS in the search for individuals marked with VHF radio collars (Soriano, Caballero, and Ollero 2009, Körner et al. (2010); Bayram et al. 2016; Cliff et al. 2015; Leonardo et al. 2013).

Given the large amount of information generated, it is not surprising that novel software tools have been developed in the field of computer vision and machine learning that allow the automatic detection, recognition and counting of individuals captured in scenes acquired by visible and thermal-infrared sensors, replacing otherwise time-consuming manual tasks (Lhoest et al. 2015; Abd-Elrahman, Pearlstine, and Percival 2005; Gemert et al. 2015, Chabot and Francis (2016), Christiansen et al. (2014)).

Outside the scientific literature, there are projects for monitoring wildlife in both marine and terrestrial ecosystems, generally supported by non-governmental organizations and research centers. Based on information gathered at https://conservationdrones.org several studies have been identified pursuing methods for registering individuals in marine mammal populations, primates and macrofauna in general, located in protected areas or frequently visited by wildlife under some legal figure of threat. For instance, a work conducted in the Amazon Basin in Brazil is testing the use of RPAS to improve the density and abundance estimation of different species of dolphins, compared with direct observation by specialists (S. Wich 2017). The main research aims include the validation and harmonization of both methodologies and, indirectly, evaluate the feasibility for its regular application in monitoring projects with a similar purpose, taking into account the cost-benefit of the execution.

Study	Aims	Country	Place	Species	RPAS platform	Sensor	Costs
			ESTUDIOS DE FAUNA Y VIDA SILVESTRE				
?	Telemetry / RPAS SDM comparative study	Spain	Doñana N.P.	Bos taurus	Fixed-wing: Easy Fly plane, Ikarus autopilot, Eagletree GPS logger	Panasonic Lumix LX-3 11MP	5700 euros
?	comparative survey RPAS / land based observation; abundance estimation	Australia	North Stradbroke Island	humback whales	Fixed-wing: ScanEagle	Nikon D90 12MP, Standard Definition Electro-Optical Camera	?
?	Dugongs detenction. Test RPAS performance. Ideal h and res.	Australia	Shark Bay Marine Park	Dugong	Fixed-wing: ScanEagle	Nikon D90 12MP	?
?	SofInfrared termic species detecion software development	Englash	?	Wildlife	Rotor-wing: 750mm carbon-folding Y6 multi-rotor APM 2 autopilot 3Drobotics	FLIR, Tau 2 LWIR Thermal Imaging Camera Core	?
?	Monitoreo bioacústico con RPAS	USA	State Game Lands	Aves	Rotor-wing: DJI Phantom 2	ZOOM H1 Handy Recorder	?
?	Detección de collares VHF	?	?	Bears (Ursus)	Rotor-wing: DJI F550 hexarotor, Pixhawk autopilot	Telonics MOD-500 VHF, Uniden handheld scanner	?
?	Estimación abundancia	USA	Aleutian Islands	Steller Sea Lion (Eumetopias jubatus)	Rotor-wing: APH- 22 hexacopter	?	$ 25.000 , $ 3000 vessel rent, or $ 1700 per site
?	Abundace estimation	USA	Monte Vista National Wildlife Refuge	Grus canadensis (sandhill cranes)	Fixed-wing: Raven RQ- 11A	?	$ 400
?	Sumatran orangutan nest detection for distribution and density.	?	?	?	Fixed-wing: Skywalker 2013	Canon S100	?
?	chimpanzee nest detection for distribution and density.	Africa	Loango National Park	Chimpanzee (Pan troglodytes)	Fixed-wing: Maja	Canon Powershot SX230 HS	$ 5000
?	?	?	?	?	?	?	?
?	develop semi-automated image processing tools to detect and map sea eagle nests	Australia	Houtman Abrolhos Islands	white-bellied sea eagle (Haliaeetus leucogaster)	?	?	?
?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?
			MONITOREO DE ECOSISTEMAS TERRESTRES Y ACUÁTICOS				
?	Tropical invasive plants	USA	Pahoa, Hawai	Miconia calvescens	Rotor-wing: DJ Inspire-1	DJI FC350 camera	?
?	Habitat Mapping	Indonesia	Gunung Leuser National Park	Orangutan (Pongo abelii)	Fixed-wing: Skywalker	Canon S100	$ 4000
?	Coral reef mapping	French Polynesia	Tiahura, Moorea	Coral reef	Rotor-wing: DJI Phantom 2	Modified GoPro HERO4	$ 1678
?	Marine fish nursery areas mapping	Italy	Giglio Island	Marine fish nursery areas	Rotor-wing: homemade prototype	Mobius HD, GoPro HERO3 Black Edition	$ 100

?	Monitoreo hábitats zonas restringidas; Modelos; RPAS performance test	South Korea	Chiaksan National Park;Taeanhaean National Park	?	Rotor-wing: DJI Phantom 2 Vision+	full HD videos 1080p/30fps and 720p/60fps, 14 MP 4384x3288	?
?	Discriminación de especies de hoja caduca, inventario forestal	Bélgica	Grand-Leez	English oak, birches, sycamore maple ,common ash and poplars	Fixed-wings: Gatewing X100	Ricoh GR2 GR3 GR4 10 megapixels CCD	?
?	Caracterización ecosistemas afectados por la actividad del castor	UK	Devon Beaver Project site	Eurasian beaver (Castor fiber)	Rotor-wing: 3D Robotics Y6	Canon ELPH 520 HS	?
?	Caracterización estructura bosques tropicales para acciones de restauración	Costa Rica	Devon Beaver Project site	Varias especies	Rotor-wing: 3D Robotics Y6	Canon S100	$ 1500
?	Monitoreo de bosques	Brasil	Riverine Forests (Permanent Protected Areas), Rio de Janeiro, Barrãcao do Mendes, Santa Cruz and São Lorenço	Bosques de rivera	Rotor-wing: DJI Phantom Vision 2S	RGB digital camera with 14 mega pixels	$ 9700
?	Modelamiento 3D, clasificación de especies arbóreas	Italy	Parco Adda Nord	Varias especies	Rotor-wing: Microdrones TM MD4-200	RGB CCD 12 megapixels Pentax Optio A40, modified NIR Sigma DP1 with a Foveon X3 sensor	?
?	Clasificación de especies en humedales	Japón	Humedales de Kushiro	Varias especies	Globo helio ?	NIKON F-801, NIKKOR 28 mm f/2.8	Helio $ 600, globo $ 1000
?	Mapping coral reefs	?	?	?	DJI Phantom 2	GoPro HERO4	?

EVALUACIÓN DE INFRAESTRUCTURAS Y RIESGO, VIGILANCIA, ECOTURISMO, IMPACTO EN LA FAUNA

?	Mitigar el riesgo de colisión mediante la instalación de marcadores en líneas electríca	USA	?	Aves	Rotor-wing: Mikrokopter Hexa XL	KX 171 Microcam	?
?	Evaluación riesgo riesgo eléctrico de nidos en postes de alta tensión	Spain	Parque Nacional de Doñana	Aves	Fixed-wing: Easy fly St-330	GoPro Hero2 11MP, Panasonic LX3 11MP	7800 euros
?	Anti-poaching	Africa	KwaZulu-Nata	black rhinocero (Diceros bicornis), white rhinocero (Ceratotherium simum)	Fixed-wing: Easy Fly St-330	Panasonic Lumix LX-3 11 MP, GoPro Hero2, Thermoteknix Micro CAM microbolometer	13750 euros
?	Visitors Surveillance	Sweden	Kosterhavet National Park	Humans	?	?	?
?	Aplicaciones RPAS en actividades ecoturismo	Suecia	Kosterhavet National Park	Humanos	?	?	?
?	Impacto RPAS especies aves lacustres	Francia	e Zoo du Lunaret, Cros Martin Natural Area	Anas platyrhyncho, Phoenicopterus roseus, Tringa nebularia	Rotor-wing: Phantom	GoPro HERO3	?
?	RPAS Impact	USA	Kosterhavet National Park	Black bear(Ursus americanus)	Rotor-wing: 3DR IRIS Pixhawk	GoPro HERO3+	?

3.2. *Infrastructure and risk assessment*

Other research projects highlight the convenience of RPAS in assessing the risk that human infrastructure posed for wildlife, which results in the implementation of more cost-effective preventive measures. For instance, some species of birds nest on high voltage power lines poles, making them especially vulnerable to death by electrocution. (Margarita Mulero-Pázmány 2014) used a fixed-wing RPAS for the visual evaluation of linear electrical structures in which low operational costs and enduring flight time are crucial. On the other hand, one of the most common causes of death in birds is due to collisions with the wiring. (Lobermeier et al. 2015) proposed to install marks that are easily visible through the use of robotics arms installed in multicopters. Due to the ease of maneuvering of the platform, multicopters are more suitable for precision work. Another possible use case is related to birds nesting in the soil, especially in cereal crops. As a pre-harvest activity, generally performed under mechanical procedures, (Mulero-Pázmány Margarita 2011) suggested a flyby to identify possible nests, and if necessary, take the appropriate actions to avoid their destruction.

3.3. *Monitoring and mapping of terrestrial and aquatic ecosystems*

During the last decades, the emergence of remote sensors on board air or space platforms has led to an increase in applications for the study of ecosystems (Wulder et al. 2004). The data obtained have enabled the development of vegetation and soil maps, enhance the characterization of habitats or the understanding of the structure and function of forest ecosystems, develop digital elevation models or geomorphological maps of application in the modeling of species distribution. The emergence of RPAS has led to the quantitative analysis of habitats at a level of detail that had not been possible previously, either for economic reasons or for technological limitations. This impulse has been especially notable with the parallel development of multispectral and hyperspectral sensors adapted to small aircraft, whose price is expected to decrease according to trends in the sector. The United States Geological Survey (USGS) has conducted flights to classify vegetation cover in wetlands (USGS 2014). Other studies monitored the distribution of invasive species under different flight conditions and vegetation cover (Perroy, Sullivan, and Stephenson 2017), while the characterization of forest stands constitutes an important section, considering the number of articles facing the issue from different perspectives. (Gini et al. 2012) employed a quadcopter model operated at low-height and RGB and NIR cameras in small areas. Due to the reduced reliability and autonomy of the platform and the difficulties to increase the load capacity, the flight planning is reduced to three passes with a percentage of 80% and 30% of longitudinal and transverse overlap respectively. (Lisein et al. 2015) performs a multitemporal analysis of the spectral response to phenological variations in different species of deciduous trees and concluded that intraspecific spectral variation is of maximum interest for the optimization of classification algorithms and discrimination between species. During the research, the authors operated a fixed wing RPAS model, used different sensors in the visible and near infrared range and optimized the flight parameters to cover the maximum surface area with the fewest possible number of flights. (Zahawi et al. 2015) applies the Ecosynth methodology, a toolkit for mapping and measuring 3D vegetation using digital cameras and open source artificial vision software, in order to evaluate the effectiveness of restoration actions in forests using RPAS as a viable alternative for traditional field measurements and applying different predictive models of the presence of frugivorous birds from height and canopy structure data. Recently, shallow coastal habitats were also mapped using cost-effective consumer grade RPAS (Casella et al. 2017, Ventura et al. (2016)).

3.4. *Surveillance and support for compliance with laws in protected areas*

RPAS have also relevance in the control and surveillance of protected areas, documented through different experiences focused mainly on controlling poaching. This type of study is characterized in giving greater emphasis on improving first-person view methods (FPV) in order to obtain a real-time view of the monitored area. Also, it is worth mentioning the suitability of fixed-wing RPAS as provide longer flight times to cover large areas, the convenience of using thermal cameras in low visibility conditions, generally related to hours of greater furtive activity, along with advances in computer vision systems programmed to detect the presence of humans and target species under pressure from illegal trade in protected areas. (Mulero-Pázmány et al. 2014) focused on the African rhinoceros (*Diceros bicornis*, *Ceratotherium simum*) and noted the advantages of real time video compared to still photography, which despite the better overall quality, requires longer post-processing time. In addition, authors emphasized the need to improve the resolution of thermal sensors to increase the chances of detecting suspicious activity at night time. (Franco et al. 2016) suggested using RPAS to combat poaching and illegal fishing activities in marine protected areas (MPA), claiming million-dollar economic losses in the fishing sector. (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. With respect to coastal zones, a quick search on Internet allows collecting several initiatives that try to optimize the control of illegal fishing through RPAS. However we have not been able to verify scientific studies that endorse such initiatives, so it opens an interesting field of research. To illustrate some examples, a pioneering survey was conducted in Belize for fisheries monitoring using a fixed-wing model Skywalker. The Government of the Canary Islands is considering the use of RPAS in hard to reach coastal areas to deal with poaching (INFORCASA 2017). Finally http://soarocean.org/ is an initiative of National Geographic and Lindblad Expedition fostering the use of low cost drones in the protection of the oceans and it looks a good starting point to search for latest applications in this field.

3.5. *Ecotourism*

The high degree of diversification offered by RPAS in the ecotourism industry is summarized in a recent article, which shows possible recreational activities, business opportunities, search and rescue operations, mapping and formulas for granting RPAS flight permits in designated areas (King 2014). Within the still scarce literature, (Hansen 2016) values the effectiveness of RPAS in monitoring visitors in marine and coastal areas, in combination with other innovative solutions. According to the author the RPAS would theoretically allow to operate under different environmental conditions, improving the level of detail and offering a continuous coverage in the flow and behavior of visitors, as opposed to other techniques of habitual use like the manual observation or the installation of networks of surveillance cameras.

3.6. *Impact of RPAS on wildlife*

Animal welfare should be present on wildlife monitoring and ecological research using RPAS , establishing ethical principles that complement the current standards in research and conservation (Wilson and McMahon 2006). (Vas et al. 2015) analyzed the response of birds to RPAS, assessing the impact of color, speed and angle of flight on the behavioral responses of wetland birds to the approach of multicopters. The latter factor is considered as the primary trigger for changes in behavioral patterns, especially in vertical approaches at an angle of 90^o. Finally, a core set of recommendations is included, and authors encouraged to extend the trials to a wide range of RPAS and species. (McEvoy, Hall, and McDonald 2016) accomplished the most intensive disturbance assesment on waterfowl to date, by combining an array of fixed wing and multirotor RPAS at various altitudes. (**???**) quantified noise detection by several representative species, suggesting flying higher than 200 meters to minimise noise disturbance. (Ditmer et al. 2015) measured physiological stress in American black bear (*Ursus americanus*) by electronic recording of cardiac activity in the presence of RPAS. Although no changes in behavior patterns are detected, the increase in beats per minute (bmp) is significant in most cases observed. (Pomeroy, O'Connor, and Davies 2015) noted evidence of variation in reactivity in seal populations based on a variety of factors, from the RPAS platform, height and lateral distance to the breeding or moulting season. No adverse reactions have been reported in elephants (*Loxodonta africana*) or cattle (*Bos taurus*) on flights at a minimum height of 100 meters (Jain 2013, Mulero-Pázmány et al. (2015)), while could substitute more intrusive techniques when inspecting the status of nesting sites (Weissensteiner, Poelstra, and Wolf 2015). In the absence of further experiences to date, explicitly addressing the phenomenon, (Hodgson and Koh 2016) suggested a series of general recommendations as the basis for a code of good practice, highlighting the adoption of the precautionary principle and respect for aviation standards, the specific training of operators, the appropriate selection of equipment, the cessation of operations in the case of obvious disturbances in the populations studied and the reporting of observations in scientific publications, that allows sharing of knowledge to progressively improve the protocols of operations with RPAS that involve the observation of the wild fauna.

4. Environmental monitoring and decision support

As service providers, protected areas are inherently subject to face with periodic and unforeseen tasks, quality control procedures. RPAS potential to easer decision making

(McCaldin, Johnston, and Rieker 2015)

(Zaman, Jensen, and McKee 2011)

(???)

(Fornace et al. 2014)

5. Discussion

Most of the sources analyzed focus on local-scale conservation projects and feasibility studies of RPAS in the characterization of distribution and abundance of wildlife populations. Literature begins to be equally prolific in monitoring and mapping activities in terrestrial and aquatic ecosystems, a niche currently occupied by aerial and space platforms for environmental remote sensing. Despite the low number of scientific articles addressing the use of RPAS in the control and surveillance of natural protected areas, it is still one of the issues that more social debate generates and it is not strange to find governmental initiatives or promoted by environmental organizations in the fight against poaching. From the economic point of view, expenses derived from the operation with RPAS are hardly quantifiable. Also, not all studies consider the effort required for the development of technical and analytical skills of the staff involved. The computational requirements are demanding and certain phases of information processing requires the acquisition of software whose price is generally high. Also, operations with RPAS are not exempt from accidents, which has an negative impact on the budget originally planned.

5.1. *Wildlife Monitoring and Management*

Most fixed-wing RPAS studies focus on population counts, obtaining promising results in macrofauna. It is still early to generalize its use in smaller species and areas of high vegetation coverage, although the development of LIDAR technology and wide-spectrum sensors could help to overcome technical barriers. If succesfully implemented, parks managers could benefit from RPAS when estimating spatial distribution of foraging domestic herbivores impacting food availability in natural areas (Mulero-Pázmány et al. 2015). Also, periodic monitoring campaigns usually undertaking by rangers could be overly simplified by RPAS mapping capabilities. As a downsize, the use of RPAS can increase the complexity of research and management, requiring highly skilled work teams and computational resources not available to many institutions. In addition, the lack of statistical methods to tackle the analisys of data. Also further efforts should be made in order to refine the planning of sampling performed with RPAS, to avoid errors in estimation. Multicopters could cover some of the limitations mentioned above, but there still seem to be a scarcity of studies combining both systems. In any case, RPAS could become an essential tool for ecologist and its use could be justified as long as there are no advances in other traditional techniques supporting wildlife research.

5.2. *Infrastructure and risk assessment*

RPAS have demonstrated their capacity for the technical inspection of industrial premises [@]. They could be also of special interest in buffer zones, where anthropic development may lead to conflict with the surrounding fauna. Wildlife risk assessment may benefits from such methods, promoting their use for preventive purposes in areas of high incidence of deaths where otherwise high cost manual inspection where applied. As previously discussed, relative low operational cost of RPAS make them an attractive alternative, which may foster such activities. RPAS could also prevent accidents by applying dissuasive measures to avoid the collision of birds in wind farms. Other uses include the revision of natural areas facilities, by scheduling periodic flights. Also RPAS are positioned as fundamental tools in the prevention and evaluation of forest fires and it could assist in environmental impact assessment in sensitive areas.

5.3. *Monitoring and mapping of terrestrial and aquatic ecosystems*

The integration of the classical remote sensing elements developed during the last decades in the scope of the RPAS open new possibilities in the observation of environmental phenomena at multiple scales. The high resolution of images will allow the discrimination of plant communities at the species level, observe the evolution of ecosystems in shorter periods of time or more accurately quantify the volume and structure of canopy. Also it will allow attending to urgent needs of mapping in areas affected by natural and anthropic disasters. The ability of computer systems to process massive amount of information is closely linked to such applications.

5.4. *Surveillance and support for compliance with laws in natural protected areas*

The integration of RPAS in the fight against poaching and illegal fishing in protected areas faces important technical and legal constraints. In the first point, the reviewed literature mention the need to design more efficient live vision systems. The low autonomy of RPAS is especially critical in large natural parks, limiting the area under surveillance.

The 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 the suitable specifications are costly, especially in developing countries. However, as technology becomes more accesible, 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 (Banzi 2014). Some detractors are skeptical about the ability of RPAS to persuade offenders, who in many cases face situations of greatest 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 in unauthorized areas have great potential and may be easier to implement.

5.5. *Ecotourism*

A permissive regularization of the use of RPAS in ecotourism activities in natural parks could lead to unpredictable situations. On the one hand, the constant presence of propeller and engine noise, the sensation of invasion or lack of privacy and the visual impact of RPAS on the landscape could negatively affect the tourist experience. It remains to be seen whether it could significantly alter the state of ecosystems. Awareness of the abuse of RPAS for recording wildlife has resulted in a ban on flying for recreational purposes in natural parks in the United States and other parts of the world. As result of potential enviromental 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 could be the way forward for other protected areas to adapt the allowed activities with RPAS. It seems obvious to think that in the hands of non-professionals, the risk of accidents and losses would increase. This may lead to disturbing widlife, contamination of water supplies or triggering fires in sensitive areas due to the presence of flammable components. 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.

5.6. *Impact of RPAS on wildlife*

The review of the literature suggests that there are still certain niches that need more attention from the research community. The 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, we consider that further trials aimed at quantifying physiological and behavioral changes should be carried out. A set of best practices and recommendations targeting a wider group of wild species could increase the chances of integrating the responsible use of RPAS in conservation and management activities in natural parks. 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 could be reduced and its objective observation facilitated. Nonetheless we consider 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 (Z. Jewell 2013, Wilson and McMahon (2006)). This should be taken into account by managers of protected area when reluctant to allow RPAS to be essential part of research and conservation activities.

6. Conclusions

The consolidation of the RPAS as management and research tools in natural protected areas is closely linked to the technological development of the elements associated with the platform and to the establishment of measures that favorably regulate its use, increasing opportunities in the sector and stimulating innovation in priority conservation areas. There are continually improvements in navigation control and flight autonomy, while we are witnessing the progressive miniaturization and diversification of sensors along with advances in the field of artificial intelligence. This rapidly expanding confluence of factors encourages the emergence of new scenarios with ethical and legal implications. Most governments have reacted by setting constraints that could have a negative impact on the capacity to integrate RPAS into the civilian sphere, despite some progress in this regard. As result, it is difficult to foresee the actions that each country will adopt from now on in an attempt to harmonize the contradictions presented by RPAS, reason why it is probable that the future of the RPAS in protected areas is conditioned fundamentally by political and social factors.

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