ARTICLE TEMPLATE

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

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ABSTRACT:

Nature conservation has benefited from a wide range of technological advances, from remote sensing, camera traps or wildlife tracking devices to a continuous development of computational tools and analytical techniques to deal with large amounts of data collected. All of them play an important role in safeguarding biodiversity and better understanding of ecosystem functions. In the last few decades, we have witnessed a growing interest in projects aimed to evaluate the feasibility of RPAS for conservation purposes. So far, RPAS have been tested or directly applied for a variety of research and management activities including environmental and wildlife monitoring or anti-poaching strategies. It remains to be seen how well RPAS complement conservation actions in protected areas, since there are technical, ethical and legal barriers that currently limit their effectiveness. However, through the development of novel solutions and continuous improvement of performance and sensor characteristics, the parallel design of computer intensive statistical methods and a greater concern for animal welfare issues, there are high expectations in the research community and RPAS applications in protected areas are increasingly justified.

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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 growing number of scientific articles. During the last few years there have been a significant amount of wildlife research projects in natural protected areas using RPAS (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 strengths 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 (Colomina and Molina 2014), we found some references dating back to the early 1980s, where first trials with RPAS applied on environmental issues began with the objective of acquiring aerial photographs and demonstrating their usefulness in forestry applications, fish resource management or the coupling of sensors for atmospheric studies (Tomlins and Lee 1983). At the beginning of the 21st century, first mapping surveys of vegetation in threatened species appeared (Quilter and Anderson 2000), while accross the first decade 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 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 environmental sphere. As result, a significant production of 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 differ-

ent sensors and control systems, according to the particular needs of each project and without having to depend on others beyond the research group itself (Koh and Wich 2012). In the commercial field, more companies offer RPAS of high performance and reliability together 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, 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). Despite the fact that the number of protected areas has raised 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 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 threats to biodiversity (Barnosky et al. 2011; Secretariat of the Convention on Biological Diversity and UNEP World Conservation Monitoring Centre 2006). To address the current environmental crisis, the Convention on Biological Diversity (CBD) established in Nagoya, Japan, a strategic plan for the period 2011-2020 which includes the so-called Aichi targets for biological diversity. Among the stated objectives is the increase of protected area systems of particular importance for biodiversity and ecosystem services (target 11).

Protected areas are reference sites for monitoring and managing biodiversity. As part of the large array of observing systems monitoring ecosystems and measuring human impacts (Forum 2008, Pereira et al. (2013)), 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; 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, added to 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 on foot, particularly in hadarzous and inaccessible spots. Finally, while manned aerial vehicles offers an optimal alternative for covering much larger areas, they suffer from excessively high operational costs and when not used for aerial mapping, they could be affected by observer bias. In addition, air accidents are ranking as the leading cause of death in wildlife specialists in the United States (Sasse

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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 instance, 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 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 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). (Consulting 2017) is a relative accurate database informing RPAS regulations by country. 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) (UAVSI 2017) being the largest nonprofit organization in the world dedicated to advancing the community of unmanned aerial vehicles users. Also, a relative up-to-date database has been published online where users can consult the regulatory framework of RPAS by country (Consulting 2017).

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 (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, UAS, drones), along with a variety of terms referring to natural protected areas, primarily in English. Last references revised were published on June, 2017.

The selected information was categorized according to the role played by RPAS in direct or indirect relation to conservation in protected 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 identified 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 inconveniences. 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) conducted an extensive bibliographic revision to unveil the potential of RPAS to monitor species relying on coastal and marine ecosystems in placed on manned aircraft. In this context, (Hodgson, Peel, and Kelly 2017) performed a comparative study using both RPAS and traditional methods to survey humpback whales (*Megaptera novaeangliae*), while described a novel statistical method to estimate marine mammal populations. 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 multi-rotors (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), Wich et al. (2016)).

On the other hand, 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 tech-

niques. 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 when estimating spatial distribution of foraging domestic herbivores impacting food availability in natural areas, easily identifiable by high-resolution aerial images obtained by photographic sensors on board. Targeting cattle (*Bos taurus*), 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, it is argued that 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 software have been developed in the field of computer vision and machine learning to handle the automatic detection, recognition and counting of individuals captured in scenes acquired by visible and thermal-infrared sensors, replacing otherwise time-consuming manual tasks (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. 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 (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.

Table 1.: WILDLIFE MONITORING AND MANAGEMENT

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Mulero-Pázmány et al. 2015)	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	$ 6500
(Hodgson, Peel, and Kelly 2017)	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	?
(Hodgson, Kelly, and Peel 2013)	Dugongs detection	Australia	Shark Bay Marine Park	Dugong	Fixed-wing: ScanEagle	Nikon D90 12MP	?
(Wilson, Barr, and Zagorski 2017)	Bioacustic monitoring	USA	State Game Lands	Birds	Rotor-wing: DJI Phantom 2	ZOOM H1 Handy Recorder	?
(Bayram et al. 2016)	VHF collars tracking	?	?	Bears (Ursus)	Rotor-wing: DJI F550	Telonics MOD-500 VHF, Uniden handheld scanner	?
(Christie et al. 2016)	Abundance estimation	USA	Aleutian Islands	Steller Sea Lion (Eumetopias jubatus)	Rotor-wing: APH-22	?	$ 25.000
(Christie et al. 2016})	Abundace estimation	USA	Monte Vista National Wildlife Refuge	Grus canadensis (sandhill cranes)	Fixed-wing: Raven RQ- 11A	?	$ 400
(Wich et al. 2016)	Sumatran orangutan nest detection	?	?	?	Fixed-wing: Skywalker 2013	Canon S100	?
(Andel et al. 2015)	Chimpanzee nest detection	Africa	Loango National Park	Chimpanzee (Pan troglodytes)	Fixed-wing: Maja	Canon Powershot SX230 HS	$ 5000
(Koski et al. 2009)	Marine mammals monitoring	USA	Admiralty Bay	Marine mammals	Fixed-wing: ScanEagle	NTSC Video Camera	?
(Andrew and Shephard 2017)	Semi-automated image processing tools to detect and map sea eagle nests	Australia	Houtman Abrolhos Islands	White-bellied sea eagle (Haliaeetus leucogaster)	?	?	?
(Longmore et al. 2017)	Software development to help detect animals in thermal images	UK	Arrowe Brook Farm Wirral	Wildlife	Rotor-wing: 3DR robotics Y6	FLIR, Tau 2 LWIR Thermal Imaging Camera Core	?
(Martin et al. 2012)	Estimate the distribution of organisms using statistical models	USA	?	Manatee (*Trichechus manatus latirostris*)	Fixed-wing: Nova 2.1	Olympus H E-420	?

Table 2.: MONITORING OF TERRESTRIAL AND AQUATIC ECOSYSTEMS

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Perroy, Sullivan, and Stephenson 2017)	Tropical invasive plants	USA	Pahoa, Hawai	*Miconia calvescens*	Rotor-wing: DJ Inspire-1	DJI FC350 camera	?
(Szantoi et al. 2017)	Habitat Mapping	Indonesia	Gunung Leuser National Park	Orangutan (Pongo abelii)	Fixed-wing: Skywalker	Canon S100	$ 4000
(Casella et al. 2017)	Coral reef mapping	French Polynesia	Tiahura,; Moorea	Coral reef	Rotor-wing: DJI Phantom 2	Modified GoPro HERO4	$ 1678
(Casella et al. 2016)	Monitoring coastal erosion dynamics in shorelines	French Polynesia	Tiahura; Moorea	Coral reef	Rotor-wing: Mikrokopter Okto XL	Canon G11	$ 7500
(Müllerová et al. 2016)	Monitoring plant invasion	?	?	Exotic species	Fixed-wing: VUT 712 713 720	Canon S100	?
(Ventura et al. 2016)	Marine fish nursery areas mapping	Italy	Giglio Island	Marine fish nursery areas	Rotor-wing: homemade prototype	Mobius HD, GoPro HERO3 Black Edition	$ 100
(Ivošević et al. 2015)	Habitat monitoring and modeling in restricted areas; RPAS performance test & South Korea & Chiaksan National Park;Taeanhaean National Park	South Korea	Chiaksan National Park;Taeanhaean National Park		Rotor-wing: DJI Phantom 2 Vision+	Full HD videos 1080p/30fps and 720p/60fps	?
(Lisein et al. 2015)	Discrimination of deciduous species; Forest inventory	Belgium	Grand-Leez	English oak, birches, sycamore maple ,common ash and poplars	Fixed-wings: Gatewing X100	Ricoh GR2 GR3 GR4 10 megapixels CCD	?
(Puttock et al. 2015)	Characterization of ecosystems affected by beaver activity	UK	Devon Beaver Project site	Eurasian beaver (*Castor fiber*)	Rotor-wing: 3D Robotics Y6	anon ELPH 520 HS	?
(Zahawi et al. 2015)	Characterization of tropical forest structure for restoration actions	Costa Rica	Devon Beaver Project site	Several species	Rotor-wing: 3D Robotics Y6	Canon S100	$ 1500
(Bustamante 2015)	Forest monitoring	Brasil	Riverine Forests (Permanent Protected Areas), Rio de Janeiro, Barrãcao do Mendes, Santa Cruz and São Lorenço	Riverbank forests	Rotor-wing: DJI Phantom Vision 2S	RGB digital camera 14MP	$ 9700
(Gini et al. 2012)	3D modeling and classification of tree species	Italy	Parco Adda Nord	Several species	Rotor-wing: Microdrones TM MD4-200	RGB CCD 12 megapixels Pentax Optio A40; modified NIR Sigma DP1 with a Foveon X3 sensor	?
(Miyamoto et al. 2004)	Classification of species in wetlands	Japan	Kushiro Wetlands	Several species	Helium balloon	NIKON F-801, NIKKOR 28 mm f/2.8	$ 1600
(Casella et al. 2017)	Mapping coral reefs	?	?	?	Rotor.wing: DJI Phantom 2	GoPro HERO4	?

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Table 3.: INFRASTRUCTURES AND RISK ASSESSMENT, ECOTOURISM, IMPACT
ON WILDLIFE AND ECOSYSTEMS

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Lobermeier et al. 2015)	Mitigate the risk of collision by installing markers on electrical lines	USA	?	Birds	Rotor-wing: Mikrokopter Hexa XL	KX 171 Microcam	?
(Margarita Mulero-Pázmány 2014})	Bird risk hazards in power lines	Spain	Doñana National Park	Birds	ixed-wing: Easy fly St-330	GoPro HERO2 11MP;Panasonic LX3 11MP	$ 8863
(Mulero-Pázmány et al. 2014)	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	$ 15700
(Hansen 2016)	Visitors Surveillance	Sweden	Sweden & Kosterhavet National Park	Humans	?	?	?
(Sabella et al. 2017)	Visitors Surveillance	Italy	R.N.O. Oasi faunistica di Vendicari	Humans	Rotor-wing: DJI Phantom 3	?	?
(King 2014)	RPAS applications in ecotourism activities	Sweden	Sweeden & Kosterhavet National Park	Humans	?	?	?
(Vas et al. 2015)	RPAS impact	France	Zoo du Lunaret, Cros Martin Natural Area	*Anas platyrhyncho, Phoenicopterus roseus, Tringa nebularia*	Rotor-wing: Phantom	GoPro HERO3	?
(Weissensteiner, Poelstra, and Wolf 2015)	RPAS Impact	Sweden	?	Hooded crow (*Corvus corone cornix*)	Rotor-wing: DJI Phantom 2 Vision	?	$ 1000

Table 4.: ENVIRONMENTAL MONITORING AND DECISION SUPPORT

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Zang et al. 2012)	Pollution monitoring	China	Several cities	Rivers	Fixed-wing	Canon 50D, ACD multispectral camera	?
(Cornell, Herman, and Ontiveros 2016)	Water sampling	USA	Lake Ontari0	?	Rotor-wing: DJI Phantom 3	50mL Falcon tube	?
(McCaldin, Johnston, and Rieker 2015)	Aerial baiting	Australia	Christmas Island	Cat (*Felis catus*)	Rotor-wing: V-TOL Hornet I-II	Canon S100; Drop mechanism with HD Video Recorder	?
(Fornace et al. 2014)	Spatial epidemiology	Malaysia / Philippines	Sabah / Palawan	?	Fixed-wing: Sensefly eBee	16mp	$ 25000

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Van Tilburg 2017)	Search and Rescue (SAR)	USA	Columbia Gorge National Scenic Area	Humans	Rotor-wing: Phantom 3, SAR Bot, Inspire 1	DJI 12MP; VUE PRO 640 thermal imager	?
(Schwarzbach et al. 2014)	Water sampling	Spain	Doñana N.P.	Freshwater ecosystems	Rotor-wing: Helicopter	Water sampling mechanism	?
(Schmale, Dingus, and Reinholtz 2008)	Aerobiological sampling	USA	Virginia Tech's Kentland Farm	Prokaryotic and eukaryotic microorganisms	Fixed-wing: Senior Telemaster	Aerobiological sampling devices	?

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 long endurance fixed-wing RPAS as a low cost alternative for visual evaluation of linear electrical structures. Collisions with the wiring is one of the most common causes of death in birds. (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, multi-rotors are more suitable for precision work. As a pre-harvest activity, generally performed under mechanical procedures, (Mulero-Pázmány Margarita 2011) suggested a flyby to identify possible nests on the ground, and if necessary, take appropriate actions to avoid their destruction.

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

The maturity 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. The emergence of RPAS permits the quantitative analysis of habitats to a level of detail ever reached, either for economic reasons or for technological limitations. This momentum has been especially notable with the parallel development of affordable multispectral and hyperspectral sensors adapted to small aircraft (Bareth et al. 2015). RPAS has been used by The United States Geological Survey (USGS) to classify vegetation cover in wetlands (USGS 2014). (Zaman, Jensen, and McKee 2011) monitored the spread of invasive species in such ecosystems while (Müllerová et al. 2016) assessed the importance of spectral and spatial resolution to detect plant invasion using satellite, aerial and RPAS data. (Perroy, Sullivan, and Stephenson 2017) conducted several flight to quantify the detection rate of invasive species under different flight parameters, environmental conditions and vegetation cover. The characterization of forest stands constitutes an important section, considering the number of papers 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 artificial vision open source software. Such project was aimed 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 frugivorous birds presence by means of height and canopy structure data. Recently, shallow coastal habitats were also mapped using consumer grade RPAS (Casella et al. 2017, Ventura et al. (2016)), including monitoring erosion dynamics in shorelines. (Casella 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. As a result of these preliminary results, emphasis has been placed on improving first-person vision (FPV) methods to obtain a clear, real-time view of the monitored area. Also, fixed-wing RPAS are prefered, since they offered longer flight times and consequently cover greater areas. Other requisites include 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. Surveillance of other less contentious illegal activities in natural parks using an affordable small rotor-wing were also recently described (Sabella et al. 2017).

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 oppor-

tunities, 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 and ecosystems*

Animal welfare in wildlife management practices and ecological research is a sensitive issue from which ethical issues arise (Wilson and McMahon 2006). Not surprisingly, RPAS are not exempt of discussion. (Vas et al. 2015) assessed the impact of color, speed and angle of flight on the behavioral responses of wetland birds. The latter factor was considered the primary trigger for changes in behavioral patterns, especially in vertical approaches at an angle of 90º. 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 rotor-wings RPAS at various altitudes, while (BORRELLE and FLETCHER 2017) reviewed the published literature tackling the impact of RPAS on surface-nesting seabird. (Scobie and Hugenholtz 2016) 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, heart rate (measure in beats per minute) was significant higher in most cases observed. (Pomeroy, O'Connor, and Davies 2015) noticed evidence of variation in reactivity in seal populations based on a variety of factors, from the RPAS platform, flight height and lateral distance to the breeding or moulting season. No adverse reactions were 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)). (Weissensteiner, Poelstra, and Wolf 2015) observed similar disturbance patterns using RPAS with respect to manual inspection when documenting nesting status in hooded crows (*Corvus corone cornix*), but they emphasized the shorter period of stress to which birds are exposed, along with reducing or eliminating risk in climbers and avoiding damages to trees. In the absence of further experiences to date explicitly addressing animal welfare, (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 opera-

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tions 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 fauna. (Mulero-Pázmány et al. 2017) carried out an up-to-date systematic review of literature documenting RPAS disturbance effects in wildlife and outlined some findings, while complementing the previously mentioned recommendations. The authors agreed that noise level and intensity are the main, but not the only factor inducing animal reactions in presence of RPAS, where birds are the most sensitive species, followed by terrestrial mammals and aquatic animals. These response patterns are also influenced by life-history stage and level of aggregation of targeted species.

4.   Environmental management and decision support

Planning in protected areas is reflected through a variety of management programs that are difficult to fit into some of the previously discussed categories. An extensive report based on Christmas Island proposed dropping poisoned baits from RPAS to eradicate feral cats disturbing threatened native species (McCaldin, Johnston, and Rieker 2015). (Cornell, Herman, and Ontiveros 2016) obtained ground truth data by adapting RPAS to take water samples for comparison with hyperspectral measurements of Landsat 8 Operational Land Imager (OLI). (Zang et al. 2012) identified several pollution agents in riparian areas using RPAS imagery. (Schwarzbach et al. 2014) goes further away by performing several aerial water sampling methods using an unmaned helicopter to monitor water pollution, while (Schmale, Dingus, and Reinholtz 2008) collected a broad spectrum of both prokaryotic and eukaryotic microorganisms using a fixed-wing aircraft equiped with a custom made aerial sampling device. (Fornace et al. 2014) considered mapping enviromental risk factors for predicting zoonotic diseases as part of a extensive epidemiological study carried out in Philippines and so on. Literature citing RPAS for search and rescue activities is profuse and an in-depth revision is beyond the scope of this article, but a recent publication ilustrate several examples where RPAS were succesfully operated to assist rescue teams (Van Tilburg 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).

5.   Discussion

Most of the sources analyzed focus on local-scale conservation projects and feasibility studies of RPAS monitoring distribution and abundance of wildlife populations. Literature begins to be equally prolific in mapping activities in terrestrial and aquatic ecosystems, a niche until recently entirely 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. Not all studies consider the effort required for the development of technical and analytical skills of work teams. 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. In addition, statistical and sampling methods approaching the analysis of data are mostly in its infancy and further research should be accompased to assess the overall performance of these methods.

5.1. *Wildlife Monitoring and Management*

Both fixed-wing and rotor-wing RPAS might become very handy tools for conservation practitioners. Wildlife census campaigns, usually carried out by going in on foot, terrestrial vehicles or by vessel deployment in aquatic environments, could be supplemented or replaced by RPAS mapping and monitoring capabilities. As becoming easier to operate, there are sufficient grounds to encourage park rangers training in the use of RPAS, which are subject in many cases to time-consuming and often dangerous raids. If operated responsibly, it could be closer of being considered a non-invasive and reliable monitoring technique (Z. Jewell 2013a). From the technological point of view, "Follow-me" capabilities of RPAS constitute a promising advance in animal movement and remote sensing disciplines, by having high-resolution aerial imagery from places frequently visited or crossed by electronically tagged species.

5.2. *Infrastructure and risk assessment*

Wildlife risk assessment could benefit from RPAS by promoting their use for preventive purposes in conflicting areas where human factor is indirectly causing the killing of many species. Relative low operational cost of RPAS make them an attractive alternative to manual inspection, which may foster such practices. Since the literature citing RPAS for such purposes is limited, we propose that they could serve to reduce fatalities by scheduling periodic flights monitoring facilities, roads crossing sensitive areas and coastal ecosystems where vessels strikes with aquatic species is frequent. 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.

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

The integration of classical remote sensing elements developed during the last decades 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. As requirements change, Information Technology (IT) departments in protected areas must be ready to integrate data into effective conservation strategies and better decision-making. The inclusion of RPAS in monitoring activities should be weighed against the major complexity of such systems.

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

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

5.5. *Ecotourism*

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

5.6. *Impact of RPAS on wildlife and ecosystems*

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 reflected in a emergent set of guidelines (Hodgson and Koh 2016; Mulero-Pázmány et al. 2017) , we consider that further trials aimed at quantifying physiological and behavioral changes targeting a broader group of wild species should be carried out. The establishment of a best practices and recommendations manual could increase the chances of integrating the responsible use of RPAS in conservation and management activities in natural areas. Moreover, some authors mentioned the lack of commercial operators with sufficient expertise to carry out such activities (McEvoy, Hall, and McDonald 2016). Also, an optimal trade-off between benefits and environmental costs should be pursued (Grémillet et al. 2012; Sepúlveda et al. 2010). By designing quieter, non-polluting and safer components, the impact on wildlife and ecosystems could be reduced and its objective observation facilitated. Nonetheless we trust that, as far as further testing be done, RPAS has great potential to replace more invasive monitoring techniques, whose reliability is challenged by the potential to induce conditions of unacceptable stress in wildlife that could ultimately invalidate the results of the research (Z. Jewell 2013b, Wilson and McMahon (2006)). This should be consciously taken into account by the many actors involved in protected areas activities when they are reluctant to allow RPAS to be an essential part of research and conservation activities.

6.   Environmental monitoring and decision support

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

7.   Conclusions

The consolidation of the RPAS as management and research tools in 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 a 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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