ARTICLE TEMPLATE

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

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ABSTRACT:
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 proposed for a variety of research and management activities including environmental and wildlife monitoring or law enforcement. It remains to be seen how well RPAS complement conservation actions in protected areas, since beyond technical, ethical and legal barriers that compromise their effectiveness, it is a common source of discussion that bias in research efforts is often of limited utility in addressing practical issues, particularly those claimed by natural park managers. We carried out a systematic review of the published literature in order to consider whether more attention should be given to certain conservation activities where the contribution of RPAS could improve the efficiency in the management of protected areas. After discussing results, we expose main drawbacks and identify those areas that requires further research investment, highlighting some trends and opportunities that apparently have not yet been adequately exploited.

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

1. 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

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the long term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). Protected areas have been declared under different reasons and circumstances but there is a general consensus on its importance in safeguarding biodiversity, contribute to human well-being and ensure persistece of the natural heritage for the enjoyment of future generations. Despite such praiseworthy intentions, the reality faced by protected areas is subject to a wide variety of requirements and unforeseen challenges requiring rapid and effective solutions.

To ensure its ability to meet both long-term and short-term conservation goals, protected areas have benefited from a extensive regulatory framework, to a certain extent implemented through the management plans. These plans aimed to establish the basic guidelines to protect the natural and socioeconomic values by which protected areas were declared. In the field of competences derived from such instruments, available human and material resources have mainly been allocated to regulate tourism and recreational activities, monitoring law enforcement including various forms of illegal resource extraction, wildfire prevention and fighting, wildlife monitoring campaigns to maintain up-to-date fauna inventories, environmental assesment or actions aimed at strengthen environmental education and research programs. Those activities have benefit from a wide range of technological advances, including remote sensors, field monitoring stations, manned surveys, camera traps, wildlife tracking devices or computational tools. More recently, applications of remotely piloted aircraft systems (RPAS, also known as unmanned aerial systems, UAS, drones) have been the subject of a growing interest in both the civilian sphere and scientific community. Not surprisingly, there have been a significant amount of research projects facing conservation issues using RPAS, especially during the last decade (Linchant et al. 2015; Chabot and Bird 2015; Christie et al. 2016). As a consequence, RPAS have been suggested as an appropriate complement for conservation activities (Koh and Wich 2012; Rodríguez et al. 2012; Chabot and Bird 2015, Wulder et al. (2004), Zahawi et al. (2015)).

However, to date, it has not been adequately considered whether research efforts using RPAS meet the demands of conservation practitioners. The fact that the RPAS has received increasing attention in studies addressing its feasibility to approach ecological issues and practical conservation problems does not necessarily respond to the priorities raised. In addition, budgetary constraints are common in protected area management and available resources are generally insufficient for optimal compliance. While park managers are responsible for acquiring as much information as possible to ensure that such potential source of investment will have a positive effect on the management efficiency and quality of services provided, the commitment of the research community is to provide the appropriate responses to facilitate better decision-making. We note that wildlife and habitat monitoring has received considerable attention. However, the scarcity of lines of research in other areas of equal importance is an important gap to consider when attempting to demonstrate the true potential of RPAS, encouraging its formal application in protected area management tasks.

However, to date, it has not been adequately considered whether research efforts using RPAS meet the demands of conservation practitioners. As noted, wildlife and habitat monitoring have received major emphasis. Consequently, this effort does not necessarily respond to practical conservation priorities. In addition, budgetary constraints are common in protected area management and available resources are generally insufficient for optimal compliance. Park managers must have sufficient guarantees to ensure that such potential source of investment will have a positive effect on the management efficiency and quality of services provided. The commitment of the research community is to provide the appropriate responses to facilitate better decision-making. Fostering RPAS in protected areas requires cover this important gap to consider when attempting to demonstrate the true potential of RPAS, encouraging its formal application in protected area management tasks.

, while there are important gaps to consider when uncovering the true potential of RPAS for conservation tasks.

There is an uneven amount of studies facing

2. Methods

To achieve the proposed objectives, a systematic bibliographical review (see PRISMA Flowchart) of scientific articles, gray literature, postgraduate theses, websites and specialized journals was carried out, following a similar line to other related studies (Linchant et al. 2015; Christie et al. 2016; Mulero-Pázmány et al. 2017). Last reference revised was published on June, 2017. The main tools for selecting 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, primarily in English, include RPAS in their various meanings and acronyms, reflecting the varied terminology used: “remotely piloted aerial system (RPAS)”, “drone”, “unmaned aircraft system (UAS)” “unmaned aircraft”, “model aircraft”, “radio control aircraft” , “unmaned aerial vehicle (UAV)” along with several terms referring to common activities carried out in protected areas, from the general to the particular: “conservation”, “protected areas”, “ecology” “ecosystem”, “habitat”, “vegetation”, “forest”, “wetland”, “reforestation”, “monitoring”, “survey”, “sampling”, “inventory”, “wildlife”, “fauna”, “bird”, “mammal”, “fish,”amphibian“,”reptile“,”wildfire“,”remote sensing“,”tourism“,”ecotourism“,”law enforcement“,”poaching“,”logging“,”risk management“,”pollution" and so on. For example, a restricted search was carried out with a logical statement as follows: “conservation drone” OR “conservation UAS” OR “conservation UAV” OR “conservation unmanned aircraft system” OR “conservation unmanned aircraft” OR “conservation RPAS” OR “conservation radio control aircraft”, both in singular and plural forms, as there are limits in the number of words in a single search statement. That counts for more than 80 posible combinations. We also included references from above mentioned review articles and those not indexed in research results but relevant for the purpose of this study.

From the total number of publications (x), we excluded duplicated results or those with no relevance for conservation, based on activities included in protected area management plans worldwide. The selected publications (x) were categorized according to the main purpose of the study. These categories include: "wildlife monitoring and management", for those feasibility studies facing alternative population surveys and fauna tracking methods, together with advances in software development focused on automatic animal counting and detection; "monitoring and mapping of terrestrial and aquatic ecosystems", for vegetation surveys, ecosystem dynamics studies and habitat characterization; "Law enforcement" encompasses poaching, illegal logging and fishing activities; "ecotourism" refers mainly to recreational activities and visitors management; "risk management, enviromental assesment and decision support" encompass a wide variaty of duties, including pollution sampling, disaster management. Finally, legal constraints and actions to minimize impact on fauna are also considered, as both shape the feasibility of RPAS to approach conservation and environmental issues.

The collected information is presented in tabular format, identifying where the study was conducted, the expected accomplishments and technical specifications of the aerial platform. After expose main results, gaps are identified and possible scenarios for implementing RPAS as essential tools to help achieve conservation goals in protected areas are discussed.

3. Results

3.1. *Wildlife Monitoring and Management*

Wildlife science generally refers to the study, monitoring, and management of wild mammals, birds, reptiles, and amphibians (and occasionally fish), as well as their habitats.

Several studies focused on develop survey methods aimed at locating, counting and characterizing wildlife communities and habitats, ranging from large and medium size terrestrial mammals (Lancia et al. 2005; Jain 2013, Barasona et al. (2014)), birds (Wilson, Barr, and Zagorski 2017, Hodgson et al. (2016),Christie et al. (2016) Sardà-Palomera et al. (2012), Chabot and Bird (2012)), but also species relying on coastal and marine ecosystems (Colefax, Butcher, and Kelaher 2017; Hodgson, Peel, and Kelly 2017; **???**; Koski et al. 2015, Dulava, Bean, and Richmond (2015), Durban et al. (2015), Koski et al. (2009)). RPAS have as well been applied as a means of inspecting and assess breeding and nesting areas at inaccessible sites in several species (Szantoi et al. 2017; Wich et al. 2016, Puttock et al. (2015); 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); Leonardo et al. (2013); Soriano, Caballero, and Ollero (2009);]. Given the large amount of information generated, it is not surprising that computer vision software have been developed 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 (Andrew and Shephard 2017; Chabot and Francis 2016; Gonzalez et al. 2016, Lhoest et al. (2015); Gemert et al. 2015; Christiansen et al. 2014; Martin et al. 2012; Abd-Elrahman, Pearlstine, and Percival 2005).

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Mulero-Pázmány et al. 2015)	Telemetry/RPAS SDM comparative study	Spain	Doñana National Park	*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	-
[(Chabot and Bird 2012)]	Waterbirds surveys	Canada	Ste-Anne-de-Bellevue, Baie-du-Feb- vre	Canada Geese (*Branta canadensis*), Snow Geese (*Chen caerule- scens*)	Fixed-wing; CropCam	Pentax Optio A20 10MP	$ 11000
(Koski et al. 2015)	Reidentification of photographed whales	Canada	Igloolik Island	Bowhead whales (*Balaena mysticetus*)	Fixed-wing: TD100E	GoPro, Nikon D800 50 mm f1.2 Nikon lens	-

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Durban et al. 2015)	Photogrammetry studies	Canada	Vancouver Island	Killer whales (*Orcinus orca*)	Rotor-wing: APH-22	Olympus E-PM2 Olympus M.Zuiko 25 mm F1.8 lens	-
(Lhoest et al. 2015)	Develop algorithm for automatic count of hippos	Congo	Garamba National Park	Common hippopotamus (*Hippopotamus amphibius L.*)	Fixed-wing: Falcon	Tamarisk 640	-
(Goebel et al. 2015)	Estimating abundance and size of Antarctic predators	Antarctica	Cape Shirreff, Livingston Island, South Shetland Islands	Antarctic fur seal (*Arctocephalus gazella*), Penguin (*Spheniscidae*), Leopard seal (*Hydrurga leptonyx*)	Rotor-wing: md4-1000, APQ-18, APH-22	Sony NEX-5, Canon EOS-M,Olympus E-P1	-
(Dulava, Bean, and Richmond 2015)	Waterbirds surveys	USA	Ruby Lake NWR, Tomales Bay	mallard (*Anas platyrhynchos*), northern shoveler (*Anas clypeata*), gadwall (*Anas strepera*), blue-winged teal (*Anas discors*), northern pintail (*Anas acuta*), American wigeon (*Anas americana*), canvasback (*Aythya valisineria*), scaup (*Aythya marila/ Aythya affinis*), surf scoter (*Melanitta perspicillata*), American coot (*Fulica americana*)	Rotor-wing: Honeywell RQ-16 T-Hawk , Fixed-wing: AeroVironment RQ-11A	Canon PowerShot SX230, SX260 12.1MP, GoPro Hero3	-
(Cliff et al. 2015)	Online Localization of Radio-Tagged Wildlife	Australia	-	Noisy miner (M*anorina Melanocephala*)	Rotor-wing: Falcon 8	Radiometrix LMR1 receiver, Digi XTend radio modem	-
(**???**)	Salmon spawning surveys	USA	Lower Snake River	Chinook salmon (*Oncorhynchus tshawytscha*)	Rotor-wing: Aeryon Scout	GoPro Hero3	-
(Barasona et al. 2014)	Epidemiological study	Spain	Doñana National Park	Red deer (*Cervus elaphus*), Fallow deer (*Dama dama*), Cattle (*Bos taurus*)	Fixed-wing: Easy Fly plane	Panasonic Lumix LX-3 11MP	-

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(Jain 2013)	Elephant surveys	Burkina Faso	Nazinga Game Ranch	Elephant (*Loxodonta africana*)	Fixed-wing: Gatewing x100	Ricoh GR III	-
(Rodríguez et al. 2012)	UAS and GPS Data Loggers	Spain	Doñana National Park	Lesser kestrel (*Falco naumanni*)	Fixed-wing: ST-model Easy Fly	Panasonic Lumix LX-3	-
(Sardà-Palomera et al. 2012)	Fine-scale bird monitoring	Spain	Estany d'Ivars i Vila-Sana	Black-headed (*Gull Chroicocephalus ridibun*)	fixed-wing: Multiplex Twin Star II	Panasonic Lumix FT-1 12MP 28–128 mm	$ 1645
(Hodgson et al. 2016)	Ccolony nesting birds surveys	Ashmore Reef Commonwealth Marine Reserve, Adele Island, Macquarie Island	Australia	Frigatebirds (*Fregata ariel*), Crested Terns (*Talasseus bergii*), Royal Penguins (*Eudyptes schlegeli*)	Rotor-wing: X8 3D Robotics, Fixed-wing: FX79	Canon EOS M 40mm	$ 5100

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Table 2.: WILDLIFE MONITORING AND MANAGEMENT

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

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(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	?

Table 3.: MONITORING OF TERRESTRIAL AND AQUATIC 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	?	?	?

Study	Aims	Country	Place	Target	RPAS platform	Payload	Costs
(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	Sweeden	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	Sweeden	?	Hooded crow (*Corvus corone cornix*)	Rotor-wing: DJI Phantom 2 Vision	?	$ 1000

Table 4.: INFRASTRUCTURES AND RISK ASSESSMENT, ECOTOURISM, IMPACT ON WILDLIFE AND ECOSYSTEMS

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
(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 National Park	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	?

Table: ENVIRONMENTAL MONITORING AND DECISION SUPPORT

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

So far RPAS have been used to classify vegetation cover in wetlands (USGS 2014), monitoring the spread and detection rate of invasive species (Müllerová et al. 2016, Zaman, Jensen, and McKee (2011), Perroy, Sullivan, and Stephenson (2017)), the characterization of forest stands (Gini et al. 2012), including the evaluation of the effectiveness of restoration actions (Zahawi et al. 2015) or multitemporal analysis of the spectral response to phenological variations in different species of deciduous trees (Lisein et al. 2015). Recently, shallow coastal habitats were also mapped using consumer grade RPAS (Casella et al. 2017, Ventura et al. (2016)), but also to monitor erosion dynamics in shorelines. (Casella et al. 2016). This momentum has been especially notable with the parallel development of affordable multispectral and hyperspectral sensors adapted to small aircraft (Bareth et al. 2015).

3.3. *Infrastructure and risk assessment*

Other research projects highlight the convenience of RPAS in assessing the risk that linear electrical infraestructures posed for birds (Margarita Mulero-Pázmány 2014; Lobermeier et al. 2015) or identify nests on the ground at risk of destruction by harvesting (Mulero-Pázmány Margarita 2011).

3.4. *Law enforcement*

RPAS have also relevance in the control and surveillance of protected areas, documented through different experiences and considerations focused mainly on poaching and illegal fishing activities (Mulero-Pázmány et al. 2014, Franco et al. (2016), Olivares-Mendez et al. (2014)) but also other less contentious illegal activities (Sabella et al. 2017). (Duffy 2014) analyzed the consequences of the militarization of conservation practices as an increasing trend in natural protected areas around the world and illustrates the use of RPAS through several examples.

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, 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.

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).

4.1. *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 and several trials measure the disturbance effects of RPAS on birds (Vas et al. 2015, McEvoy, Hall, and McDonald (2016),BORRELLE and FLETCHER (2017), Scobie and Hugenholtz (2016), Weissensteiner, Poelstra, and Wolf (2015)) and mammals (Ditmer et al. 2015, Pomeroy, O'Connor, and Davies (2015)), while other studies marginally inform observed behavioural patterns (Jain 2013, Mulero-Pázmány et al. (2015)). Finally,a code of good practice and recommendations is build upon the learned experiences.

5. Discussion

5.1. *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 have 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).

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.

5.2. *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 (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.

5.3. *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.

5.4. *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.

5.5. *Law enforcement*

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.

5.6. *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.

5.7. *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 (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.

References

Abd-Elrahman, Amr, Leonard Pearlstine, and Franklin Percival. 2005. "Development of Pattern Recognition Algorithm for Automatic Bird ." *Surv. L. Inf. Sci.* 65 (1): 37.

America, New. 2017. "*World of Drones.*" http://drones.newamerica.org/#regulations [Accessed: 17 June, 2017].

Andel, Alexander C. van, Serge A. Wich, Christophe Boesch, Lian Pin Koh, Martha M. Robbins, Joseph Kelly, and Hjalmar S. Kuehl. 2015. "Locating Chimpanzee Nests and Identifying Fruiting Trees with an Unmanned Aerial Vehicle." *Am. J. Primatol.* 77 (10): 1122–1134. doi:10.1002/ajp.22446.

Andrew, Margaret E, and Jill M Shephard. 2017. "Semi-Automated Detection of Eagle Nests: An Application of Very High-Resolution Image Data and Advanced Image Analyses to Wildlife Surveys." doi:10.1002/rse2.38.

Andrews, C. 2014. "*Wildlife Monitoring: Should Uav Drones Be Banned?*" https://prod-eandt.theiet.org/content/articles/2014/07/wildlife-monitoring-should-uav-drones-be-banned/ [Accessed: 07 Abril, 2017].

Banzi, Jamali Firmat. 2014. "A Sensor Based Anti-Poaching System in Tanzania National Parks." *International Journal of Scientific and Research Publications* 4 (4).

Barasona, José A., Margarita Mulero-Pázmány, Pelayo Acevedo, Juan J. Negro, María J. Torres, Christian Gort??zar, and Joaquín Vicente. 2014. "Unmanned Aircraft Systems for Studying Spatial Abundance of Ungulates: Relevance to Spatial Epidemiology." *PLoS One* 9 (12): 1–17. doi:10.1371/journal.pone.0115608.

Bareth, Georg, Helge Aasen, Juliane Bendig, Martin Leon Gnyp, Andreas Bolten, Andr?s Jung, Ren? Michels, and Jussi Soukkam?ki. 2015. "Low-Weight and UAV-

Based Hyperspectral Full-Frame Cameras for Monitoring Crops: Spectral Comparison with Portable Spectroradiometer Measurements." *Photogrammetrie - Fernerkundung - Geoinformation* 2015 (1): 69–79. doi:10.1127/pfg/2015/0256.

Bayram, Haluk, Krishna Doddapaneni, Nikolaos Stefas, and Volkan Isler. 2016. "Active Localization of VHF Collared Animals with Aerial Robots," no. 13: 74–75. doi:10.1109/COASE.2016.7743503.

BORRELLE, SB, and AT FLETCHER. 2017. "Will Drones Reduce Investigator Disturbance to Surface-Nesting Seabirds?" bibtex: borrelle_will_2017. *Marine Ornithology* 45: 89–94.

Bustamante, Luis Antonio Esquivel. 2015. "Forest Monitoring with Drones : Application Strategies for Protected Riverine Forest Ecosystems in the Atlantic Forest of Rio de," 96.

Casella, Elisa, Antoine Collin, Daniel Harris, Sebastian Ferse, Sonia Bejarano, Valeriano Parravicini, James L. Hench, and Alessio Rovere. 2017. "Mapping Coral Reefs Using Consumer-Grade Drones and Structure from Motion Photogrammetry Techniques." *Coral Reefs* 36 (1): 269–275. doi:10.1007/s00338-016-1522-0.

Casella, Elisa, Alessio Rovere, Andrea Pedroncini, Colin P. Stark, Marco Casella, Marco Ferrari, and Marco Firpo. 2016. "Drones as Tools for Monitoring Beach Topography Changes in the Ligurian Sea (NW Mediterranean)." *Geo-Marine Letters* 36 (2): 151–163. doi:10.1007/s00367-016-0435-9.

Chabot, Dominique, and David M. Bird. 2012. "Evaluation of an Off-the-Shelf Unmanned Aircraft System for Surveying Flocks of Geese." *Waterbirds* 35 (1): 170–174. doi:10.1675/063.035.0119.

Chabot, Dominique, and David M. Bird. 2015. "Wildlife Research and Management Methods in the 21st Century: Where Do Unmanned Aircraft Fit in?" *J. Unmanned Veh. Syst.* 3 (4): 137–155. doi:10.1139/juvs-2015-0021.

Chabot, Dominique, and Charles M. Francis. 2016. "Computer-Automated Bird Detection and Counts in High-Resolution Aerial Images: A Review." *Journal of Field Ornithology* 87 (4): 343–359. doi:10.1111/jofo.12171.

Christiansen, Peter, Kim A rild Steen, Rasmus N yholm Jørgensen, and Henrik Karstoft. 2014. "Automated Detection and Recognition of Wildlife Using Thermal Cameras." *Sensors (Basel).* 14 (8): 13778–13793. doi:10.3390/s140813778.

Christie, Katherine S., Sophie L. Gilbert, Casey L. Brown, Michael Hatfield, and Leanne Hanson. 2016. "Unmanned Aircraft Systems in Wildlife Research: Current and Future Applications of a Transformative Technology." *Front. Ecol. Environ.* 14 (5): 241–251. doi:10.1002/fee.1281.

Cliff, Oliver M, Robert Fitch, Salah Sukkarieh, Debra L Saunders, and Robert Heinsohn. 2015. "Online Localization of Radio-Tagged Wildlife with an Autonomous Aerial Robot System." *Robot. Sci. Syst.*, no. November 2016: 1–9. doi:10.15607/RSS.2015.XI.042.

Colefax, Andrew P., Paul A. Butcher, and Brendan P. Kelaher. 2017. "The Potential for Unmanned Aerial Vehicles (UAVs) to Conduct Marine Fauna Surveys in Place of Manned Aircraft." *ICES Journal of Marine Science*, June. doi:10.1093/icesjms/fsx100.

Consulting, OZYRPAS. 2017. "*Global Drone Regulations Database*." https://www.droneregulations.info/index.html [Accessed: 19 July, 2017].

Cornell, Dylan, Maryann Herman, and Fernando Ontiveros. 2016. "Use of a UAV for Water Sampling to Assist Remote Sensing of Bacterial Flora in Freshwater Environments." http://fisherpub.sjfc.edu/undergraduate_ext_pub/17/.

Ditmer, Mark A., John B. Vincent, Leland K. Werden, Jessie C. Tanner, Timothy G. Laske, Paul A. Iaizzo, David L. Garshelis, and John R. Fieberg. 2015. "Bears Show a Physiological but Limited Behavioral Response to Unmanned Aerial Vehicles." *Curr. Biol.* 25 (17): 2278–2283. doi:10.1016/j.cub.2015.07.024.

Dudley, Nigel. 2008. *Guidelines for Applying Protected Area Management Categories.* bibtex: dudley_guidelines_2008. IUCN.

Duffy, Rosaleen. 2014. "Waging a War to Save Biodiversity: The Rise of Militarized Conservation." *Int. Aff.* 90 (4): 819–834. doi:10.1111/1468-2346.12142.

Dulava, Sharon, William T. Bean, and Orien M. W. Richmond. 2015. "ENVIRONMENTAL REVIEWS AND CASE STUDIES: Applications of Unmanned Aircraft Systems (UAS) for Waterbird Surveys." *Environ. Pract.* 17 (3): 201–210. doi:10.1017/S1466046615000186.

Durban, J W, H Fearnbach, W L Perryman, and D J Leroi. 2015. "Photogrammetry of Killer Whales Using a Small Hexacopter Launched at Sea." *J. Unmanned Veh. Syst.* 3 (June): 1–5. doi:dx.doi.org/10.1139/juvs-2015-0020.

Fornace, Kimberly M., Chris J. Drakeley, Timothy William, Fe Espino, and Jonathan Cox. 2014. "Mapping Infectious Disease Landscapes: Unmanned Aerial Vehicles and Epidemiology." *Trends Parasitol.*, October, 1–6. doi:10.1016/j.pt.2014.09.001.

Franco, Antonio Di, Pierre Thiriet, Giuseppe Di Carlo, Charalampos Dimitriadis, Patrice Francour, Nicolas L Gutiérrez, Alain Jeudy De Grissac, et al. 2016. "Five Key Attributes Can Increase Marine Protected Areas Performance for Small-Scale Fisheries Management." *Nat. Publ. Gr.*, no. November: 1–9. doi:10.1038/srep38135.

Gemert, Jan C. van, Camiel R. Verschoor, Pascal Mettes, Kitso Epema, Lian Pin Koh, and Serge Wich. 2015. "Nature Conservation Drones for Automatic Localization and Counting of Animals." *Lect. Notes Comput. Sci. (Including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)* 8925: 255–270. doi:10.1007/978-3-319-16178-5_17.

Gini, R., D. Passoni, L. Pinto, and G. Sona. 2012. "Aerial Images from an Uav System: 3D Modeling and Tree Species Classification in a Park Area." *ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci* XXXIX-B1 (September): 361–366. doi:10.5194/isprsarchives-XXXIX-B1-361-2012.

Goebel, Michael E., Wayne L. Perryman, Jefferson T. Hinke, Douglas J. Krause, Nancy A. Hann, Steve Gardner, and Donald J. LeRoi. 2015. "A Small Unmanned Aerial System for Estimating Abundance and Size of Antarctic Predators." *Polar Biol.*

38 (5): 619–630. doi:10.1007/s00300-014-1625-4.

Gonzalez, Luis F., Glen A. Montes, Eduard Puig, Sandra Johnson, Kerrie Mengersen, and Kevin J. Gaston. 2016. "Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation." *Sensors (Switzerland)* 16 (1). doi:10.3390/s16010097.

Grémillet, David, William Puech, Véronique Garçon, Thierry Boulinier, and Yvon Le Maho. 2012. "Robots in Ecology: Welcome to the Machine." *Open J. Ecol.* 02 (2): 49–57. doi:10.4236/oje.2012.22006.

Hansen, Andreas Skriver. 2016. "Applying Visitor Monitoring Methods in Coastal and Marine Areas – Some Learnings and Critical Reflections from Sweden." *Scand. J. Hosp. Tour.* 2250 (June): 1–18. doi:10.1080/15022250.2016.1155481.

Hodgson, Amanda, Natalie Kelly, and David Peel. 2013. "Unmanned Aerial Vehicles (UAVs) for Surveying Marine Fauna: A Dugong Case Study." *PLoS One* 8 (11): 1–15. doi:10.1371/journal.pone.0079556.

Hodgson, Amanda, David Peel, and Natalie Kelly. 2017. "Unmanned Aerial Vehicles for Surveying Marine Fauna: Assessing Detection Probability." *Ecological Applications*. http://onlinelibrary.wiley.com/doi/10.1002/eap.1519/full.

Hodgson, Jarrod C, Shane M Baylis, Rowan Mott, Ashley Herrod, and Rohan H Clarke. 2016. "Precision Wildlife Monitoring Using Unmanned Aerial Vehicles." *Sci. Rep.* 6 (March): 22574. doi:10.1038/srep22574.

Hodgson, Jarrod C., and Lian Pin Koh. 2016. "Best Practice for Minimising Unmanned Aerial Vehicle Disturbance to Wildlife in Biological Field Research." *Curr. Biol.* 26 (10). doi:10.1016/j.cub.2016.04.001.

Ivošević, Bojana, Yong Gu Han, Youngho Cho, and Ohseok Kwon. 2015. "The Use of Conservation Drones in Ecology and Wildlife Research." *J. Ecol. Environ.* 38 (1): 113–118. doi:10.5141/ecoenv.2015.012.

Jain, Mukesh. 2013. "Unmanned Aerial Survey of Elephants." *PLoS One*. doi:10.1371/ journal.pone.0054700.

Jewell, Zoe. 2013a. "Effect of Monitoring Technique on Quality of Conservation Science: Ethics and Science in Conservation." *Conservation Biology* 27 (3): 501–508. doi:10.1111/cobi.12066.

Jewell, Zoe. 2013b. "Effect of Monitoring Technique on Quality of Conservation Science: Ethics and Science in Conservation." *Conservation Biology* 27 (3): 501–508. doi:10.1111/cobi.12066.

King, Lisa M. 2014. "Will Drones Revolutionise Ecotourism?" *J. Ecotourism* 13 (1): 85–92. doi:10.1080/14724049.2014.948448.

Koh, Lian Pin, and Serge A. Wich. 2012. "Dawn of Drone Ecology: Low-Cost Autonomous Aerial Vehicles for Conservation." *Trop. Conserv. Sci.* 5 (2): 121–132. doi:WOS:000310846600002.

Koski, William R., Travis Allen, Darren Ireland, Greg Buck, Paul R. Smith, A. Michael Macrander, Melissa A. Halick, Chris Rushing, David J. Sliwa, and Trent L.

McDonald. 2009. "Evaluation of an Unmanned Airborne System for Monitoring Marine Mammals." *Aquatic Mammals* 35 (3): 347–357. doi:10.1578/AM.35.3.2009.347.

Koski, William R., Gayan Gamage, Andrew R. Davis, Tony Mathews, Bernard LeBlanc, and Steven H. Ferguson. 2015. "Evaluation of UAS for Photographic Re-Identification of Bowhead Whales, Balaena Mysticetus." *J. Unmanned Veh. Syst.* 3 (1): 22–29. doi:10.1139/juvs-2014-0014.

Körner, Fabian, Raphael Speck, Ali Haydar, and Salah Sukkarieh. 2010. "Autonomous Airborne Wildlife Tracking Using Radio Signal Strength," 107–112.

Lancia, Richard A, William L Kendall, Kenneth H Pollock, and James D Nichols. 2005. "Estimating the Number of Animals in Wildlife Populations." bibtex: lancia_estimating_2005.

Leary, David. 2017. "Drones on Ice: An Assessment of the Legal Implications of the Use of Unmanned Aerial Vehicles in Scientific Research and by the Tourist Industry in Antarctica." *Polar Record*, May, 1–15. doi:10.1017/S0032247417000262.

Leonardo, Miguel, Austin Jensen, Calvin Coopmans, Mac McKee, and YangQuan Chen. 2013. "A Miniature Wildlife Tracking UAV Payload System Using Acoustic Biotelemetry." *Proc. ASME Int. Des. Eng. Tech. Conf. Comput. Inf. Eng. Conf.*, no. July 2015. doi:10.1115/DETC2013-13267.

Lhoest, S., J. Linchant, S. Quevauvillers, C. Vermeulen, and P. Lejeune. 2015. "How Many Hippos (Homhip): Algorithm for Automatic Counts of Animals with Infra-Red Thermal Imagery from UAV." *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch.* 40 (3): 355–362. doi:10.5194/isprsarchives-XL-3-W3-355-2015.

Linchant, Julie, Jonathan Lisein, Jean Semeki, Philippe Lejeune, and Cédric Vermeulen. 2015. "Are Unmanned Aircraft Systems (UASs) the Future of Wildlife Monitoring? A Review of Accomplishments and Challenges." *Mamm. Rev.* 45 (4): 239–252. doi:10.1111/mam.12046.

Lisein, Jonathan, Adrien Michez, Hugues Claessens, and Philippe Lejeune. 2015. "Discrimination of Deciduous Tree Species from Time Series of Unmanned Aerial System Imagery." *PLoS One* 10 (11). doi:10.1371/journal.pone.0141006.

Lobermeier, Scott, Matthew Moldenhauer, Christopher Peter, Luke Slominski, Richard Tedesco, Marcus Meer, James Dwyer, Richard Harness, and Andrew Stewart. 2015. "Mitigating Avian Collision with Power Lines: A Proof of Concept for Installation of Line Markers via Unmanned Aerial Vehicle." *J. Unmanned Veh. Syst.* 3 (4): 252–258. doi:10.1139/juvs-2015-0009.

Longmore, S. N., R. P. Collins, S. Pfeifer, S. E. Fox, M. Mulero-Pazmany, F. Bezombes, A. Goodwind, M. de Juan Ovelar, J. H. Knapen, and S. A. Wich. 2017. "Adapting Astronomical Source Detection Software to Help Detect Animals in Thermal Images Obtained by Unmanned Aerial Systems" 00 (0): 1–16. doi:10.1080/01431161.2017.1280639.

Margarita Mulero-Pázmány, Miguel Ferrer, Juan José Negro. 2014. "A Low Cost Way for Assessing Bird Risk Hazards in Power Lines: Fixed-Wing Small Unmanned

Aircraft Systems” 2.

Martin, Julien, Holly H. Edwards, Matthew A. Burgess, H. Franklin Percival, Daniel E. Fagan, Beth E. Gardner, Joel G. Ortega-Ortiz, Peter G. Ifju, Brandon S. Evers, and Thomas J. Rambo. 2012. “Estimating Distribution of Hidden Objects with Drones: From Tennis Balls to Manatees.” *PLoS One* 7 (6): 1–8. doi:10.1371/journal.pone.0038882.

Maza, Iv?n, Fernando Caballero, Jes?s Capit?n, J. R. Mart?nez-de-Dios, and An?bal Ollero. 2011. “Experimental Results in Multi-UAV Coordination for Disaster Management and Civil Security Applications.” *Journal of Intelligent & Robotic Systems* 61 (1): 563–585. doi:10.1007/s10846-010-9497-5.

McCaldin, Guy, Michael Johnston, and Andrew Rieker. 2015. *Use of Unmanned Aircraft Systems to Assist with Decision Support for Land Managers on Christmas Island (Indian Ocean).* October. Australia: V-TOL Aerospace; Department of parks; Wildlife, Western Australia.

McEvoy, John F., Graham P. Hall, and Paul G. McDonald. 2016. “Evaluation of Unmanned Aerial Vehicle Shape, Flight Path and Camera Type for Waterfowl Surveys: Disturbance Effects and Species Recognition.” *PeerJ* 4 (March): e1831. doi:10.7717/peerj.1831.

Miyamoto, Michiru, Kunihiko Yoshino, Toshihide Nagano, Tomoyasu Ishida, and Yohei Sato. 2004. “Use of Balloon Aerial Photography for Classification of Kushiro Wetland Vegetation, Northeastern Japan.” *Wetlands* 24 (3): 701–710. doi:10.1672/0277-5212(2004)024[0701:UOBAPF]2.0.CO;2.

Mulero-Pázmány Margarita, Negro JJ. 2011. “AEROMAB Small UAS for Montagu’s Harrier’s Circus Pygargus Nests Monitoring.” *AEROMAB Small UAS Montagu’s Harrier’s Circus Pygargus Nests Monit. RED UAS Intenational Congr. Univ. Eng. Seville, Spain. December 2011.*

Mulero-Pázmány, Margarita, Jose Ángel Barasona, Pelayo Acevedo, Joaquín Vicente, and Juan José Negro. 2015. “Unmanned Aircraft Systems Complement Biologging in Spatial Ecology Studies.” *Ecol. Evol.* 5 (21): 4808–4818. doi:10.1002/ece3.1744.

Mulero-Pázmány, Margarita, Susanne Jenni-Eiermann, Nicolas Strebel, Thomas Sattler, Juan José Negro, and Zulima Tablado. 2017. “Unmanned Aircraft Systems as a New Source of Disturbance for Wildlife: A Systematic Review.” *PloS One* 12 (6): e0178448. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0178448.

Mulero-Pázmány, Margarita, Roel Stolper, L. D. Van Essen, Juan J. Negro, and Tyrell Sassen. 2014. “Remotely Piloted Aircraft Systems as a Rhinoceros Anti-Poaching Tool in Africa.” *PLoS One* 9 (1): 1–10. doi:10.1371/journal.pone.0083873.

Müllerová, Jana, Josef Brůna, Dvořák, Peter, Tomáš Bartaloš, and Michaela Vítková. 2016. “DOES THE DATA RESOLUTION/ORIGIN MATTER? SATELLITE, AIRBORNE AND UAV IMAGERY TO TACKLE PLANT INVASIONS.” *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information*

Sciences XLI-B7 (June): 903–908. doi:10.5194/isprsarchives-XLI-B7-903-2016.

Nugraha, Ridha Aditya, Deepika Jeyakodi, and Thitipon Mahem. 2016. "Urgency for Legal Framework on Drones : Lessons for Indonesia , India , and Thailand." *Indones. Law Rev.* 6 (2): 137–157.

Olivares-Mendez, Miguel A., Tegawendé F. Bissyandé, Kannan Somasundar, Jacques Klein, Holger Voos, and Yves Le Traon. 2014. "The NOAH Project: Giving a Chance to Threatened Species in Africa with UAVs." *Lect. Notes Inst. Comput. Sci. Soc. Telecommun. Eng. LNICST* 135 LNICST: 198–208. doi:10.1007/978-3-319-08368-1_24.

Perroy, Ryan L., Timo Sullivan, and Nathan Stephenson. 2017. "Assessing the Impacts of Canopy Openness and Flight Parameters on Detecting a Sub-Canopy Tropical Invasive Plant Using a Small Unmanned Aerial System." *ISPRS J. Photogramm. Remote Sens.* 125: 174–183. doi:10.1016/j.isprsjprs.2017.01.018.

Pomeroy, P., L. O'Connor, and P. Davies. 2015. "Assessing Use of and Reaction to Unmanned Aerial Systems in Gray and Harbor Seals During Breeding and Molt in the UK [1]." *Journal of Unmanned Vehicle Systems* 3 (3): 102–113. doi:10.1139/juvs-2015-0013.

Puttock, A.K., A.M. Cunliffe, K. Anderson, and R.E. Brazier. 2015. "Aerial Photography Collected with a Multirotor Drone Reveals Impact of Eurasian Beaver Reintroduction on Ecosystem Structure 1." *J. Unmanned Veh. Syst.* 3 (3): 123–130. doi:10.1139/juvs-2015-0005.

Rodríguez, Airam, Juan J. Negro, Mara Mulero, Carlos Rodríguez, Jesús Hernández-Pliego, and Javier Bustamante. 2012. "The Eye in the Sky: Combined Use of Unmanned Aerial Systems and GPS Data Loggers for Ecological Research and Conservation of Small Birds." *PLoS One* 7 (12). doi:10.1371/journal.pone.0050336.

Sabella, Giorgio, Fabio Massimo Viglianisi, Sergio Rotondi, and Filadelfo Brogna. 2017. "Preliminary Observations on the Use of Drones in the Environmental Monitoring and in the Management of Protected Areas. the Case Study of 'RNO Vendicari', Syracuse (Italy)." bibtex: sabella_preliminary_2017. *Biodiversity Journal* 8: 79–86. http://www.biodiversityjournal.com/pdf/8(1)_79-86.pdf.

Sardà-Palomera, Francesc, Gerard Bota, Carlos Viñolo, Oriol Pallarés, Víctor Sazatornil, Lluís Brotons, Spartacus Gomáriz, and Francesc Sardà. 2012. "Fine-Scale Bird Monitoring from Light Unmanned Aircraft Systems." *Ibis (Lond. 1859).* 154 (1): 177–183. doi:10.1111/j.1474-919X.2011.01177.x.

Schmale, DG, Benjamin R. Dingus, and Charles Reinholtz. 2008. "Development and Application of an Autonomous Unmanned Aerial Vehicle for Precise Aerobiological Sampling Above Agricultural Fields." *J. F. Robot.* 25 (3): 133–147. doi:10.1002/rob.

Schwarzbach, Marc, Maximilian Laiacker, Margarita Mulero-Pazmany, and Konstantin Kondak. 2014. "Remote Water Sampling Using Flying Robots." *2014 Int. Conf. Unmanned Aircr. Syst. ICUAS 2014 - Conf. Proc.*, 72–76. doi:10.1109/ICUAS.2014.6842240.

Scobie, Corey A., and Chris H. Hugenholtz. 2016. "Wildlife Monitoring with

Unmanned Aerial Vehicles: Quantifying Distance to Auditory Detection: UAV Sound and Wildlife Aural Detection." *Wildlife Society Bulletin* 40 (4): 781–785. doi:10.1002/wsb.700.

Sepúlveda, Alejandra, Mathias Schluep, Fabrice G. Renaud, Martin Streicher, Ruediger Kuehr, Christian Hagelüken, and Andreas C. Gerecke. 2010. "A Review of the Environmental Fate and Effects of Hazardous Substances Released from Electrical and Electronic Equipments During Recycling: Examples from China and India." *Environmental Impact Assessment Review* 30 (1): 28–41. doi:10.1016/j.eiar.2009.04.001.

Soriano, P, F Caballero, and A Ollero. 2009. "RF-Based Particle Filter Localization for Wildlife Tracking by Using an UAV." *40 Th Int. Symp. Robot.*, 239–244. http://grvc.us.es/publica/congresosint/documentos/isr_soriano.pdf.

Stöcker, Claudia, Rohan Bennett, Francesco Nex, Markus Gerke, and Jaap Zevenbergen. 2017. "Review of the Current State of UAV Regulations." *Remote Sensing* 9 (5): 459. doi:10.3390/rs9050459.

Szantoi, Zoltan, Scot E. Smith, Giovanni Strona, Lian Pin Koh, and Serge A. Wich. 2017. "Mapping Orangutan Habitat and Agricultural Areas Using Landsat OLI Imagery Augmented with Unmanned Aircraft System Aerial Photography." *Int. J. Remote Sens.* 38 (8): 1–15. doi:10.1080/01431161.2017.1280638.

UAVSI. 2017. "*Association for Unmanned Vehicle Systems International.*" http://www.auvsi.org [Accessed: 27 July, 2017].

USGS. 2014. "*US Geological Survey National Unmanned Aircraft Systems Project.*" http:// rmgsc.cr.usgs.gov/UAS [Accessed: 13 April, 2017].

Van Tilburg, Christopher. 2017. "First Report of Using Portable Unmanned Aircraft Systems (Drones) for Search and Rescue." *Wilderness & Environmental Medicine.* http://www.sciencedirect.com/science/article/pii/S1080603217300042.

Vas, E., A. Lescroel, O. Duriez, G. Boguszewski, and D. Gremillet. 2015. "Approaching Birds with Drones: First Experiments and Ethical Guidelines." *Biol. Lett.* 11 (2): 20140754–20140754. doi:10.1098/rsbl.2014.0754.

Ventura, Daniele, Michele Bruno, Giovanna Jona Lasinio, Andrea Belluscio, and Giandomenico Ardizzone. 2016. "A Low-Cost Drone Based Application for Identifying and Mapping of Coastal Fish Nursery Grounds." *Estuar. Coast. Shelf Sci.* 171. doi:10.1016/j.ecss.2016.01.030.

Weissensteiner, M. H., J. W. Poelstra, and J. B. W. Wolf. 2015. "Low-Budget Ready-to-Fly Unmanned Aerial Vehicles: An Effective Tool for Evaluating the Nesting Status of Canopy-Breeding Bird Species." bibtex: weissensteiner_low-budget_2015. *Journal of Avian Biology* 46 (4): 425–430. doi:10.1111/jav.00619.

Wich, Serge, David Dellatore, Max Houghton, Rio Ardi, and Lian Pin Koh. 2016. "A Preliminary Assessment of Using Conservation Drones for Sumatran Orang-Utan (Pongo Abelii) Distribution and Density." *J. Unmanned Veh. Syst.* 4 (1): 45–52. doi:10.1139/juvs-2015-0015.

Wilson, Andrew M, Janine Barr, and Megan Zagorski. 2017. "The Feasibility of Counting Songbirds Using Unmanned Aerial Vehicles." *Auk* 134 (2): 350–362. doi:10.1642/AUK-16-216.1.

Wilson, Rory P., and Clive R. McMahon. 2006. "Measuring Devices on Wild Animals: What Constitutes Acceptable Practice?" *Frontiers in Ecology and the Environment* 4 (3): 147–154. doi:10.1890/1540-9295(2006)004[0147:MDOWAW]2.0.CO;2.

Wulder, Michael A, Ronald J Hall, Nicholas C Coops, and Steven E Franklin. 2004. "High Spatial Resolution Remotely Sensed Data for Ecosystem Characterization" 54 (6): 511–521. doi:10.1641/0006-3568(2004)054.

Zahawi, Rakan A., Jonathan P. Dandois, Karen D. Holl, Dana Nadwodny, J. Leighton Reid, and Erle C. Ellis. 2015. "Using Lightweight Unmanned Aerial Vehicles to Monitor Tropical Forest Recovery." *Biol. Conserv.* 186 (June): 287–295. doi:10.1016/j.biocon.2015.03.031.

Zaman, Bushra, Austin M. Jensen, and Mac McKee. 2011. "Use of High-Resolution Multispectral Imagery Acquired with an Autonomous Unmanned Aerial Vehicle to Quantify the Spread of an Invasive Wetlands Species." *Int. Geosci. Remote Sens. Symp.*, 803–806. doi:10.1109/IGARSS.2011.6049252.

Zang, Wenqian, Jiayuan Lin, Yangchun Wang, and Heping Tao. 2012. "Investigating Small-Scale Water Pollution with UAV Remote Sensing Technology." In *World Automation Congress (WAC), 2012*, 1–4. IEEE. http://ieeexplore.ieee.org/abstract/document/6321515/.