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

Park managers demands practical, cost-effective and innovative solutions to handle an overwhelming amount of environmental issues requiring appropriate data-driven decision making. While RPAS have been called upon to revolutionize conservation, bottlenecks for integrating them into PAs come from different fronts, ranging from legal and social issues to operational challenges. A bibliographic survey was conducted to value the current state and prospects of RPAS, and how they can strengthen effective management in the scope of protected areas. We discuss multiple facets of applications, provide specific examples and suggest plausible scenarios to help achieve conservation goals in PAs, highlighting some trends, drawbacks and opportunities that apparently have not yet been adequately exploited.

Keywords: protected areas, RPAS, conservation, review, effective management, threats, pressures, wildlife, ecosystems, environmental assessment, emergency response, ecotourism

# Introduction

As defined by UICN, "a protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). Despite such praiseworthy intentions, PAs are still subject to a wide variety of unforeseen challenges requiring rapid and effective solutions (Watson et al. 2014). Habitat change and fragmentation, pollution, overexploitation of natural resources, climate change and invasive species have been identified as main global threats to biodiversity (Groom, Meffe, and Caroll 2006). To curb the loss of biodiversity while attending other inherent activities, PAs have benefit from a wide range of technological advances, methods or innovative application of existing technologies (Pimm et al. 2015) to assess, monitor and predict the state and pressures of PAs. More recently, remotely piloted aircraft systems (RPAS, also known as unmanned aerial systems, UAS, drones) have been the subject of a growing interest in both the civilian and scientific sphere and indeed avowed as a new distinct era of remote sensing for the study of environment (Melesse et al. 2007). RPAS offer a relatively risk-free and low-cost manner to rapidly and autonomously observe natural phenomes at high spatiotemporal resolution. Not surprisingly, RPAS have become a major trend in conservation according to the bibliography (Koh and Wich 2012; Anderson and Gaston 2013; Linchant et al. 2015a; Christie et al. 2016; Torresan et al. 2017). To date, however, it has not been adequately weighted how the full range of RPAS applications can help decision-makers to effectively attend management and face threats to PAs. To shed light on this question, we carried out an extensive literature revision to get a snapshot of the current state and perspectives of RPAS within PAs. We found that RPAS applications for wildlife research and habitat monitoring are suitable to track species and ecosystems responses to management at local scale, but potential disturbance effects and technological shortcomings should be carefully considered. Other facets, such enforcement have ostensibly received minor attention from the academia, despite the fact that poaching and other forms of illicit biological resource use are a major threat to biodiversity (Leverington et al. 2010). In addition, RPAS have been applied to support emergency response and hazard risk management, wildfires, pollution monitoring and ecotourism, representing a set of conceivable operational scenarios claiming a place on the PAs management toolset.

# Methods

A bibliographical review (see PRISMA Flowchart) of scientific articles, gray literature, postgraduate theses and websites was carried out, following a similar line to other related studies (Linchant et al. 2015b; Christie et al. 2016; Mulero-Pázmány et al. 2017). Last reference revised was published on October 2017. The main tool for selecting bibliography was Google Scholar. Key search criteria, primarily in English, encompass RPAS in their various meanings and acronyms, reflecting the varied terminology used. Keywords were combined with terms referring to topics related to RPAS, threats and common conservation measurements in PAs (see table 1) using logical disjunctions. A total of 42 search terms and X combinations were applied. A sweep of bibliographical citations and related articles was performed and further complemented with some other recent references found elsewhere (Research Gate, Mendeley Desktop, Review articles, Internet search engines), resulting in more than 500 articles. After removing duplicated, review articles and spurious results, the remaining publications (377) were revised at different levels of depth, summarized (figures 1, 2 and 3) and grouped according to the following interrelated categories: “wildlife research and management” (102), for those projects aimed at observing wildlife, estimate population parameters such abundance and distribution, and devising management measures to mitigate human-wildlife conflicts; “terrestrial and aquatic ecosystems monitoring" (114), with regards to applications for the study and mapping of natural habitats; “Law enforcement” encompasses poaching, and other illicit activities; "Ecotourism" is restricted to recreational activities and visitors management; “Environmental management and emergency response" (84) span from environmental monitoring and protection, search and rescue activities, natural risk assessment and similar issues. We briefly tackled legal and ethical issues, including potential impact on wildlife and habitats, but also economic and technological factors, since all shape the feasibility of RPAS to approach conservation and environmental issues. To guide the study, we identify common threats and essential management measures in PAs from the “Management effectiveness evaluation in protected areas – a global study” (Leverington et al. 2010) report and other alternatives sources. Examples are provided (table 2) and plausible scenarios to help achieve conservation goals in PAs are suggested, highlighting some trends, drawbacks and opportunities that apparently have not yet been adequately exploited.

# Results and discussion

## Wildlife research and management

Ecological monitoring is essential to track the response of wildlife to management and environmental factors, and assess whether distinct or further measurements are required to maintain viable populations (Gibbs et al. 1999). Compared with other methodologies, remotely sensed capabilities of RPAS offer a less invasive, non-hazardous and reliable monitoring technique (Jewell 2013) to collect abundance, distributional, behavioural, life-history and environmental data. Recent examples target large and medium size terrestrial mammals (Chrétien et al. 2016; Wich et al. 2016), marine mammals (Sweeney et al. 2016; Seymour et al. 2017; Hodgson et al. 2017), birds (Weissensteiner et al. 2015; Christie et al. 2016; J. C. Hodgson et al. 2016; Sardà-Palomera et al. 2017), reptiles (Evans et al. 2015; Elsey et al. 2016; Schofield et al. 2017), and fishes (Groves et al. 2016; Kiszka et al. 2016). While most surveys opted for both optical and thermal cameras, others implement acoustic sensors (Wilson et al. 2017) and RPAS based wildlife tracking systems (Mulero-Pázmány et al. 2015; Bayram et al. 2016; Xu et al. 2016).

On the other hand, human-wildlife conflicts are also present both in PAs and nearby locations as result of increasingly pressures on natural habitats. Within this topic, RPAS have been used to move elephants out of human settlements (Hahn et al. 2017), calculate compensation costs for wildlife damage on crops (Michez, Morelle, et al. 2016), select suitable locations to install ecological corridors in populations impacted by roadkill (Gülci and Akay 2016) or dropping fake baits targeting feral species (McCaldin, Johnston, and Rieker 2015). RPAS also constitute an attainable low-cost alternative to assess and reduce the risk that hazardous facilities (Mulero-Pázmány, Negro, and Ferrer 2014; Lobermeier et al. 2015) and mechanical harvesting (Israel 2012; Christiansen et al. 2014; Israel and Reinhard 2017) pose to wildlife. Finally, direct observation and mapping of environmental correlates have been applied for epidemiological and zoonotic studies threatening wildlife and humans (Fornace et al. 2014; Barasona et al. 2014; Hardy et al. 2017), providing a rapid manner to inform prevention and reinforce biosecurity programmes.

### Impact of RPAS on wildlife and ecosystems

Animal welfare and perturbation of sensitive habitat in wildlife management and ecological research is source of strong debate (F. Dormann et al. 2007; Wilson et al. 2006). RPAS are not exempt of discussion and consequently disturbance effects of RPAS on birds (Duriez et al. 2015; McEvoy et al. 2016; Fletcher 2017; Scobie et al. 2016; Weissensteiner et al. 2015; Lyons et al. 2017) and mammals (Ditmer et al. 2015; Pomeroy et al. 2015) were mainly documented. Despite a greater degree of awareness reflected in a emergent set of guidelines (Hodgson et al. 2016; Mulero-Pázmány et al. 2017; Gonzalez et al. 2017), most of studies marginally inform reactions and further trials aimed at quantifying changes in behavioural patterns and physiological effects targeting a broader group of wildlife is recommended. Also, we believe that development of RPAS platforms suited to wildlife projects remain fundamentally unexplored. Furthermore, a trade-off between benefits and environmental costs should be weighted (Grémillet et al. 2012; Sepúlveda et al. 2010). By designing quieter, non-polluting and safer components, the impact on wildlife and ecosystems could be reduced and its objective observation facilitated (Jewell 2013; Wilson et al. 2006), reducing sources of bias. Nonetheless, RPAS has great potential to evolve, replacing more invasive monitoring techniques. This should be consciously considered by those reluctant to integrate RPAS in research and conservation activities. Step by step, a code of best practice and recommendations could be continuously updated based on lessons learned (McEvoy et al. 2016), forming the basis for wildlife certified RPAS operators.

## Habitat research and management

Remote sensing environmental changes on threatened ecosystems from RPAS has the potential to surpass spatio-temporal scale challenges from aerial and satellite earth observation (Whitehead et al .2014), at affordable cost and providing rapid, flexible and precise in-situ measurements (Gross et al. 2009) in a regular basis, and without being affected by cloud coverage (Ballari et al. 2016). Similarly, mapping and quantifying ecosystem services from RPAS constitute an efficient mean to inform site design and planning in PAs where otherwise data is scarce or based on coarse environmental correlates. RPAS can also serve to assess whether higher rates of ecosystem degradation (land cover clearing, habitat loss and fragmentation) occur on surroundings areas (Mas 2005; Ewers and Rodrigues 2008), providing a mean to inform effectiveness of PAs designation and management. Experimental monitoring projects using RPAS have increased notoriously both by governmental institutions (U.S. Geological Survey National 2017) and research groups, where RPAS have been used to inform on the distribution (Puliti et al. 2015), health (Näsi et al. 2015; Michez et al. 2016) , productivity (Tian et al. 2017) , composition (Franklin et al. 2017) , structure and biomass (Messinger, Asner, and Silman 2016; Bedell et al. 2017; Rödig et al. 2017) of forests using both passive and active sensors (Sankey et al. 2017). As a result, RPAS forestry applications to inventory, characterization and habitat restoration are maturing fast, but scaling-up and linking the information collected at local scales to relatively coarse remote sensing data covering greater extensions remain a knowledge gap (Adam M. Wilson et al. 2011). RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014), providing a novel mean to engage developing countries within the carbon market (Reducing Emissions from Deforestation and forest Degradation, REDD). Other contributions focus on measuring the spread of invasive species (Michez, Piégay, Jonathan, et al. 2016; Müllerová et al. 2017; Perroy, et al. 2017), mapping coastal marine habitats (Ventura et al. 2016), wetlands (Pande-Chhetri et al. 2017; Marcaccio, Markle et al. 2015), grasslands (Lu and He 2017; Wang et al. 2017), polar (Fraser et al. 2016; Malenovský et al. 2017) and riparian ecosystems (Husson 2016), representing a non-exhaustive list of different environments where RPAS have successfully operated.

## Law enforcement

Effective control and surveillance of illicit activities is considered an essential management measurement to maintain the integrity of threatened species and ecosystems (Hilborn et al. 2006). But difficulty of enforcement is especially patent in large PAs, where many species are on the verge of extinction due to illegal hunting, fishing, encroachment or habitat loss. RPAS constitute a technological advance to complement insufficient staff and resourcing in anti-poaching (Mulero-Pázmány et al. 2014; Franco et al. 2016; M. A. Olivares-Mendez et al. 2014; Shaffer and Bishop 2016) and other less contentious acts (Sabella et al. 2017; Weber and Knaus 2017). However, the lack of scientific articles proving the use of RPAS to combat poaching might be explained by technological shortcomings and legal constraints, in spite of attract considerable attention from environmental organizations and media. Relative low endurance of affordable platforms limits the area under surveillance, a major obstacle to cover large natural areas. Technical and operational deployment is a complex undertaking and issues concerning recognition of suspicious activity or flying in adverse weather conditions have not yet been completely resolved. Notwithstanding, meeting the optimal specifications can be considered costly, especially in developing countries (Banzi 2014). However, as technology increasingly will become more accessible and sophisticated, it is expected that main barriers will appear in the legislative and sociopolitical sphere. For instance, flying beyond the visual line of sight (BVLOS) or above a certain altitude is often forbidden, restricting the usefulness of the inspection. This highlights the urgent need to seek consensus among countries and adapt legislation to distinguish amongst the purpose of leisure, research and management. But ethical and social issues are also factors to bear in mind. Detractors are skeptical about the ability of RPAS to persuade offenders, who in many cases go through a situation of great need. (Duffy 2014) analyzed the consequences of the militarization of conservation practices as an increasing trend in PAs around the world and illustrates how RPAS and other technologies can contribute to human right breaching, compromising effective conservation through the lack of commitment of the communities (Sandbrook 2015). However, some studies have remarked that the effectiveness of antipoaching depends on a greater allocation of resources (Hilborn et al. 2006). For instance, vessel patrol are considered difficult and expensive, but the record of illegal fishing within the boundaries of marine protected areas may be considered a reliable evidence for the court, even when offenders are seized outside the no catchment area. 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.

## Ecotourism

Well-managed ecotourism serves conservation and brings socioeconomic benefits to local communities, stressing the need for environmental stewardship. On the contrary, it can also negatively affect animal welfare and their habitats (Samia et al. 2017). In the midst of the dilemma, RPAS have been proposed for recreational and educational purposes (King 2014; Chamata and King 2017), social research and visitor surveillance (Hansen 2016; Park and Ewing 2017). However, RPAS can also disturb wildlife, compromise tourist experience or lead to unexpected hazardous events in case of accidents, like water pollution or wildfires in sensitive areas due to the presence of toxic and flammable components. Subsequently, to restrain the uncontrolled presence of RPAS in PAs, stakeholders agreed on a set of policies to establish permitted activities in Antarctica (Leary 2017), opted for simpler rules and recommendations (OEH 2017) or, not without founded reasons, completely banned RPAS arguing safety reasons and wildlife impact (Peyer 2015). Even when the economic benefits and leisure possibilities are promising, undesirable events and a lack of ethical practise can fuel the low popularity of RPAS in detriment of the advantages they bring. Thus, it would be advisable to be cautious in the face of the demand of the ecotourism industry to incorporate RPAS within their promoted services and learn from others experience to evaluate the trade-off between the benefits and drawbacks they bring to PAs.

# Environmental management and emergency response

Anthropogenic disturbances, worsened by natural hazards are amid the most prevalent threats to maintain healthy and resilient ecosystem. Effectively managing PAs requires continuous monitoring of environmental indicators and physical parameters to ensure that potential sources of contamination are controlled or remain below a safety threshold and, if necessary, take corrective and restoration measures. In other cases, a rapid response is crucial to diminish the effects that natural and man-made disasters pose to natural resources and human being. Hazard risk assessment, planning and response are therefore essential measures to prevent and respond adequately to such circumstances. Although these actions are conventionally carried out in a combination of field work , airborne and satellite remote sensing , RPAS capabilities provide a valid alternative to remotely assist water, soil and air pollution sampling (Schwarzbach et al. 2014; Zang et al. 2012; Ore et al. 2015) and enable rapid image acquisition to monitor erosion (D’Oleire-Oltmanns et al. 2012), sediments dynamics (Casella et al. 2016, 2014), landslides (Jaukovic 2017), flood events (Izumida, Uchiyama, and Sugai 2016) oil spills (Messinger and Silman 2016) and wildfires (Cruz et al. 2016) at different stages. RPAS are also a valuable tool for rangers in search and rescue missions in the face of catastrophic scenarios (Cui et al. 2015), but also in remote mountainous (Karaca et al. 2017; Van Tilburg et al. 2017) and coastal marine regions. Such applications have operational requirements which eventually are costly. For instance, sophisticated on-board instruments, environmental sensors, advanced communications system, gas powered engines for longer endurance and heavier payloads or gear designed to assist sampling, hold cargo or deliver assistance. Besides, there are a variety of plausible scenarios where RPAS can demonstrate their usefulness, such assess damage in trails and amenities after natural hazard events, inspect facilities posing a risk to the environment (Gómez and Green 2017), or support plant invasion control by means of aerially deployed herbicide on target species (Rodriguez, Jenkins, and Leary 2017).

## Economic and technological factors

Expenses derived from the operation with RPAS are hardly quantifiable (AUVSI 2013) and depend on a confluence of factors. Although RPAS are relatively easy to operate, investment on technical and analytical expertise is not often adequately weighted. Computational requirements are demanding, big data storage options remain overpriced and certain phases of data processing requires the acquisition of commercial software or alternatively the recruitment of high-level specialized services. Also, operations with RPAS are not exempt from accidents thus having a negative impact on the budget originally planned. This is especially true with payload onboard, which is often the most expensive but also breakable part of the platform. Moreover, park rangers should be aware that there is no single solution covering all the conservation purposes (Koski 2010) and a trade-off analysis among available platforms should be pondered. While do-it-yourself (DIY) RPAS are often considered more versatile than commercial alternatives, further time is required for proper assembling and lack of experience could affect reliability. Suppliers often provide support, training and companion software, albeit services could be occasionally charged. On the other hand, environmental sensors and cameras deployed on RPAS collect massive amount of information, resulting in processing and methodological bottlenecks. When used for wildlife census, recurring to manual counting and identifying individuals is time consuming. Progress in computer vision and machine learning algorithms are intended to automate such procedures (Andrew and Shephard 2017; Chabot and Francis 2016; L. F. Gonzalez et al. 2016; Lhoest et al. 2015; van Gemert et al. 2015; Christiansen et al. 2014; Martin et al. 2012; Abd-Elrahman, Pearlstine, and Percival 2005; Longmore et al. 2017; Seymour et al. 2017). Despite encouraging results, these methods should be adapted to a broader range of species and probably implemented in more user-friendly packages. Also, further research should be encompassed to assess the overall performance of RPAS data collection techniques compared to more mature options where statistical and sampling methods to address the analysis and modelling of species distribution are available (J. C. Hodgson et al. 2016). Additionally, traditional pixel-based remote sensing algorithms for land-cover and vegetation classification are ineffective for ultra-high spatial resolution data from RPAS. As a result, machine learning techniques and object-based image analysis (OBIA) are likely to cope the next generation of classification methods (Whitehead and Hugenholtz 2014). The expected the arrival of hyperspectral miniaturized sensors (Pande-Chhetri et al. 2017), will bring more complexity to the matter, requiring novel analytical approaches not currently implemented. Conversely, the photogrammetric process is well documented and supported by a myriad of commercial software and emerging open source alternatives (Colomina and Molina 2014), probably at expense of major complexity.

## Protected Areas: Galapagos National Park and Doñana National Park

We wondered how RPAS can improve the effectiveness of management in two distinct, representative and well-known Unesco world heritage PAs in the world where RPAS have been successfully deployed (table 3): Ecuador’s Galapagos National Park (Ballari et al. 2016) and Doñana National Park (Mulero-Pázmány et al. 2015; Barasona et al. 2014; Schwarzbach et al. 2014; Mulero-Pázmány, Negro, and Ferrer 2013) in Spain. These PAs encompass universal conservation challenges, and constitute a perfect laboratory to undertake RPAS based pilot studies. In the case of Galapagos, threats and pressures to biodiversity are manifold, ranging from invasive and feral species, poaching (illegal fishing), tourism, overpopulation, overexploitation of natural resources, mining, climate change, natural hazards, roadkill, boat strikes and so on. Within management, search and rescue operations, emergency response, wildlife surveys, environmental assessment, forest health monitoring, restoring degraded ecosystems. Doñana N.P. suffer similar pressures and threats, but wildfires, marsh drainage, agriculture, and water pollution, aggravated by, have become a major concern to maintain the integrity of ecological process.

# Conclusions

We found that RPAS tailor to a wide range of circumstances matching critical management measures within protected areas. It would be desirable to conduct and report more proof-of-concept and integral studies within protected areas and assess effectiveness when RPAS are used in place of other conventional techniques. This require ponder socioeconomic factors, technological restrictions, wildlife impact, planning management, adequate resourcing and staff training. Moreover, unlike satellite remote sensing where global facilities exist, establishing a management framework for easy integration and exploitation of the data gathered from the platform remain fundamentally unexplored and implies a technological barrier for those remote PAs lacking an adequate infrastructure. Still, it is likely that in the next decade we get used to see RPAS flying on PAs performing essential tasks not currently unthinkable for most people.

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Table 1 Search terms

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| **Search Terms** |
| protected area, conservation, ecology, ecosystem, habitat, ecosystem, vegetation, forest, wetland, reforestation, monitoring, survey, sampling, inventory, wildlife, fauna, bird, mammal, fish, amphibian, reptile, wildfire, landslide, remote sensing, tourism, ecotourism, law enforcement, poaching, anti-poaching, logging, risk management, pollution, unmanned aircraft systems, UAS, remotely piloted aerial system, RPAS, drone. model aircraft, unmanned aerial vehicle, UAV, unmanned aircraft system, search and rescue, landslide, flood, multispectral, hyperspectral |
| **Search example** |
| "vegetation drone" OR "vegetation UAS" OR "vegetation UAV" OR "vegetation unmanned aircraft system" OR "vegetation unmanned aircraft" OR "vegetation RPAS" OR "vegetation radio control aircraft" |

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| Publication | Category | Aim | Target | Location | RPAS type | RPAS model | Payload |
| (A. Hodgson, Peel, and Kelly 2017) | Wildlife Research and Management | Assess proportion of whales detected | Humpback whale *Megaptera novaeangliae* | North Stradbroke Island (Australia) | Fixed-Wing | ScanEagle | Nikon D90, Standard Definition Electro- Optical Camera |
| (Kiszka et al. 2016) | Wildlife Research and Management | Estimate elasmobranchs density in coral-reef ecosystems | Blacktip reef shark *Carcharhinus melanopterus*, Pink whipray *Himantura fai* | Moorea (French Polynesia) | Rotor-wing | DJI Phantom II | GoPro Hero 3+ |
| (Habel et al. 2016) | Wildlife Research and Management | Aerial pictures to help identify micro-habitat | Common blue butterfly *Polyommatus icarus*, Adonis blue butterfly *Polyommatus bellargus* | Dietersheimer Brenne (Germany) | Rotor-wing | DJI Phantom II | GoPro Hero 4 Black |
| (Michez, Morelle, et al. 2016) | Wildlife Research and Management | Assess wildlife damage to crops | Wild boar *Sus scrofa* | Wallonia (Belgium) | Fixed-Wing | Gatewing X100 | Ricoh GR3 |
| (Lobermeier et al. 2015) | Wildlife Research and Management | Mitigate avian collision with power lines using markers | Birds | USA | Rotor-wing | Mikrokopter Hexa XL | BirdMark BM-AG |
| (Alvarez-taboada, Paredes, and Julián-Pelaz 2017) | Ecosystem monitoring | Mapping invasive plant using RPAS / RS following an object-oriented image analysis approach. | Needlebush *Hakea sericea* | Viana de Castelo, Portugal | Fixed-Wing | Ebee SenseFly | Canon IXUS 220 HS; Canon ELPH 300HS |
| (Messinger, Asner, and Silman 2016) | Ecosystem monitoring | Monitoring of aboveground carbon density for ecological studies and payment for ecosystem services ventures. | Lowland Tropical Forest | Los Amigos Biological Station, Peru | Fixed-Wing | Kestrel | Canon S110 |
| (Murfitt et al. 2017) | Ecosystem monitoring | Compares UAV remote sensing / on-ground monitoring surveys; explain observed intertidal algal and invertebrate assemblages from geomorphological features. | Intertidal reefs | Pickering Point, Shelly Beach, Point Lonsdale, Point Lonsdale, Australia | Rotor-wing | Swellpro Splashdrone | Canon D30 |
| (Weber and Knaus 2017) | Law enforcement | Detect human winter activities in threatened wildlife in sensitive mountain areas | capercaillie (Tetrao urogallus) | Entlebuch Biosphere Reserve, Switzerland | Fixed-wing | Maja-D | Canon SX260HS, GoPro 3 |
| (Mulero-Pázmány et al. 2014) | Law enforcement | Monitor poaching activities | Black rhinocero (Diceros bicornis), white rhinocero (Ceratotherium simum) | KwaZulu-Nata (Africa) | Fixed-wing | Easy Fly St-330 | Panasonic Lumix LX-3, GoPro Hero2; Thermoteknix Micro CAM |
| (M. Olivares-Mendez et al. 2015) | Law enforcement | Detection and tracking of animals and poachers | White rhinocero (Ceratotherium simum), elephant (Loxodonta africana), human (Homo sapiens) | Africa | Rotor-wing | AscTec Firefly | UEye UI-1240ML-C-HQ |
| (Shaffer and Bishop 2016) | Law enforcement | Methods for identifying high risk elephant poaching areas and modeling drone surveillance capabilities | African elephant (Loxodonta africana), | Tsavo NP, Kenya | Fixed-wing | RQ-84Z AeroHawk | FLIR Tau 2 640 |
| (Park and Ewing 2017) | Ecotourism | Measure park-based physical activity | Park users | Neighborhood parks Lake City, Utah | Rotor-wing | DJI Phantom 3 Advanced | Sony EXMOR |
| (Van Tilburg et al. 2017) | Enviromental management and emergency response | Search and Rescue | Park users | Columbia Gorge National Scenic Area, Oregon | Rotor-wing | DJI Phantom 3 | Sony EXMOR |
|  | Enviromental management and emergency response |  |  |  |  |  |  |
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Table 3. Threats and potential RPAS applications to Protected Areas. Adapted from (Leverington et al. 2010; Safety 2016)

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| **Galapagos National Park** | | | |
| **Threats** | **Galapagos National Park** | **Doñana National Park** | **RPAS** |
| **Residency and commercial development**  Dwelling and human settlement , Commercial and industrial areas, Tourism and recreation, Agriculture and aquaculture in the protected area, Annual and other crop cultivation, Animal husbandry, Aquaculture – fishing, fish farming, and farming of other river organisms | Tourism and recreation, Agriculture and aquaculture in the protected area, |  |  |
| **Mining and energy production**  Extraction of coal, oil, and gas  Exploitation of mineral raw materials  Energy production, including hydropower stations | Exploitation of mineral raw materials |  |  |
| **Transportation network, infrastructure**  Roads and railroads  Communication infrastructure and services (e.g. power lines, telephone lines, etc.)  Numerous canals and locks  Air traffic  Roadkill | Boat strike(sea turtles), roadkill (birds) | Roadkill (birds, mammals), Communication infrastructure and services | Wildlife risk assessment, identifying hot spot areas of accidents (death birds, species distribution and density), ecological corridors, awareness |
| **Use of biological resources and damage**  Hunting, killing, and collection of land animals (includes killing of animals due to conflicts between humans and wild animals)  Collection of land plant species and related products  Deforestation and woodsmanship  Fishing and exploiting aquatic wildlife | Deforestation and woodsmanship  Fishing and exploiting aquatic wildlife  Deforestation frequent on the past, mangrove lost, human-galapagos conflict persists, fish overexploitation, illegal fishing (sharks) | Hunting | Law enforcement, surveillance, record suspicious activity. Monitor deforestation rates |
| **Impact of humans and disturbance**  Tourism and recreational activities  War activities, military exercises, etc.  Research, educational, and other activities in the protected area  Activities of the protected area manager (e.g. construction, use of vehicles, artificial dams, etc.)  Vandalism and other forms of destructive activity affecting the protected area, the managing structure, or the visitors | Tourism and recreational activities  War activities, military exercises, etc.  War activities, military exercises, etc  Vandalism and other forms of destructive activity affecting the protected area, the managing structure, or the visitors |  | Law enforcement, surveillance, aerial surveys for exploring sensitive areas, virtual tourism, tourist infrastructure assessment, educational programs , community engagement |
| **Natural system modifications**  Fires and fire prevention  Dams, modifications of water surfaces, water management, and water use  Increased fragmentation within the protected area  Isolation from other natural habitats (e.g. deforestation, dams without proper passages for aquatic life, etc.)  Other “borderline” effects on the area’s values  Loss of keystone species (e.g. apex predators, pollinators, etc.) | Fires and fire prevention  Dams, modifications of water surfaces, water management, and water use |  |  |
| **Invasive / Feral species**  Invasive introduced plant species or their seed  Invasive introduced animal species  Pathogenic microorganisms (introduced or native, but causing new problems / increased detrimental effect)  Introduced genetic material (e.g. genetically modified organisms) | Invasive introduced plant species or their seed  Invasive introduced animal species  Pathogenic microorganisms (introduced or native, but causing new problems / increased detrimental effect) |  |  |
| **Pollution** |  |  | Enviromental assessment, sampling pollution, monitoring |
| **Geological events** |  |  |  |
| **Climate change and extreme weather conditions** |  |  |  |
| **Specific cultural and social threats** |  |  |  |

