

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

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Over the past decade, we have witnessed a growing interest in projects aimed to evaluate the feasibility of RPAS for conservation purposes, including environmental and wildlife monitoring or law enforcement. Beside legal, ethical, technical and methodological barriers hindering the potential of RPAS to deliver a wide range of benefits to protected areas, it remains to be seen whether research attends the needs demanded by natural park managers. A bibliographic survey was conducted to value the current state of RPAS in the scope of protected areas, and how they can support conservation actions aimed at reducing threats to biodiversity and strengthen effective management. We found multiple facets of application, but common factors impeding the consolidation of RPAS within protected areas remain.

Keywords: protected areas, RPAS, conservation, effective management, threats

Introduction

As defined by UICN, "a protected area is a clearly defined geographical space,

recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (Dudley 2008). Protected areas (PAs) have been declared under different reasons and circumstances but there is a consensus on its importance in safeguarding biodiversity, preserving ecosystem services and ensure persistence of the natural heritage (Watson et al. 2014; Chape, Spalding, and Jenkins 2008). Despite such praiseworthy intentions, PAs are 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 Carroll 2006) . To curb the loss of biodiversity while attending other inherent activities, financial allocations have targeted, among others, staff recruitment and training, infrastructure and equipment, planning, communication programs, tourism and recreational activities, law enforcement, support decision-making and disaster management, biodiversity monitoring, environmental assessment research and educational programs. Moreover, conservation in PAs have benefit from a wide range of technological advances, methods or innovative application of existing technologies, including remote sensors, field-based monitoring stations, manned surveys, camera trapping, wildlife tracking devices and computing resources (Pimm et al. 2015).

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, with conservation projects representing a major trend 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 potential 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 within the spectrum of management activities and . Examples are provided 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. We found that RPAS applications for wildlife research and habitat monitoring are suitable to track species and ecosystems responses to management. Nevertheless, other potential applications such law enforcement have ostensibly received minor attention from the academia, despite hunting, logging and fishing, being considered as a major threat globally (Leverington et al. 2010).

revealed that “adequacy of infrastructure, equipment and facilities” was among the closer management indicator related to overall effectiveness, while “biological resources use”, including

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 references revised were 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 threats and conservation measurements in PAs (table 1) using logical disjunctions. Next, 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). After removing duplicated and spurious results, a total 377 articles were selected and grouped according to the following interrelated categories: “wildlife research and management”, for studies tackling alternative fauna surveys and measures to mitigate human-wildlife conflicts; “Ecosystem monitoring”, regarding methods to map invasive species, health forest monitoring and ; “Law enforcement” comprise poaching and other illicit activities surveillance; "Ecotourism" is restricted to recreational activities and visitors management ; “Environmental management and emergency response" span from environmental monitoring and assessment, anthropogenic and natural based disasters to search and rescue activities. Common challenges to above categories are briefly summarize within legal constraints, RPAS impact on wildlife and ecosystems, operational costs and technological issues, since all shape the feasibility of integrating RPAS within PAs activities. Recent studies are displayed (see table 2), identifying the location, the expected accomplishments and technical specifications of the aerial platform. We finally exposed a concise analysis of potential RPAS applications to mitigate threats and complement management in two recognized PAs in the world (table 3).

Results and discussion

Wildlife research and management

Monitoring is essential to track the response of wildlife to management, and assess whether further measurements are required . In this field, RPAS have mostly been applied for abundance and distribution studies targeting large and medium size terrestrial mammals (Jain 2013; Barasona et al. 2014; Stark et al. 2017; Chrétien, Théau, and Ménard 2016), birds (A. M. Wilson, Barr, and Zagorski 2017; J. C. Hodgson et al. 2016; Christie et al. 2016; Sardà-Palomera et al. 2012; Chabot and Bird 2012; Ratcliffe et al. 2015) , fishes (Groves et al. 2016; Kiszka et al. 2016), species relying on coastal and marine ecosystems (Colefax, Butcher, and Kelaher 2017; A. Hodgson, Peel, and Kelly 2017; W. R. Koski et al. 2015; Dulava, Bean, and Richmond 2015; Durban et al. 2015; W. R. Koski et al. 2009). but also to inspect breeding and nesting areas at inaccessible sites (Szantoi et al. 2017; Wich et al. 2016; Puttock et al. 2015; van Andel et al. 2015; Weissensteiner, Poelstra, and Wolf 2015) or as a complement for wildlife telemetry tracking methods (Christie et al. 2016; Bayram et al. 2016; Mulero-Pázmány et al. 2015; Körner et al. 2010; Cliff et al. 2015; Ordóñez-Delgado et al. 2016; Soriano, Caballero, and Ollero 2009; Xu et al. 2016). Authors mostly coincide on the broad potential of RPAS to complement surveys, traditionally carried out by ground-based crews, terrestrial vehicles, manned aircrafts or vessels. As becoming easier to operate, there are sufficient grounds to instruct rangers on the use of RPAS, who are often subject to time-consuming and often dangerous raids. If appropriate safety measures are taken, RPAS might be considered a less invasive, nonhazardous and reliable monitoring technique (Jewell 2013) compared with other methodologies requiring approaching, capturing or indirectly disturbing wildlife.

RPAS also constitute an attainable low-cost alternative to manually inspecting hazardous facilities and detecting ground nest or vulnerable species at agricultural fields where mechanical harvesting pose risk of death (Barasona et al. 2014; Lobermeier et al. 2015; Christiansen et al. 2014; Israel and Reinhard 2017; Mulero-Pázmány, Negro, and Ferrer 2014). Human-wildlife conflicts are also present both in PAs and nearby locations as result of increasingly pressures. 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). Without going into debate, some park managers could contemplate the adoption of RPAS for wildlife capture procedures, through devices adapted to release tranquilizing darts where otherwise manual approaching free-range animals is often considered ineffective, biased or dangerous.

Ecosystem monitoring

Deployment of RPAS to inform adaptive management has the potential to complement aerial remote sensing and earth observation (EO), surpassing spatio-temporal scale challenges at affordable cost and providing rapid and precise in-situ measurements (Gross, Goetz, and Cihlar 2009). Ecosystem mapping and monitoring projects using RPAS have increased notoriously both by governmental institutions (U.S. Geological Survey National 2017) and research groups. Studies on this topic range from quantifying the spread and detection rate of invasive species (Müllerová et al. 2016; Zaman, Jensen, and McKee 2011; Perroy, Sullivan, and Stephenson 2017; Müllerová et al. 2017; Michez, Piégay, et al. 2016), analyze the dynamic, structure and biophysical attributes of forest

stands (Gini et al. 2012; Zahawi et al. 2015; Lisein et al. 2015; Kachamba et al. 2016; L. F. Gonzalez et al. 2016; Zhang et al. 2016; Getzin, Nuske, and Wiegand 2014; Getzin, Wiegand, and Schöning 2012; Ivosevic, Han, and Kwon 2017; Stark et al. 2017) or mapping sensitive shallow coastal habitats (Ventura et al. 2016; Casella et al. 2017) , wetlands (Chabot and Bird 2013), grasslands (Lu and He 2017; Wang et al. 2017), polar environments (Fraser et al. 2016) and riparian ecosystems (Husson 2016). Considering that “Involvement of communities and stakeholder” is moderately correlated to effective management in PAs, it is fortunate that RPAS has also been suggested as an appropriate tool for community-based forest monitoring (Paneque-Gálvez et al. 2014). Moreover, RPAS can play a fundamental role on actions aimed to evaluate efficiency of PAs compared to buffer zones and surroundings where it is assume that higher rates of ecosystem degradation occur (Ewers and Rodrigues 2008). Despite undeniable progress, efforts to design standardized RPAS based surveying protocols remain fundamentally unexplored.

Law enforcement

RPAS also have their place in the control and surveillance of illicit activities, ranging from campfires, logging, fishing, unauthorized wells, sewage and waste water spills, mining, encroachment, vandalism, poaching (Mulero-Pázmány et al. 2014; Franco et al. 2016; M. A. Olivares-Mendez et al. 2014; Shaffer and Bishop 2016) to other less contentious acts (Sabella et al. 2017; Weber and Knaus 2017). In spite of the relevance on environmental organizations and media, the lack of scientific articles probing the use of RPAS to combat poaching might be explained by technological shortcomings and legal constraints. Relative low endurance of affordable platforms limits the area under

surveillance, a major obstacle to cover large natural parks. 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. Moreover, 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. 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). Moreover, registering forbidden activities, such illegal fishing within the limits of marine parks, can prove to be valid evidence against offenders, even when they were seized outside the no catchment areas. 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

Within the still scarce literature (King 2014) summarized possible recreational

activities and formulas for granting RPAS flight permits in designated areas. (Hansen 2016; Park and Ewing 2017) valued the effectiveness of RPAS to monitor visitors activities in PAs and (Chamata and King 2017) proposed possible profitable concession scenarios. Stakeholders agreed on a set of policies to establish permitted activities with RPAS within tourist locations in Antarctica (Leary 2017). Other PAs opted for simpler rules (OEH 2017) or, not without founded reasons, completely banned RPAS arguing safety reasons and wildlife impact (Peyer 2015). Accidents could lead to unexpected hazardous events, like water supply pollution or wildfires in sensitive areas due to the presence of toxic and flammable components. Even when the economic benefits and leisure possibilities are promising, it would be advisable to be cautious in the face of the demand of the ecotourism industry to incorporate RPAS in their activities, as undesirable events can fuel the low popularity of RPAS in detriment of the advantages they bring.

Environmental management and disaster response

RPAS has been adapted for remotely sensing pollution and air / water quality measurements (Schwarzbach et al. 2014; Zang et al. 2012; Ore et al. 2015), mapping environmental risk factors for predicting zoonotic diseases (Fornace et al. 2014), erosion and sediments dynamics (Casella et al. 2016, 2014) and natural hazards assessment and emergency response, including landslides (Jaukovic 2017), volcanic activity, flood events (Izumida, Uchiyama, and Sugai 2016), wildfires (Cruz et al. 2016) or assist in search and rescue missions (Van Tilburg et al. 2017). Such applications have operational requirements which eventually are costly. For instance, sophisticated on-board instruments, environmental sensors, gas powered engines for longer endurance and higher payloads or gear designed to assist sampling, hold cargo or deliver assistance. Plausible scenarios

include automate procedures to assess damage in trails and amenities after natural hazard events, assist human-based environmental disaster prevention (Gómez and Green 2017), or support plant invasion control by means of aerially deployed herbicide on target species (Rodriguez, Jenkins, and Leary 2017).

Current Challenges

Legal barriers and ethical constraints

RPAS operations faces important social and legal barriers that undermine their true potential in the civilian sphere (Stöcker et al. 2017; Sandbrook 2015). An overly restrictive regulatory framework is currently limiting the applications of RPAS in the field of conservation and their use has not been without problems, resulting in governments that have totally or partially prohibited RPAS operations in PAs. This highlights the urgent need to seek consensus among countries and adapt legislation to distinguish amongst the purpose of leisure, research and management.

Impact of RPAS on wildlife and ecosystems

Animal welfare and perturbation of sensitive habitat in wildlife management and ecological research is source of strong debate (F. Dormann et al. 2007; R. P. Wilson and McMahon 2006). RPAS are not exempt of discussion and consequently disturbance effects of RPAS on birds (Duriez et al. 2015; McEvoy, Hall, and McDonald 2016; Fletcher 2017; Scobie and Hugenholtz 2016; Weissensteiner, Poelstra, and Wolf 2015; Lyons et al. 2017) and mammals (Ditmer et al. 2015; Pomeroy, Connor, and Davies 2015) were mainly documented. Despite a greater degree of awareness reflected in a emergent set of guidelines (Hodgson and Koh 2016; Mulero-Pázmány et al. 2017; Gonzalez and Johnson 2017), most

of studies marginally inform reactions and further trials aimed at quantifying changes in behavioral 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, an optimal trade-off between benefits and environmental costs should be weighted (Grémillet et al. 2012; Sepúlveda et al. 2010). By designing quieter, non-polluting and safer components, the impact on wildlife and ecosystems could be reduced and its objective observation facilitated (Jewell 2013; Wilson and McMahon 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, Hall, and McDonald 2016), forming the basis for wildlife certified RPAS operators.

Costs of RPAS operation

From the economic point of view, expenses derived from the operation with RPAS are hardly quantifiable (AUVSI 2013). While RPAS are relatively easy to operate, investment on technical and analytical expertise is not often adequately weighted. Computational requirements are demanding, big data storage options remain a challenge and certain phases of information processing requires the acquisition of pricey commercial software or alternatively the recruitment of high-level specialized services. Also, operations with RPAS are not exempt from accidents affecting both the structural components and payload, thus having a negative impact on the budget originally planned. Moreover, park rangers should be aware that there is no single solution covering all the conservation

purposes (W. Koski 2010) and a trade-off analysis among available platforms should be pondered. While do-it-yourself (DIY) RPAS are often considered more versatile than commercial alternatives, 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. Furthermore, coupled sensors are often the more expensive but also breakable parts of the platform. Despite these drawbacks, RPAS are increasingly being considered a cost-effective and safer alternative to manned aircraft and brings advantages to both ground surveys and satellite remote sensing .

Technological issues

Environmental sensors and cameras deployed on RPAS collect massive amount of information, resulting in storage, processing and methodological bottlenecks. When used for wildlife census, recurring to manual counting and identifying individuals is time consuming. Progress in computer vision and machine learning algorithms are intended to automate such procedures (Andrew and Shephard 2017; Chabot and Francis 2016; 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. On the other hand, traditional pixel-based remote sensing algorithms for land-cover and vegetation classification are ineffective for ultra-high spatial resolution data from RPAS, and machine learning techniques and object-based image analysis (Piragnolo, Masiero, and Pirotti 2017) are expected to cope the next generation of classification methods, especially under the upcoming arrival of new high spectral resolution sensors *cita* . Also, further

research should be encompassed to assess the overall performance of RPAS data collection techniques compared to more mature options where statistical and sampling methods to address the analysis and modeling of species distribution are available cita. Conversely, the planning phase and photogrammetric process is guaranteed from both commercial software and emerging open source alternatives (Duarte et al. 2017). probably at expense of major complexity. Unfortunately, weak performance of “adequacy of staff training” has been negatively correlated to effective management, thus diminishing the applicability of RPAS in PAs. As a consequence, efforts should be driven to facilitate the use of technology and knowledge transfer.

Protected Areas: Galapagos National Park and Doñana National Park

We wondered how RPAS multiple capabilities can improve the effectiveness of management in two distinct, representative and well-known 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, geohazards, roadkill, boat strikes. Within management search and rescue, emergency response, wildlife surveys, environmental assessment, forest health monitoring, restoring degraded ecosystems. Regarding Doñana N.P.

Conclusions

Park managers demands practical, cost-effective and innovative solutions to handle an overwhelming amount of environmental issues requiring appropriate decisions. 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. However, being a relatively young discipline, conservation RPAS have gone far and have great potential to evolve and raise better-informed decisions to cope with underlying pressures PAs face.

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Table 1 Search terms

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
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"

Table 2. Examples of studies reviewed classified according to goals

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 <i>Megaptera novaeangliae</i>	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 <i>Carcharhinus melanopterus</i> , Pink whipray <i>Himantura fai</i>	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 <i>Polyommatus icarus</i> , Adonis blue butterfly <i>Polyommatus bellargus</i>	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 <i>Sus scrofa</i>	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 <i>Hakea sericea</i>	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	Intertidal reefs	Pickering Point, Shelly Beach, Point Lonsdale, Point	Rotor-wing	Swellpro Splashdrone	Canon D30

		from geomorphological features.		Lonsdale, Australia			
(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

Table 3. Threats and potential RPAS applications to Protected Areas. Adapted from (Leverington et al. 2010; Safety 2016)

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			
Mining and energy production Extraction of coal, oil, and gas Exploitation of mineral raw materials Energy production, including hydropower stations			
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 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			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.)			
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)			

