**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 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. A bibliographic survey was conducted to value the current state and trends 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, 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, including satellite remote sensing, field-based monitoring stations, manned surveys, camera trapping, wildlife tracking devices or 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 to get a snapshot of the current state and general trend on the discipline from both point of views. We found that RPAS applications for wildlife research and habitat monitoring are suitable to track species and ecosystems responses to management, but requires accounting for operational challenges and further assess realistic scenarios to be fully implemented in PAs. Other facets, such surveillance of illicit activities have ostensibly received minor attention from the academia, despite poaching and other forms of biological resource use being observed as a major threat to biodiversity (Leverington et al. 2010). In addition, RPAS has ostensibly been applied for attending other potential activities within PAs, ranging from emergency response and hazard risk assessment, wildfires, pollution monitoring and ecotourism, completing a list of conceivable scenarios.

# 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 (table 2) and grouped according to the following interrelated categories: “wildlife research and management” (102), for projects aimed at quantifying distribution and density 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 assessment, planning, monitoring and evaluation, response to natural and man-made disasters to search and rescue activities. 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. 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).

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 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, proof-of-concept methodologies have been applied for mapping epidemiological environmental and zoonic vector correlates

### 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, 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 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 and precise in-situ measurements (Gross et al. 2009) in a regular basis, and without being affected by cloud coverage (Ballari et al. 2016). Moreover, mapping and quantifying ecosystem services from RPAS constitute a cost-effective 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 Assessing protected area effectiveness using surrounding (buffer) areas environmentally similar to the target area (Ewers et al. 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 pasive and active sensors (Sankey et al. 2017). As a result, RPAS forestry applications to inventory and characterization of such ecosystems are maturing fast, but scaling-up the information collected at local scales to relatively coarse remote sensing data 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).

## Law enforcement

Effective control and surveillance of illicit activities is considered an essential management measurement to maintain the integrity of threatened species and ecosystems. But difficulty of enforcement has been patent in many PAs. RPAS constitute a technological advance to complement insufficient staff allocation 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 probing the use of RPAS to combat poaching might be explained by technological shortcomings and legal constraints, in spite of attracted 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 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. 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). 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. This might turn enforcement of PAs effective, particularly in remote marine sites where patrol vessels is difficult and expensive. 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

As part of routinely activities of PAs, quality

Humanitarian drone

RPAS has been adapted for remotely sensing pollution and air / water quality sampling (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

### Economic and technological factors

Expense 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 (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. Moreover, 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). But, 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. As a result, novel machine learning techniques and object-based image analysis (OBIA) are expected to cope the next generation of classification methods, especially under the upcoming arrival of minituarized hyperspectral sensors (Pande-Chhetri et al. 2017), until recently only available to satellite platforms. 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). Conversely, the 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 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.

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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 |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |

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

|  |  |  |  |
| --- | --- | --- | --- |
| **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** |  |  |  |

