Application of Unmanned Aerial Systems (UAS) in wildlife conservation

Stef Brands [1]

Supervisor: Charlotte K. Hemelrijk[1]

[1]Faculty of Mathematics and Natural science, University of Groningen

July 25, 2016

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 SUMMARY

In the recent decade Unmanned Aerial System (UAS), an aircraft that harbors no crew, advanced substantially, so that conservationists can use small affordable UAS in their work. There is a lot of variation in UAS design, e.g. in their size (19 grams to 4500 kg) or mode of transportation (e.g. rotor-based and fixed wing based). UASs can be equipped with cameras (photo, video or thermal (infrared)), scientific instruments (e.g. barometer) and autopilot systems.

In this essay, I looked at four conservation projects, pioneering the use of UASs. I looked at how they used UASs, what challenges they encountered and what the future might bring. The project topics are: preventing bird mortality on power lines, countering rhinoceros poaching, surveying tropical forests, and UASs as an alternative prey in falconry (rofalconry).

Small affordable UAS can be equipped with cameras to shoot high quality images from a height that does not disturb the wildlife below. This makes is possible to monitor the environment very efficiently, systematically and cost effective. This is relevant for conservationists for mapping species abundance and movements or use it as an effective camera platform to monitor human activity (e.g. poachers or illegal wood cutting). Furthermore, a company in Great Britain designed an UAS that mimics a 2 kg prey bird, which can withstand a stooping falcon. This may provide falconers with an alternative type of prey.

There are still some constraints in using UASs. There is a lack of good legislation in many countries, especially concerning flying UAS beyond vision range and there are many no-fly zones, mainly around airports. Furthermore, many designs need favorable weather conditions; most UASs can't handle rain or strong winds.

2 INTRODUCTION

2.1 What are unmanned aerial systems?

An Unmanned Aerial System (UAS) is a flying machines that harbors no crew; i.e., piloted by remote control or with an onboard navigational computer [30]. Although, ballistic and cruise missiles fall under this definition, they are not regarded as UASs. An UAS does not exist solely of the machine in the air, another part consists of the ground personnel and supporting equipment on the ground: e.g. a control station, and communication/navigational systems. Furthermore, the UAS has a payload, defined as the carrying capacity of the UAS measured in terms of weight, this may include cargo, optionally extra fuel or equipment used for its mission, e.g. scientific instruments, a video/photo camera or a thermal camera.

The term "Unmanned Aerial System" is the official name adopted by most national and international aviation agencies (e.g. Federal Aviation Association (FAA) in the USA[2]) and the aviation industry. In the past the official term was Unmanned Aerial Vehicles (UAV) instead of Unmanned Aerial System (UAS), only UAV seems to refer solely to the flying machine itself and not the whole system. Another term sometimes used is Remotely-Piloted Aircraft System (RPAS), which refers to an UAS with a pilot remotely steering the aircraft. RPAS was introduced to settle a misunderstanding, that no person is controlling the aircraft in case of an emergency.

While the experts and authorities used the term UAS, the general media started to use the term “drones”, and drones became the common lexicon in the general public. At first, drones only concerned UASs used in the military; later people started ascribing smaller “civilian” UASs as drones as well. Although, some experts argue that the term should only be used for military systems. These experts [35, 6] argue that the general public associates drones with their intensive military use, e.g. killing civilians in war zones, giving the term “drones” a bad reputation.

Others argue [6], that drones is a great term to use, since it is a short and catchy term, globally recognized, and it is already well established in the common lexicon. Furthermore, pro-drone experts predict the civilian industry of UASs will expand and broaden, shifting the association with drones from military to civilian applications.

UAS advantages

The original idea behind UAS was to substitute manned aircrafts and for performing dangerous, strenuous and repetitive tasks. This makes UASs ideal for so called 3D-missions (dull, dirty or dangerous) [35, 26]. A big disadvantage in using manned aircrafts is the significantly higher costs compared to UASs. Manned aircraft costing hundreds of dollars per survey hour [25], while UAS costs about $ 0.20 per hectare or $ 50 per hour (excluding pilot costs) [51]. Manned aircrafts are more expensive due to personnel (pilot, ground crew), starting from an airport before moving to the survey area and getting the aircraft ready for flight. Next, local weather conditions at the airport itself might restrict use of manned aircrafts, like fog, rainy or cold weather; while UASs can take off and land virtually anywhere and are not hindered by local weather conditions.

One difficulty associated with aircrafts is the geospatial accuracy of the required data and survey repeatability [51]. Meaning that its difficult to fly an exact course with an airplane or helicopter, manned or not, even small navigational errors might have a large effect on the accuracy of aerial surveys. One option to improve the geospatial accuracy is to use an autopilot system; a computer system controlling the system without a human operator. With a computer program and a geographic positioning system (GPS), the operator sets a pre-programmed flight plan with way-points on a map [25]. Autopilot systems are expensive (> $400,000) for manned aircrafts compared to UASs, and this discourages widespread implementation for manned aircrafts. A small UAS with autopilot systems can be bought for less than $2000. Furthermore, there is a large open source community, mainly model plane hobbyist, producing autopilot systems and they get better every year.

Manned aircrafts use a lot of space to accommodate the pilot and perhaps a crew, this means UASs are a lot smaller, more maneuverable, make less noise and are more aerodynamic (fuel efficient) than manned aircrafts. Being smaller and more maneuverable gives the user more options, flying in areas that manned aircrafts can't reach, e.g. in forests and caves. Furthermore, UASs can fly at lower speeds and altitudes than manned aircrafts, without risking crashing. Crashes by small manned aircrafts is a leading cause of work-related mortality among wild life researchers [52].

UAS use

Most UASs (90%) at this time are in use by armed forces, for exploration or as a weapon delivery system. Civilian UASs have more diverse possibilities for utilization[10], shown in table 1.

In environmental research UASs are integrated in large scale projects [39, 53], mainly executed by National Aeronautics and Space Administration (NASA) or National Oceanic and Atmospheric Administration (NOAA)). These projects use large or medium sized UASs, priced over 100,000€ including payload, with large operating ranges and high endurance (> 4 hours flight time), like the global hawk (table 2), with its payload consisting of advanced sensors. These expensive UASs were used in numerous diverse research topics, most related to earth science, some topic examples are: climate change, atmospheric research (chemistry & meteorology), glacier and ice sheet dynamics, arctic and antarctic exploration, and landfall and physical oceanography [35, 39, 38].

Universities and research centers mostly use UASs in local projects to get an aerial perspective on already in progress research, the most common topics are wildlife surveys and habitat characterizations [35, 1, 23, 51, 16, 32, 3]. Local scale project have a lower budget and therefore use mostly small UASs (table 1), with a small operating range and low endurance. The payloads are more affordable, generally RGB photo/video cameras or thermal sensors, sometimes meteorological equipment, pyranometers, radiometric sensors, or small radiometers. These UASs are usually flown by individuals that followed a piloting training course.

Table 1: Civilian use of UASs [10].

Use	Examples
Commercial	Transportation (e.g. mail), aerial surveillance
Media	Sports, filming industry
Oil/gas exploitation	Finding oil and mineral deposits
Disaster relief/ medical applications	Finding victims, transporting medical cargo
Research	Archeology, weather/climate, environment
Security & law enforcement	Coastal patrol, border surveillance, public protests, drug plantations detection
Environmental monitoring:	Wildlife census, animal tracking
Land management:	Forest fire management
Agriculture	Productivity assesments, crops spraying

Figure 1: The first radio-controlled unmanned aerial vehicle, created by the British Royal flying corps at the Ruston proctor works. A small monoplane powered by a two-cylinder ABC Gnat engine of 35 horsepower. Radio guidance equipment was developed and installed on the design. [50]

2.2 History of Unmanned Aerial Systems

The first unmanned aerial vehicles were used in 1849 by the Austrian army, attacking the Venice republic by dropping bombs with unmanned aerial balloons. Although, the Austrians were unable to control these balloons and some were caught in a change of wind and blown back over Austrian lines. The first real advances of UAS technology are attributed to Nikola Tesla, granted a patent [48] in 1898 for controlling mechanisms of vehicles. In 1915, Tesla described fleets of armed, pilotless aircraft. During the great war, the first radio controlled unmanned aerial vehicles were designed and tested (Figure 1), intended to be used as aerial torpedoes, although these aircraft never made it past the testing phase. In the second world war UASs were used as radio controlled torpedo and for surveillance missions. Later, during the Vietnam war UASs acquired a new role of stealthy surveillance. These air-launched airplanes were coated in anti-radar paint and their fuselage sides were covered by radar absorbing blankets. After their surveillance mission, the UASs parachuted down in a safe recovery area [40].

During the 1970s, the USA and Israel started experimenting with UASs that were smaller, slower, cheaper and could send images in real time [10]. This is seen as the start of the modern UAS era. In the 1980s and 1990s, there was a heavy focus on research and development of UASs by the USA, Israel and European countries, increasing their range and lowering the costs, size and radar-signature [40]. From the 1980s, UASs proved to be vital in all armed conflicts in which they were implemented, e.g. Kosovo in 1999, Afghanistan since 2001 and Iraq since 2003. Well known examples are the "Predator", "Evolved reaper" and the "Global hawk".

In the last decade, UAS technology has advanced substantially; manufactures of UASs started producing smaller and more affordable designs, ideal for the civilian market. When opening UASs to the civilian market, model plane hobbyists started to incorporate other equipment to their small civilian UASs, such as radio frequency amplifiers, video cameras, stabilizing systems, GPS and autopilots. The civilian enthusiasm into UASs led to an expanding industry. A study [46] performed in 2014 calculated the UAS market at 11% civilian and 89% militarily, with it growing to 14% civilian within the next decade. UASs seem to have a bright future ahead, with the capabilities of UASs only limited by human imagination.

2.3 Different types of Unmanned Aerial Systems

There is a lot of variation in UAS design (figure 2), allowing for a wide variety of uses [1, 35]. The best way to represent this wide diversity is to classify UASs, first based on their maximum-gross take-off weight, and

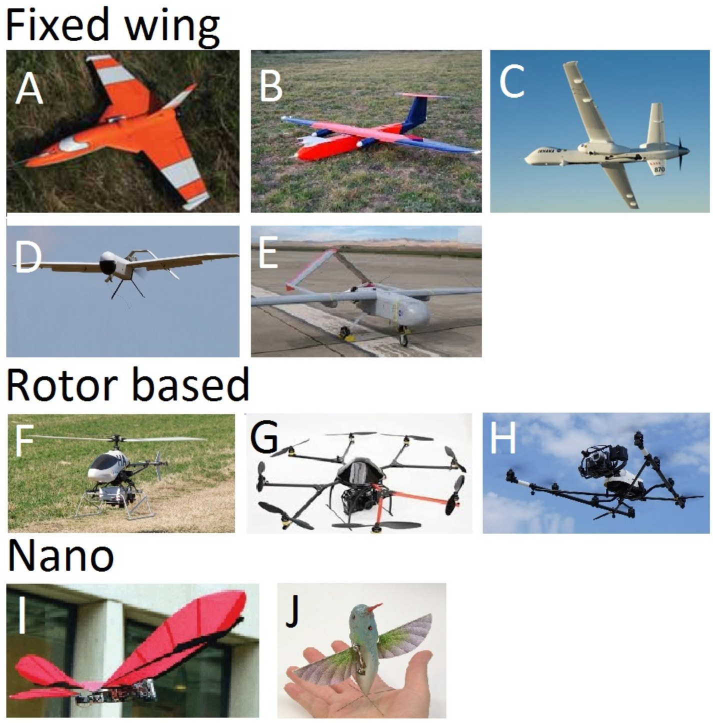

Figure 2: Some examples of UASs [1]: A. SUMO (Length: 75cm, Wingspan: 80cm, Weight: 580g) [42], B. M2AV Carolo (Wingspan: 2m, Weight: 4.5kg) [31], C. NASA Ikhana (Length: 11m, Wingspan: 20m, Weight: 4763kg) [8], D. BAT-3 UAV (Wingspan: 183cm, Weight: 10kg) [18], E. NASA Sierra (Length: 3.61m, Wingspan: 6.1m, Weight: 202kg) [11], F. CSIRO Autonomous Helicopter System (Rotor diameter: 1.78m, Weight: 12.3kg) [33], G. Droidworx Microcopter AD-8 (Size: 95x95cmx50cm, Weight: 2.25kg) [7], H. Ascending Technologies Falcon Octocopter (Size: 77x82x12.5cm, Weight: 2.3kg) [47], I. Phoenix ornithopter (Wing area: 0.22 m^2, Weight: 395g) [22], J. Nano-Hummingbird (Wingspan: 16cm, Weight: 19g) [19]

.

secondly on their operating range and endurance [41] (table 2). Further classification is based on their: method of lift (e.g. fixed wing or rotor-based), engine type, payload, mission type or wing load. Especially fixed wing aircraft (figure 2 A-E) differ from rotor based UASs (figure 2 F-H) [4]. Lastly, there are nano UAS [5] (figure 2 I-J) that fit in the palm of your hand and have their own manner of propulsion.

Fixed wing vs rotor based systems

Fixed wing systems of the same size as rotor based system can fly at higher speeds [1, 35]. Although, overall their speed is still low (max 160 km/h) compared to manned aircrafts. Furthermore, fixed wing aircrafts are larger in size than rotor based systems, with wing spans of 1-3 meters long. Fixed wing UASs have a relatively longer flight endurance compared to rotary-wing models, making them preferable when surveying large areas. Furthermore, fixed wing aircrafts are much easier to operate than rotor-based system, with rotor based systems having a much steeper learning curve for piloting the UAS. One disadvantage of fixed wing systems is in takeoff and landing, take off tends to be done by using a bungee cord and landing is done by a controlled glide towards soft ground or with a parachute. While rotor-based systems can conveniently takeoff and land vertically.

Rotor-based UASs differ from fixed wing systems in that they can hover over fixed targets and fly more easily at lower speeds, making them suitable for experiments along a vertical axis [1, 35] and shoot high quality images. Furthermore, rotor systems are more maneuverable than fixed wing UASs and thus they can fly in confined places, e.g. caves or dense forests. Rotor-based systems can vary in the number of blades utilized, e.g. octocopters (8 blades) not being uncommon. More blades reduce the risk of crashes, but increases the weight and energy usage.

Table 2: UAS Classification Guide. Based on NATO and civilian classifications[1, 41]

Class	Category	Maximum operating altitude (meters above ground)	Normal mission radius (km)	Endurance (flight time)	Example platform
Class I (<150 kg)	Micro/Nano <2 kg	250	5	1 hour	Black Widow
	Mini 2-20 kg	900	25	2 hours	Eagle Skylark Raven
	Small >20 kg	1000	10	4 hours	Luna Hermes 90
	Medium	4000	500	10 hours	NASA Sierra
Class II (150-600 kg)	Tactical	3000	200	Day	Sperwer Iview250
Class III (>600 kg)	Strike/Combat	20000	Unlimited	2 Days	
	High altitude, (HALE) Long Endurance	20000	Unlimited	2 Days	Global Hawk
	Medium altitude, (MALE) Long Endurance	13700	Unlimited	2 Days	Predator Heron Hermes 900

2.4 Legislation

Rules and regulations of UASs is a complex issue for national and international aviation organizations (e.g. FAA, EASA, JAA, Eurocontrol), they are assisted by the aviation industry and research institutes [35, 45]. Good legislation is important to prevent collisions with other air vehicles, especially manned aircrafts, and prevent damage of property or people on the ground. In most countries there is still a lack of good legal framework for operating UASs, especially for flying outside field of vision. Although, most governments and aviation organizations see the economic advantages and possibilities of UASs and are working on new legislation.

Every country is part of an aviation administration/agency, which is responsible to enforce the rules and guarantee the standards for civil aviation. I looked at rules and regulation in four countries: the Netherlands (Rijksluchtvaartdienst (RLD)) [34], Spain (Agencia Estatal de Seguridad Aérea (AESA)) [35], South Africa (South African Model Aircraft Association (SAMAA)) [44] and the USA (Federal Aviation Administration (FAA) [14, 13], and summarized the main rules for using UASs:

1. Prohibits the use of UASs in many areas (figure 3), mostly around airports or other areas frequented by aircraft.
2. Can't fly the UAS above roads, buildings or people.
3. Other aircraft have right of way.
4. UAS has to stay below a certain altitude, 120 meters in the Netherlands, USA and Spain.
5. Can only fly during day-light conditions.
6. Can not fly the UAS beyond line of sight. In Spain, an UAS below 2 kg can fly beyond line of sight, but needs to remain within radio range.
7. The UAS pilot needs a pilot license, a certificate given by an aviation agency demonstrating its ability to fly the UAS and has adequate knowledge of the UAS.
8. The UAS needs to be insured and be documented as to safety of flight. The UAS needs to carry a identification plate.

9. The aviation agency needs to be aware of any flights ahead of time.

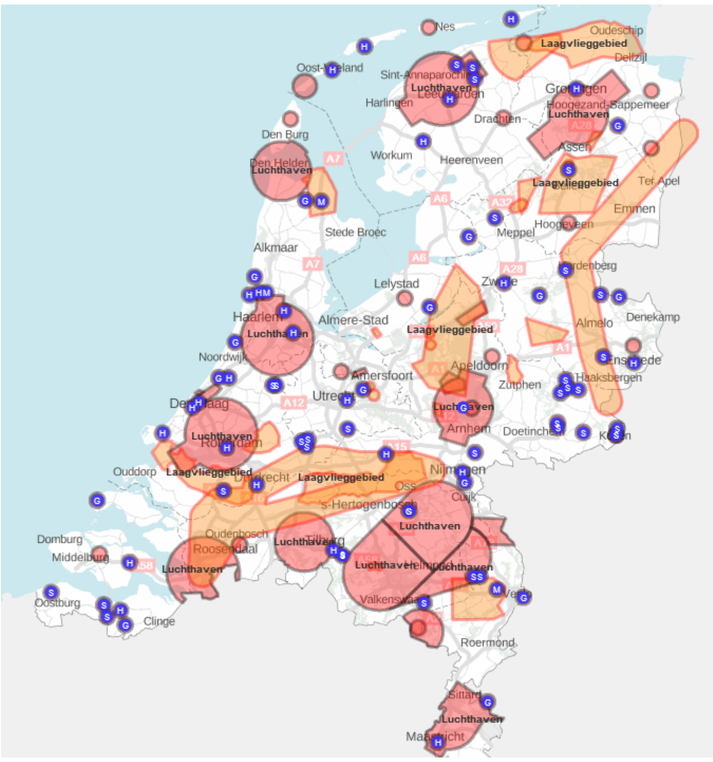

Figure 3: UAS: No fly-zones in the Netherlands [49]. Red: prohibited, Yellow: mostly prohibited, G = Glider airfield, S = Hangglider airfield, H = Helicopter pad, M= ultralight aviation airfield

2.5 Essay aims

The main aim of this essay is to investigate UAS usage in wildlife conservation. Wildlife conservation is one the main areas within biology where UASs have been implemented. To investigate these aims, I looked at a wide variety of projects:

1. How are UASs used in wildlife conservation?
2. What type of UAS did they use and why?
3. What are the challenges in using UASs?
4. What are the limitation?

3 APPLICATIONS OF UASS IN WILDLIFE CONSERVATION

Wildlife conservation is the protection of plant/animal species and their habitats, executed mostly by national governments or non-profit NGO's (e.g. WWF) . Their main focus is on preserving the biodiversity on this planet, with effective policies, e.g. Natura 2000 [9], and research, to address the most threatened systems and organisms. In this chapter, I will go trough four different projects within wildlife conservation in which UASs were important, with the following topics: bird mortality on power lines, UASs as an anti-poaching tool, surveying and mapping of forests and biodiversity and the robara: substitute prey in falconry. These projects have a wide variety of topics and should therefore give a good picture of UASs usage in wildlife conservation.

3.1 Environmental impact of infrastructure: bird mortality on power lines

Bird mortality on power lines above-ground is a problem in bird conservation [28, 15]. Power lines can be fatal when the bird collides with the power line cable or by electrocution. Electrocution occurs when the bird touches two conductors or one conductor and a metallic object, especially large and predatory birds are susceptible to electrocution. Furthermore, electrocution can generate maintenance problems of the power line system by overloading the electronic grid and tripping safety devices, this may even lead to forest fires [15]. Gregarious species and birds that fly at night are prone to collide with power line cables. Another problem is birds building nests on power line pylons (figure 5). This may increase the number of accidents (collisions and electrocutions) and damage the infrastructure; e.g. the nest might disrupt energy supplies when nest parts touches one of the conductors. A lot of money is spend on this problem, e.g. an energy company in Australia claims to spend $80 million each year on inspections power poles and in Andalucia (Spain) €2.5 million per year is spent on lowering mortality on power lines of the endangered Spanish imperial eagles (*Aquila adalberti*) [36, 28].

Previous research [36, 28] has shown that bird incidents with power lines have a significant tendency to accumulate on specific places (hotspots). Conservationists can reduce bird mortality quite dramatically by focusing on finding and correcting these hotspots. Identifying these hotspots is normally done by car or foot, but sometimes with manned aircrafts, robots moving along the power lines (climbing-flying robots) (figure 4) or satellite imaging. When a hotspot is identified, correction measures can be taken:

1. Replace pylons with suspended insulators.
2. Replacing exposed rigid insulators with suspended ones.
3. Installing protective systems on the pylons to prevent birds from touching wires
4. Creating new power lines located away from areas frequented by eagles (e.g. breeding areas).

A group of researchers [36] conducted a pilot study using UASs for power line monitoring in Andulucia (Spain): identifying pylon design, recording pylon location, identifying bird mortality and surveying habitat. The researchers aim was to find out if UASs can replace or supplement other techniques used for power line monitoring: by car, satellite imaging or with climbing-flying robots (figure 4) [24].

0 NGO = Non-governmental organization, WWF = World Wide Fund for Nature

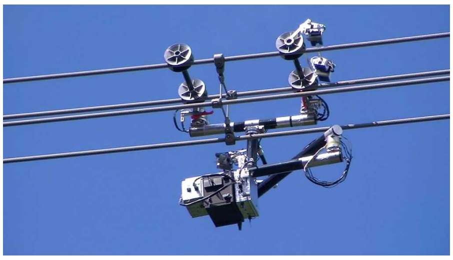

Figure 4: A climbing-flying robots for power-line monitoring [24].

Figure 5: Birds nesting on power pylons [36].

The researchers used a radio controlled UAS (Easy fly St-330) propelled by a brushless electrical motor (figure 6). The UAS has a wingspan of 1.960 m, a maximum take off weight of 2 kg with a 250 g payload, a maximum range of 10 km, an endurance of 50 minutes and it can take off and land manually in small patches of flat and open terrain. The payload consisted of two photo cameras (Panasonic LX3 and a GoPro hero 2), taking one photo/second, and a barometric altimeter. The researchers could control the airplane with an autopilot system or manually using a first person view system (FPV). In FPV, the pilot controls the UAS in real time with virtual reality glasses; the glasses show real-time images shot by a camera placed on the aircrafts nose (figure 6). The researchers used the autopilot system by setting a number of way-points on a map, the UAS then flies over each way-point using a GPS.

The biggest advantage they found is the relative low cost of UASs compared to the other methods. Furthermore, their payload gave high quality imagery. The first disadvantages with an UAS is that a staff member needs to have knowledge about maintenance, supervising and piloting the aircraft. A second disadvantage is not being able to fly in bad weather (wind/rain) with their UAS. Although, manned aircraft have the same limitations. Lastly, the researchers used a UAS with a limited range. Inspecting 12 km of power line, took 4 UAS flights, with every flight taking 2 hours, including preparation and data processing.

The researchers did not find many differences in the results using FPV or the autopilot system. Although, the researchers recommend using FPV over the autopilot, because FPV is more convenient to operate at lower altitudes and has a lower cost, when operated by an experienced technician.

Taking everything into account, the researchers concluded that their UAS proved a useful tool in power line monitoring and has many advantages in cost and time over other monitoring methods. Minimizing the time and cost needed for monitoring power lines will allow conservationist to allocate more funds into correction measures.

Figure 6: UAS (Easy fly St-330) used for power line monitoring. Right upper corner: technician operating the system manually using a first person view system (FPV) [36].

3.2 UAS as an anti-Poaching tool in South Africa

Another pilot study [37] used UAS as an anti-poaching tool in a wildlife reserve in South Africa. This study showed that low cost UAS can be used as a tool in wildlife park surveillance. Although, there are still a lot of technical challenges to overcome, explained in this chapter.

There are two endangered species of rhinoceros in South African reserve: black rhinoceros (*Diceros bicornis*) and white rhinoceros (*Ceratotherium simum*). Rhinoceros are poached for their horn, which is in high demand for traditional Asian medicines, mostly in China and for ceremonial purposes in Yemen. A high demand means high prices are paid for rhinoceros horns at black markets. Leading to a constant temptation for the poor rural population in South Africa to start poaching rhinoceros horns. Anti-poaching policy consists of horn control, strict anti-poaching legislation, cooperation with the countries importing the horn, education, rural development projects and providing reservation security. Security is provided by park rangers and security companies, working together with law enforcements and the military. The general strategy is based on deploying ground patrols, tracking animals and poachers, and monitoring the fence lines for breaks. This is quite expensive, $11000 per year to maintain guards for patrolling 700-800 ha.

UAS technology may reduce the cost and increase efficiency of security surveillance. The researchers in this study used UASs as mobile camera platforms, which can patrol a large area more efficiently than a ground patrol. The moment a UAS detects trespassers, park rangers can be notified. The aim of the study was to see if they could detect poachers and rhinoceros with camera payloads in two types of habitats: forested and open grassland. A second aim was to test the system at different altitudes.

The UAS used in this study does not differ much from the previous study: an Easy Fly St-330, wingspan of 1.96 meters, take-off weight of 2 kg, a payload of 450 grams, maximum range of 10 km and an endurance of 50 minutes (figure 6). The payload consisted of one of three cameras: photo camera (LX-3 digital), HD video camera (GoPro Hero2) or a Long wave uncooled thermal video camera. The photo- and video camera were used during the day and the thermal camera during the night.

One disadvantage of this UAS is that favorable weather conditions are required. The wind speeds need to be below 20 km/h and there should be no rain. Furthermore, lower temperatures and air density have a negative effect on the endurance of the aircraft.

With still photo cameras (figure 7), the researchers detected Rhinoceros at a minimal altitude of 31 meters above ground and a maximum of 239 meters above ground in both grassland and forest. Humans on foot were detected at an altitude of 29 meters above ground to 158 meters above ground in both forest and grassland. Although, UASs had some difficulty detecting humans wearing camouflaging clothing in forested areas, due to reduced contrast with the environment. At an altitude of 40 meters above ground, the UAS detected footprints in the sand, but the UAS was unable to check the wiring condition of the border fence. Furthermore, the time of day influenced the quality of the pictures taken. During the morning and evening hours, shades of trees produced dark areas and the air being less clean caused a blurring effect.

The big disadvantage of using still cameras compared to other methods, is the slow procedure in using them. First the aircraft has to return to base, it is possible to send them real-time, then the pictures need to be downloaded, reviewed and processed, before any park ranger can be notified of intruders. Still photo cameras may not prove a good real time anti-poaching tool, but they may provide helpful for the police in identifying intruders.

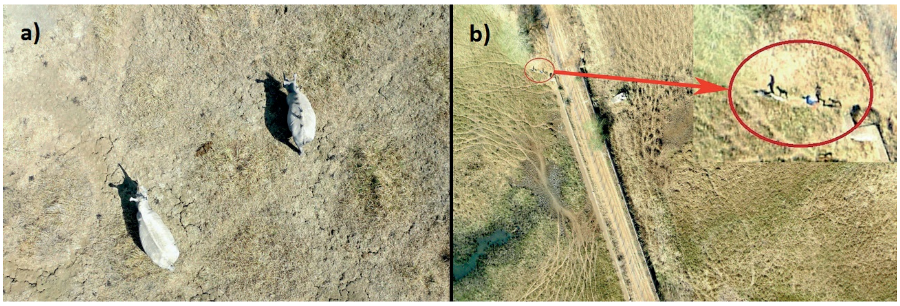

Figure 7: Photos of rhinoceros and humans from a still camera in a wildlife reservation in South Africa. a) Two rhinoceros (altitude 44 meters above ground) in grassland habitat. b) Two people accompanied by two dogs near a border fence (altitude 123 meters above ground)[37].

Flying 50 meters above ground, the HD camera could not detect humans or survey border fences. The aircraft had to fly below 40 meters above ground to get a good resolution. The researchers decided to cancel all rhinoceros detection flights with this type of camera, because flying at such a low altitude may disturb the animals. The researchers claim that a video camera with a narrower view field and zoom capability can identify targets at 100 meters above ground. This will still provide less precision on the exact location of the target, but for anti-poaching immediacy, knowing that there are poachers, is more important than knowing their exact location.

With the thermal camera (figure 8) it was challenging to get high quality images: about 5% was of high quality, 34% of medium quality and 71% of low quality. In general, the thermal camera picks up targets, which are difficult to identify on species level, because they appear as small white spots. They could use the thermal camera up to an altitude of 155 meters above ground.

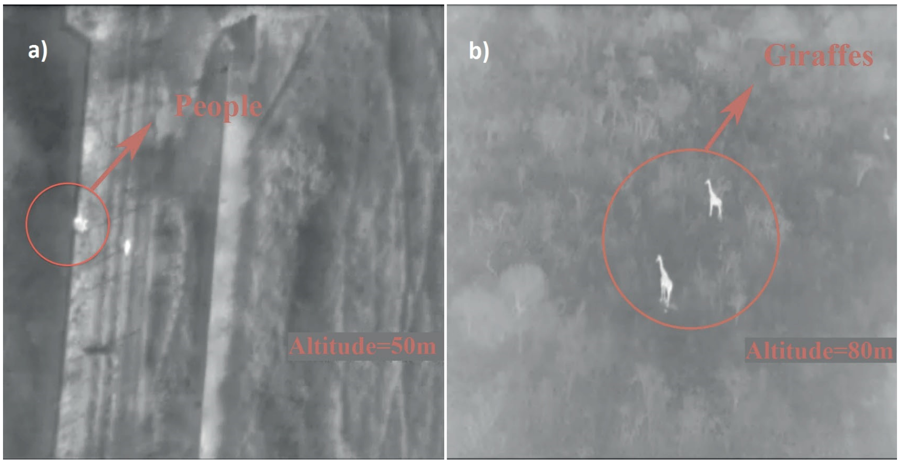

Figure 8: Photos of giraffes and humans from a thermal camera in a wildlife reserve in South Africa. a) A person near the fence (altitude 50 meters above ground). b) Two giraffes (altitude 123 meters above ground)[37].

3.3 UASs for surveying and mapping forests and biodiversity

Tropical deforestation is a major contributor in increasing greenhouse gases in the atmosphere and loss of biodiversity. In Indonesia tropical forest are turned into oil palm, rubber, cacao and Racosperma (pulp and paper) plantations. There is a high pressure to convert more tropical forest into cultural land, due to increasing global demands of food and fuel. This creates an urgent challenge for conservationists to monitor forest cover, species distribution and population dynamics. Researchers [25] in Aras Napal, Sumatra, Indonesia, used autonomous UASs for surveying and mapping forests and biodiversity . They used UASs to map local land cover, monitor illegal forest activities (e.g., logging, fires), and survey large animal species (e.g. orangutan, elephant, cheetah).

At the moment, most monitoring and mapping of land use is done by using satellite imaging. An expensive undertaking, preventing developing countries, e.g. Indonesia, to use satellite imaging to get the necessary high quality images needed for monitoring and mapping their land use. Furthermore, satellite imaging depends on clear blue skies, only the humid tropics are often obscured due to a persistent cloud cover. Researchers have to search for a series of cloud free time series, making consistent real-time monitoring and mapping of land using satellites virtually impossible. This makes a UAS, inexpensive, easy to use and capable of mapping land use of large areas more than welcome.

Monitoring biodiversity in tropical forests is achieved by ground surveys, they have many constraints: they are time consuming, financially expensive and some areas are inaccessible. The high costs of ground surveys prevent the needed frequency to monitor population trends. Furthermore, some tropical forests are not even surveyed at all due to the constrains of ground surveys.

The researchers used an inexpensive conservation drone (figure 9) on a popular model airplane (Hobbyking Bixler [20], €53.44). The airplane is lightweight (650 grams), powered by a 2200 mAh (milliampere-hour) battery, has a 25 minutes endurance, and a range of 15 kilometers. To control the aircraft they used an autopilot system, the "ArduPilot Mega", developed by an on-line community [12]. Before the flight, the operator sets a preset number of way points in a Google satellite map interface. Furthermore, the operator can set other flight parameters, such as grounds speed and altitude.

Figure 9: HobbyKing Bixler v1.1 EPO 1400mm [20]. Weight = 650 grams, Battery = 2200 mAh, Endurance = 25 minutes, range = 15 km.

Once set, the aircraft flies the mission autonomously, this includes getting off the ground and landing.

The payload consisted of one of two still photo cameras: a Canon IXUS 220 HS (resolution: 4000 x 3000 pixels; sensor: Complementary Metal-Oxide-Semiconductor; sensor size: 6.17 x 4.55 mm) or a Pentax Optio WG-1 GPS (resolution: 4288 x 3216 pixels; sensor: Charge-Coupled Device; sensor size: 6.17 x 4.55 mm), placed 15 cm from the nose of the aircraft. They set the cameras on a time lapse interval of one images per three second. Furthermore, the researchers made images with a video camera (GoPro HD Hero), attached to the belly of the aircraft (pointed at 45 degrees forwards and downwards), taking 60 images per second with a resolution of 1080 x 720 pixels.

On the images it is easy to distinguish between different land uses: plantations, maize fields, human habitation, forests, logged areas and forest trails 10. With these photos they can create geo-referenced mosaics, with which they can near real-time map and monitor land utilization, this leads to uncover any illegal deforesting activities.

The video camera of the UAS, flying at low altitudes (80-100 meters above ground), detects individual trees, oil palms, orangutans and elephants. The behavior, habitat and food resource utilization of big mammals, like orangutans and elephants, could be observed with video and photos cameras on UASs (figure 11). Flying above 200 meters above ground, activities in a larger area can be observed, e.g. fires and logging, if these are illegal then park rangers can be notified of these activities.

The researchers found that there are many factors influencing the picture resolution (quality of the picture): focal length, flight altitude and the size of the sensor (table 3). The optimal shutter speeds lay between f1/320 and f/1000, which effectively avoided motion blur. Furthermore, they found that they needed a vibration dampening system, Stable Placement of ONboard Gear and Equipment (iSPONGE), to completely remove any blur caused by the vibrations generated by the electric engine.

The main thing this study shows is that forest monitoring/mapping and study of large fauna in large areas with rough inaccessible terrain was achieved with an inexpensive UAS. Furthermore, their UAS could take-off land and fly autonomously due to an autopilot system, not needing a trained operator. Lastly, the UAS proved to be 100% reliable, i.e. the aircraft did not crash once. Although, the UAS did have some problems

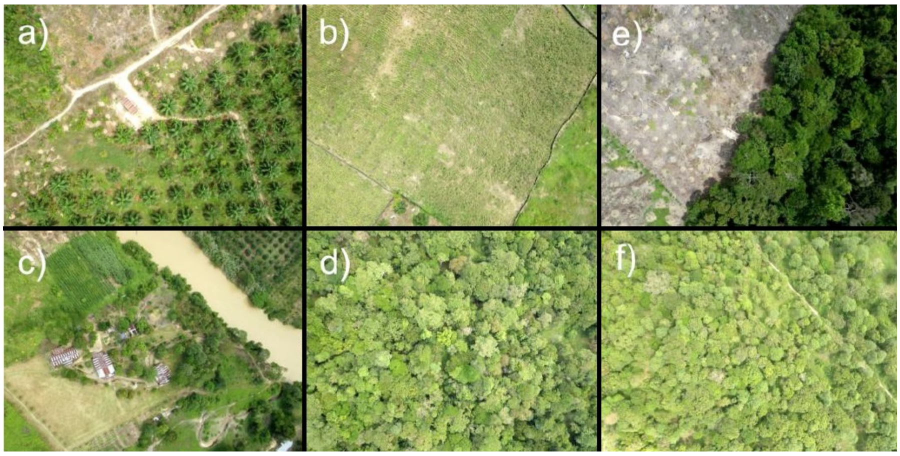

Figure 10: Aerial photographs of land uses captured by the Conservation Drone in Indonesia [25]. a) young oil palm plantation; b) maize field; c) human habitation: camp of the Elephant Patrol Unit in Aras Napal, Sumatra; d) forest; e) recently logged forest; and f) forest trail.

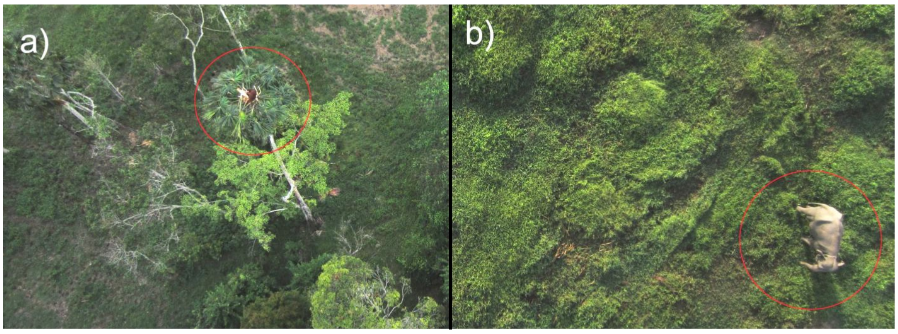

Figure 11: Aerial photographs of large mammals in Indonesia [25]. a) Sumatran orangutan; and b) Sumatran elephant.

with strong winds (20 kilometers/hour), blowing the UAS from the correct course.

3.4 Rofalconry: the Robara

Falconry is using a trained predatory bird to hunt wild quarry in a natural state. This is not always a harmless form of entertainment, because the wild quarry is sometimes endangered. In most western countries this is prohibited and heavily enforced [27]. In other parts of the world these regulations don't exist or are not enforced, leading to a great risk to the biodiversity in those regions.

To reduce mortality of prey, one option is to offer an alternative, using UASs as prey items, this is called rofalconry. Rofalconry has many advantages over real falconry, besides reducing the mortality of prey species. First, it can function as a training tool for (young) falcons, setting up an extensive training program. This will help the falcon develop a search image faster, boost confidence and increases its flying skill faster; i.e. the falcon can gain a years experience within a month. Secondly, rofalconry can be undertaken in a relatively small area, so a falconer needs no access to many square kilometers of hunting grounds. Thirdly, rofalconry can form its own sport, it is much easier to set up controlled conditions with an UAS as prey. This makes setting up falconry competition or flying displays much easier. Lastly, rofalconry can be exercised at any time during the year, even when hunting real prey is illegal or real prey are breeding/wintering.

Table 3: Picture resolution under different combinations of camera and flight parameters

Focal length (cm)	Flight altitude (m AGL)	Picture resolution (cm)
4.1	200	7.4
4.1	100	3.7
5.7	200	5.3
5.7	100	2.7
6.9	200	4.4
6.9	100	2.2

AGL=above ground level

Two examples of endangered species threatened by falconry are the Houbara buzzard (*Chlamydotis undulata*) and the MacQueen's bustard (*Chlamydotis macqueenii*) [17]. These bird species are a traditional quarry of falconers on the Arabian peninsula, northern Africa and western Asia (figure 12); in these countries, the falconer sport is particular popular among wealthy individuals, e.g. Saudi princes.

A company (Wingbeat Ltd, Carmarthen, Wales) [43, 29] in the United Kingdom has developed a UAS that resembles a real bird, the Houbara Bustard (*Chlamydotis undulata*). The Robara is designed to act as real prey, instead of a real Houbara buzzard or MacQeen's bustard, the falcon will be hunting the UAS. The aircraft is designed to be killed, hit, clawed and wrestled to the ground from great heights. The falcon treats the Robara as a real prey item: it stoops at the head, binds to the head, forces the prey to the ground and then tries to kill the aircraft by pecking at its neck (covered in realistic lycra skin).

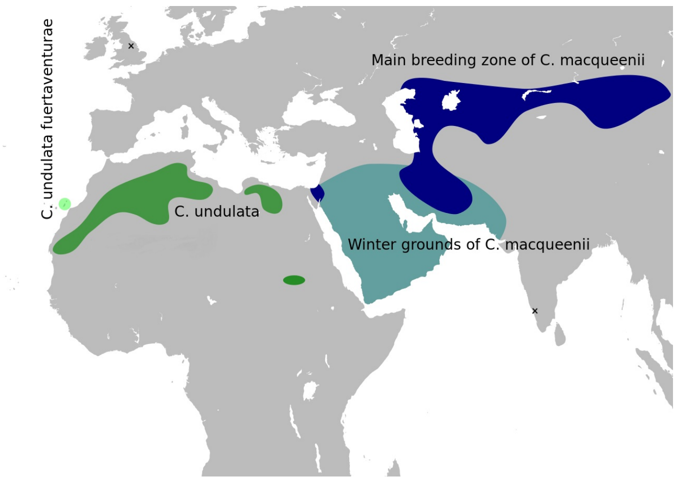

Figure 12: Home ranges of the Houbara bustard (*Chlamydotis undulata*) in green, the Canarian houbara (*Chlamydotis undulata fuertaventurae*) in light green and the MacQueen's bustard(*Chlamydotis macqueenii*) in light blue (winter) and dark blue (breeding) [17].

The Robara matches the flight performance of the best gyr/peregrine falcon; the Robara should challenge the falcon and not outperform it. The Robara weighs about 1 kg, half the weight of a real bustard. It is designed to resemble a real bird as close as possible, it has the same dimensions: 851 x 551 x 441mm, and can flap its wings. The system costs about $1350, with spare parts. The aircraft can fly up to 500 meters above ground in three minutes, can reach a speed of 24 m/s and has an endurance of 10 minutes. It is wind resistant, withstanding winds up to 61 km/h (Beaufort force 7), although it is recommended to not fly in wind speeds higher than 38 km/h (force 5).

The biggest design challenge was to prevent harm to the falcon and make the UAS resistant to the damage caused by the falcon. The external surface of the aircraft is completely smooth with no protruding elements. Furthermore, the head is made of a special foam rubber, to absorb the hit from a stooping falcon. Lastly, the internal fragile parts, the fuselage and electronics, have an extra layer of protection. The Robara is light, smooth and soft, preventing any damage to the falcon or potential bystanders.

Figure 13: The Robara [29]. UAS that resembles a Houbara bustard.

4 DISCUSSION

In this essay I show that UASs are an excellent tool to perform aerial surveys or do surveillance tasks. Saving conservationists a lot of time and money if they had to do this on foot, by car, with manned aircrafts or with satellite imaging, allowing for more resource allocation in actual mitigation measures (e.g. replacing dangerous power lines). This is not only relevant for conservation efforts, but for many types of research as well, e.g. ecological research [53, 23].

The rapid advancement of UAS technology has led to a substantial civilian UAS market; in the last decade, every year more people are exploring the possibilities of UASs. Rapid advancements have lowered the cost detrimentally to such an extent that UAS can be bought for under $100, with a 25 minutes endurance and a range of 15 kilometers.

High resolution images can be shot from UASs flying at 100-300 meters above ground with affordable commercial cameras as payload. These images can detect large fauna, including humans, on species level. Determining species distribution and movement in a large area or to locate poachers in a wildlife reserve. Furthermore, small UASs can be deployed quickly and at a moments notice, improving temporal accuracy or when it is relevant to act quickly, e.g. finding poachers.

New technologies, like UASs, may come with risks of which we have no knowledge at this time [21]. Aerial surveys with UASs may have an disturbing effect on wildlife. At this time we have no knowledge when disturbance starts to occur; effects of disturbance may vary between species and UAS types. It is advised to get data on disturbance and work to a set of rules and guidelines concerning safe use of UASs. Rhinoceros in the wildlife reserve in South Africa were not disturbed at all by a small electric UAS flying 100 meters above ground [37]; the UAS proved to be silent and visually discrete. In another study [23], easily-disturbed wading birds (e.g. white ibis (*Eudocimus albus*)) did not notice an UAS flying 100 meters above ground overhead. Visual discretion can easily be attained by smart design: make the UAS smaller, use colors that blend in with the environment or make the UAS look like a non-threatening bird species.

Good weather conditions are required to fly small UASs, rain can damage the electronics and wind can blow the UAS out of course. In the power line [36] and rhinocerus study [37] they encountered problems flying their small UAS at wind speeds higher than 20 km/h. The UAS in Indonesia [25], surveying forest and determining biodiversity, could fly in headwinds of 20 km/h, but the researchers recommended not to fly in winds stronger than 10 km/h, to ensure the aircraft flies the correct course and can take high quality images. A wind speed of 20 km/h is not uncommon and is described as a gentle breeze on the beaufort force scale. For example, the yearly average wind speed at 100 meters above ground is higher than 20 km/h in the entire Netherlands and in many parts of the Netherlands at ground level. However, the robara [29] is very wind resistant, withstanding wind speeds up to 61 km/h, although this system was not designed to shoot high quality images. The largest UASs (Class III), e.g. Ikhana employed by NASA [8], can withstand hurricanes. So conservationist should employ an UAS that is suitable to their normal weather conditions, i.e. use a wind resistant UAS at sea.

REFERENCES

[1] Karen Anderson and Kevin J. Gaston. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Frontiers in Ecology and the Environment*, 11(3):138–146, 2013.

[2] Federal Aviation Association. Unmanned aerial vehicles. https://www.faa.gov/uas/.

[3] Jose A. Barasona, Margarita Mulero-Pazmany, Pelayo Acevedo, Juan J. Negro, Maria J. Torres, Christian Gortazar, and Joaquin Vicente. Unmanned aircraft systems for studying spatial abundance of ungulates: Relevance to spatial epidemiology. *PLoS ONE*, 9(12):1–17, 2014.

[4] Dominique Chabot and David M. Bird. Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in? *Journal of Unmanned Vehicle Systems*, 3(4):137–155, 2015.

[5] Javaan Chahl, Graham Dorrington, Sarah Premachandran, and Akiko Mizutani. *The dragonfly flight envelope and its application to micro uav research and development*, volume 8. IFAC, 2013.

[6] A Chapman. It's okay to call them drones. *Journal of Unmanned Vehicle Systems*, 2:1–3, 2014.

[7] David Chen. Droidworx octocopter. http://chendavid.en.hisupplier.com/product-832978-Droidworx-Octocopter-mikrokopter-RC-Helicopter.html.

[8] Brent Cobleigh. Nasa-large uas aircraft. https://www.nasa.gov/centers/dryden/research/ESCD/ikhana.html.

[9] European commission. Natura 2000. http://ec.europa.eu/environment/nature/natura2000/index_en.htm, 2016.

[10] Timothy H Cox, Christopher J Nagy, Mark A Skoog, and Ivan A Somers. Civil UAV Capability Assessment. Technical report, 2004.

[11] Mike Craig. Nasa airborne science program. https://airbornescience.nasa.gov/aircraft/SIERRA.

[12] diydrones. Welcome to diy drones! http://www.http://diydrones.com/.

[13] Federal Aviation Administration. Small Unmanned Aircraft Systems (sUAS). Technical report, 2016.

[14] Federal Aviation Administration. Summary of small unmanned aircraft rule (part 107). Technical report, 2016.

[15] Miguel Ferrer. *Birds and power lines: From conflict to solution*. 2012.

[16] Luis F. Gonzalez, Glen A. Montes, Eduard Puig, Sandra Johnson, Kerrie Mengersen, and Kevin J. Gaston. Unmanned aerial vehicles (UAVs) and artificial intelligence revolutionizing wildlife monitoring and conservation. *Sensors*, 16(97):1–18, 2016.

[17] Paul D. Goriup. The world status of the houbara bustard Chlamydotis undulata. *Bird Conservation International*, 7(4):373–397, 1997.

[18] Mike Hanlon. The bat 3 unmanned aerial vehicle. https://www.gizmag.com/go/3844/.

[19] W. J. Hennigan. It's a bird! It's a spy! It's both. http://articles.latimes.com/2011/feb/17/business/la-fi-hummingbird-drone-20110217.

[20] hobbyking. Hobbyking bixler v1.1 epo 1400mm. http://http://www.hobbyking.com/hobbyking/store/__16544__HobbyKing_8482_Bixler_8482_v1_1_EPO_1400mm_ARF_.html.

[21] Jarrod C. Hodgson and Lian Pin Koh. Best practice for minimising unmanned aerial vehicle disturbance to wildlife in biological field research. *Current Biology*, 26(10):387–407, 2016.

[22] Zachary John Jackowski. Design and construction of an autonomous ornithopter, 2009.

[23] G P Jones, L G Pearlstine, and H F Percival. An assessment of small unmanned aerial vehicles for wildlife research. *Wildlife Society Bulletin*, 34(3):750–758, 2006.

[24] Jaka Katrasnik, Franjo Pernus, and Bostjan Likar. *Recent Advances in Mobile Robotics*. 2010.

[25] Lian Pin Koh and Serge A. Wich. Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. *Tropical Conservation Science*, 5(2):121–132, 2012.

[26] Christopher M. Korpela, Todd W. Danko, and Paul Y. Oh. MM-UAV: Mobile manipulating unmanned aerial vehicle. *Journal of Intelligent and Robotic Systems*, 65(1-4):93–101, 2012.

[27] Albert H. Korthals. Wetgeving jacht. http://wetten.overheid.nl/BWBR0011848/2013-01-01#Paragraaf5.

[28] Pascual López-López, Miguel Ferrer, Agustín Madero, Eva Casado, and Michael McGrady. Solving man-induced large-scale conservation problems: The Spanish Imperial Eagle and power lines. *PLoS ONE*, 6(3):1–6, 2011.

[29] Wingbeat Ltd. The robabra. http://www.rofalconry.com/robara.asp.

[30] Emma Marris. Drones in science : Fly , and bring me data. *Nature*, 498(7453):156–158, 2013.

[31] S. Martin, J. Bange, and F. Beyrich. Meteorological profiling of the lower troposphere using the research UAV "m2AV Carolo". *Atmospheric Measurement Techniques*, 4(4):705–716, 2011.

[32] John F. McEvoy, Graham P. Hall, and Paul G. McDonald. Evaluation of unmanned aerial vehicle shape, flight path and camera type for waterfowl surveys: disturbance effects and species recognition. *PeerJ*, 4:1–21, 2016.

[33] Torsten Merz and Scott Chapman. Autonomous Unmanned Helicopter Systemfor Remote Sensing Missions in Unknown Environments. *Remote Sensing and Spatial Information Sciences*, 38(1):1–6, 2011.

[34] Ministerie van Infrastructuur en Milieu. Regelgeving drones. Technical report, 2016.

[35] Margarita Mulero-Pázmány. *Unmanned Aerial Systems in Conservation Biology*. PhD thesis, 2015.

[36] Margarita Mulero-Pázmány, Juan José Negro, and Miguel Ferrer. A low cost way for assessing bird risk hazards in power lines: Fixed-wing small unmanned aircraft systems. *Journal of Unmanned Vehicle Systems*, 2:5–15, 2014.

[37] Margarita Mulero-Pázmány, Roel Stolper, L. D. Van Essen, Juan J. Negro, and Tyrell Sassen. Remotely piloted aircraft systems as a rhinoceros anti-poaching tool in Africa. *PLoS ONE*, 9(1):1–10, 2014.

[38] NASA Aeronautics Research Mission Directorate. NASA Aeronautics: Strategic implementation plan. Technical report, 2015.

[39] NOAA. NOAA Unmanned aircraft systems. https://uas.noaa.gov/, 2016.

[40] Nova. Time line of uavs. http://www.pbs.org/wgbh/nova/spiesfly/uavs.html.

[41] Friedricht Wilhelm Ploeger. Strategic Concept of Employment for Unmanned Aircraft Systems in NATO. *Joint Air Power Competence Centre*, pages 1–28, 2010.

[42] Joachim Reuder, Pascal Brisset, Marius Jonassen, Martin Müller, and Stephanie Mayer. The Small Unmanned Meteorological Observer SUMO: A new tool for atmospheric boundary layer research. *Meteorologische Zeitschrift*, 18(2):141–147, 2009.

[43] Aviva Rutkin. Falcon vs drone. *New Scientist*, 225(3013):28, 2015.

[44] SAMAA. National model aircraft safety code. Technical report, 2002.

[45] Chris Sandbrook. The social implications of using drones for biodiversity conservation. *Ambio*, 44(4):636–647, 2015.

[46] Teal Group. Teal Group Predicts Worldwide UAV Market Will Total $91 Billion in Its 2014 UAV Market Profile and Forecast. http://www.tealgroup.com/index.php/about-teal-group-corporation/press-releases/118-2014-uav-press-release.

[47] Ascending technologies. Asctec falcon 8. http://www.asctec.de/en/uav-uas-drones-rpas-roav/asctec-falcon-8/#pane-0-1.

[48] Nikola Tesla. Method of and apparatus for controlling mechanism of "Moving Vessels ., 1898.

[49] Ministerie van Infrastructuur en Milieu. Drone no-fly zones. https://www.rijksoverheid.nl/onderwerpen/drone/inhoud/veiligheid-drones.

[50] Gary C. Warne. The Predator's Ancestors - UAVs in The Great War. http://warnepieces.blogspot.nl/2012/07/the-predators-ancestors-uavs-in-great.html.

[51] Ac Watts and Jh Perry. Small Unmanned Aircraft Systems for Low Altitude Aerial Surveys. *The Journal of Wildlife Management*, 74(7):1614–1619, 2010.

[52] Douglas A. Wiegmann and Narinder Taneja. Analysis of injuries among pilots involved in fatal general aviation airplane accidents. *Accident Analysis and Prevention*, 35(4):571–577, 2003.

[53] S.P. Williamson. Utilization of Unmanned Aircraft Systems for Environmental Monitoring. Technical report, 2011.