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The use of unmanned aerial vehicles for wildlife research

El uso de vehículos aéreos no tripulados para el estudio de la vida silvestre

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RESUMEN

En esta revisión bibliográfica se proporciona una descripción general de los estudios de fauna silvestre que se han realizado utilizando drones (vehículos aéreos no tripulados VANT) y de las oportunidades que existen para su futura implementación, como son los sensores y cámaras térmicas y multiespectrales. Los drones son útiles para realizar censos y ver tendencias poblacionales, estudiar patrones de uso de hábitat, identificación de especies, medición de individuos, evaluar el efecto antropogénico sobre las especies y su hábitat. Los drones presentan ventajas sobre los vehículos aéreos tripulados para realizar estudios de vida silvestre, como son la obtención de imágenes y videos georreferenciados, la seguridad para los investigadores, el bajo costo de los equipos, y los pocos requerimientos logísticos. Sin embargo, los drones presentan ciertas desventajas como lo es el reducido tiempo de vuelo y limitado alcance en distancia, los drones pueden causar alteraciones a la fauna al volar muy cerca de ella, es necesario tomar ciertas medidas para cumplir con la legislación de cada país. A través de casos de estudio se demuestra que las imágenes adquiridas con los drones ayudan a mejorar y revolucionar el estudio de fauna silvestre.

Palabras clave: drones; fauna; monitoreo; revisión; VANT; vida silvestre.

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ABSTRACT

In this bibliographic review, I provide an overview of wildlife studies that have been conducted using drones (unmanned aerial vehicles) and the opportunities that exist for their future implementation. Drones are useful for census and population trends, patterns of habitat use, species identification, measurement of individuals, assessing the anthropogenic effect on species and their habitat. Drones have advantages over manned aircraft to conduct wildlife surveys, such as obtaining georeferenced images and videos, safety for the researcher, low cost, and the need for little logistics. However, drones have disadvantages, such as limited flight time and limited distance range, may present a risk when flying near wildlife, it is necessary to take certain measures to implement and comply with the legislation of each country. Through case studies it is demonstrated how the images acquired with drones have great potential to revolutionize the study of wildlife.

Keywords: drones; fauna; monitoring; revision; UAV; wildlife.

INTRODUCTION

For the wildlife management and conservation, it is necessary to perform continuous monitoring, effective biodiversity researches, abundance studies and habitat characterization (Chabot and Bird, 2015; Linchant et al., 2015; Christie et al., 2016). In most of the cases, the use of conservation methods implies an intense fieldwork, despite the cost can be variable, in general the cost is high, depending among various factors, the size of the study area (Mandujano et al., 2017). Formerly, the best option for carrying out biodiversity studies in large areas was through the use of manned aircraft (Jachmann, 1991). In several places, this is still the most used technique to monitor and count large mammals, as it is in the African Savannah (Lisein et al., 2013). Despite the unquestionable utility, wildlife studies using manned aircraft present some drawbacks such as safety problems, logistical problems, lack of airports or even adequate aircrafts, trained pilots are required, high costs, and it is difficult to plan regular long-term monitoring (Lisein et al., 2013).

The highest cause of mortality of the professionals in the field of biology in the United States from 1937 to 2000 were aircraft accidents, representing 66% of deaths during those years (Sasse, 2003). In the last decades, aerial observers have been replaced by remote sensing systems to monitor wildlife, such as satellite systems. These have been tested with success levels in some species such as ungulates (Laliberte and Ripple, 2003) and marine mammals (Burtenshaw et al., 2004). The satellite systems cover large areas (>30 kilometers) and avoids human risk. However, it remains inadequate to recognize most species and is effective only in environments with high color contrast, are expensive and less flexible (Linchant et al., 2015).

In the last 16 years a new tool for aerial monitoring of wildlife has been incorporated, the unmanned aerial vehicles (UAV's), also called drones (Mandujano et al., 2017). Drones are autonomously remotely piloted aircrafts, generally equipped with GPS, compass, barometric altimeter, camera and/or video. These vehicles have evolved in the last decade, after having been used mainly for military purposes (Ivošević et al., 2015). As drones have become more accessible, numerous applications have emerged, such as in precision agriculture, hydrology, archeology, environmental monitoring, and wildlife studies (Jachmann, 1991).

The development of drones presents possibilities for the monitoring of wildlife, since it provides images with high spatial resolution, high temporal resolution, are safe for the operator, have low operating costs and simple logistics (Jachmann, 1991). Drones can fly at low altitude, allowing to take great detail images and in closer proximity to the area to be monitored. Frequent flights can be made, and flights can be repeated systematically to compare images from different times, using specific software tools. These devices have revolutionized the acquisition of data to record the behavior of undisturbed animals, increasingly used in wildlife research and habitat characterization, play an important role in the ecology of populations because they allow automatic census of individuals through the image processing (Ivošević et al., 2015).

There is the possibility of adapting different types of instruments and sensors to drones, which increase the diversity of data and variables that can be measured with their use. Drones accompanied by multi-spectral and infrared sensors, with 10-36 Megapixel cameras and 4K cameras, offer more information at lower cost, compared to airplanes and satellite images (Pimm et al., 2015; Witczuk et al., 2018; Carrasco-Escobar et al., 2019; Giles et al., 2023). When it comes to collecting ecological data, drones are equipped with optical sensors (infrared and/or ultraviolet), physical sensors (temperature, pressure, humidity, and conductivity), acoustic sensors (mainly for underwater use, but can be used on land) and / or chemical sensors (for example, pH sensors to detect a wide variety of gases (Ivošević et al., 2015). Also, thermal cameras are used, the animals can be detected by their individual differences in body temperature, the thermal cameras can be used at night to detect nocturnal animals (Mulero-Pázmány et al., 2015).

Some of the disadvantages of using drones is the short flight time, since the most accessible commercial drones usually have a flight time of 30 minutes to four hours. The drones of propellers (Multirotor) are the most commercial and simple to maneuver, they can remain stationary in a desired place, however, they have a short range of flight (<30 kilometers). Fixed-wing drones are more expensive and more complex to maneuver, cannot remain stationary, however, can travel greater distances and flight duration is longer than the propeller drones (Mandujano et al., 2017, Ferguson et al., 2018). Sometimes tethered blimps are used for wildlife surveys, but they have the disadvantage that they can´t be used in narrow places and with wind speed of 10 km/h or higher, also there is a risk is of the blimp being blowen into trees or become entangled, nevertheless, the advantage is that the blimp operates with zero licensing and minimal training (Fürstenau et al., 2017; Adams et al., 2020; Gorkin et al., 2020) (Fig. 1).

One of the main current limitations for the use of drones in wildlife monitoring is the legal aspect. Several countries do not yet have specific regulation for the use of drones. Others, prohibit or restrict their flight in certain areas from a certain altitude or at a certain distance from the operator, licenses and liability insurance are required to pilot (Mandujano et al., 2017, Fritsch and Downs, 2020).

In this article we present a compilation of studies that have been conducted worldwide, using unmanned aerial vehicles in the study of wildlife. Through case studies it is demonstrated how the technology of unmanned aerial vehicles has great potential to revolutionize the management and conservation of wildlife.

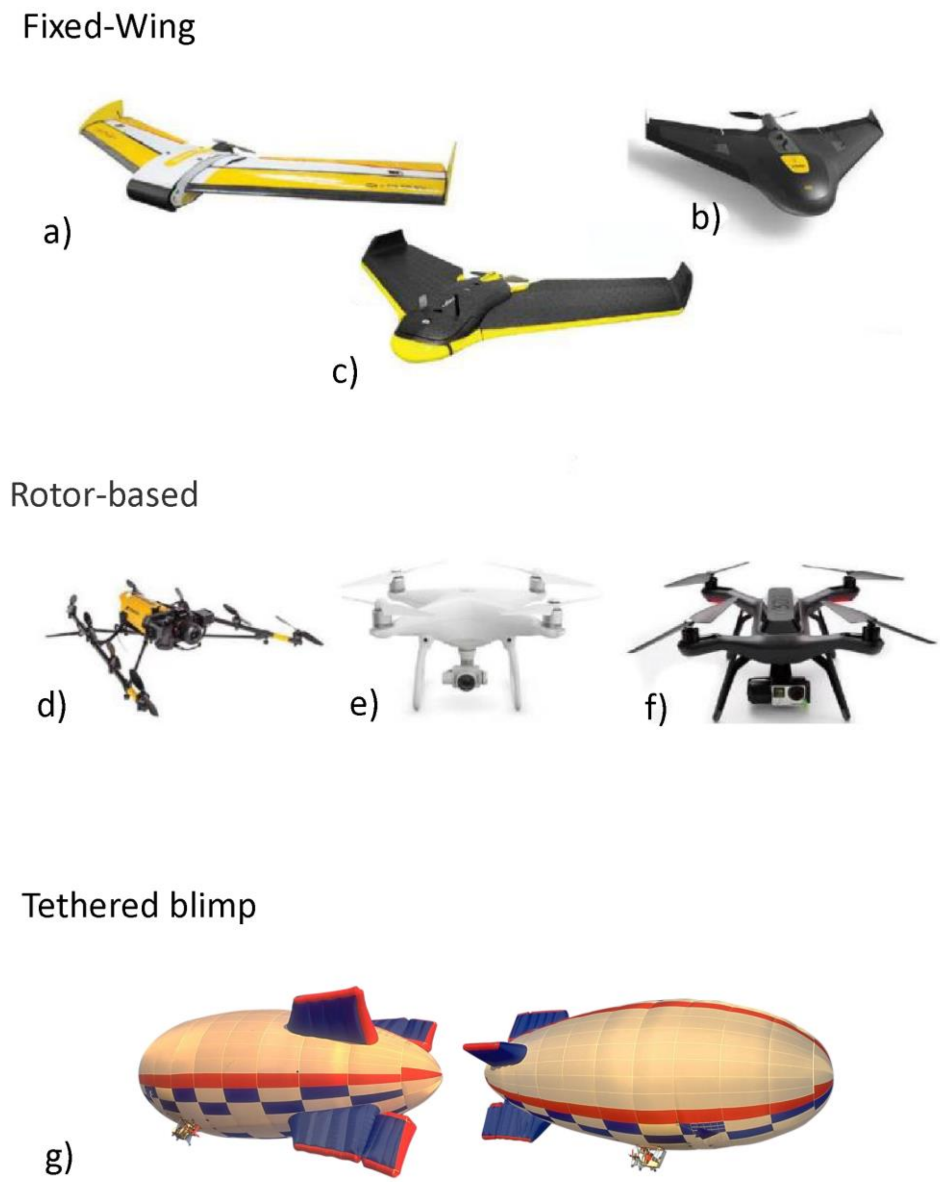

Fig. 1. Examples unmanned aerial vehicles (UAV). Fixed-wing UAVs: (a) QuestUAV Q-Pod; (b) SenseFly eBee; (c) Trimble UX5. Rotor-based UAVs: d) Topcon Falcon 8; (e) DJI Phantom 4; (f) 3DR SOLO Quadcopter. (g) Tethered blimp. The images were obtained from Pádua et al. 2017 and Pixabay.com/ Fig. 1. Ejemplos de vehículos aéreos no tripulados. Vehículos de ala fija: (a) QuestUAV Q-Pod; (b) SenseFly eBee; (c) Trimble UX5. Drones multirotor: d) Topcon Falcon 8; (e) DJI Phantom 4; (f) 3DR SOLO Quadcopter. (g) Globo cautivo. Las imágenes se obtuvieron de Pádua et al. 2017 y Pixabay.com.

MATERIALS AND METHODS

A bibliographic review was carried out during March 2018-2023 in the databases: Google Scholar, ResearchGate, EBSCO host and three articles were requested directly from the authors. The search criteria were the following: scientific articles, postgraduate theses and technical reports related to the use of unmanned aerial vehicles in the study of wildlife, with publication dates from January 2000 to 2023, in spanish or english. The keywords that were used for the search were: drones, vehículos aereos no tripulados, monitoreo, fauna, vida silvestre; and in English: wildlife, survey, monitoring, unmanned aerial vehicles, UAVs. To restrict the search and filter the work, a selective reading of the title and summary of the works was made, considering the ones that actually used unmanned aerial vehicles for the study of wildlife.

RESULTS AND DISCUSSION

A review of 96 works was carried out, of which 86 were scientific articles, seven review papers, one PhD thesis, one conference paper and a scientific report. We found 76 articles directly related to the use of drones in the study of wildlife with dates from 2009 to 2023, with more articles (10 articles) in 2017 and fewer articles in 2009, 2012 and 2013 (one article each year), the rest of the reviews and articles were used as complementary reviews to the topic.

The use of UAV for the study of wildlife has begun to be used in the last decade and has been increasing its use since then (Fig. 2). However, few studies have been conducted even though has proven its usefulness and its benefits in this field.

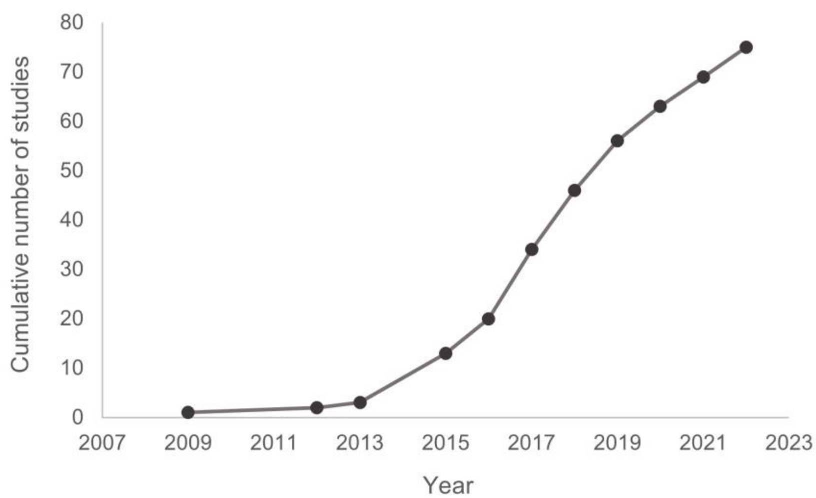

Fig. 2. Cumulative number of UAV studies on wildlife to 2023, showing an influx following 2013/ Fig. 2. Cantidad acumulativa de estudios de fauna silvestre en los que se han utilizado vehículos aéreos no tripulados hasta el año 2023.

Most of the UAV studies on wildlife are primarily focus on marine mammals including whales, pinnipeds, dolphins, dugongs. Other studies use UAV to study terrestrial mammals, reptiles, birds, and fishes (Figs. 3, 4), and one study was focus on detecting crustaceans' traps using UAV (Bloom et al., 2019). Studies on marine mammals primarily focus on Abundance and distribution (including detection and density), followed by studies of body measurements, and few studies of health and behavior (Fig. 4). For terrestrial mammals the primary focus has also been abundance and distribution with few studies of the impact of UAV (Egan et al., 2020). Reptiles had more studies about abundance and behavior, with less studies of movements (Aubert et al., 2021). For birds, interestingly, the studies of impact of UAV and nest location exceed abundance and distribution studies. Finally, for fish (including elasmobranchs) the primary focus was on abundance and distribution, followed by studies of behavior (Fig. 4).

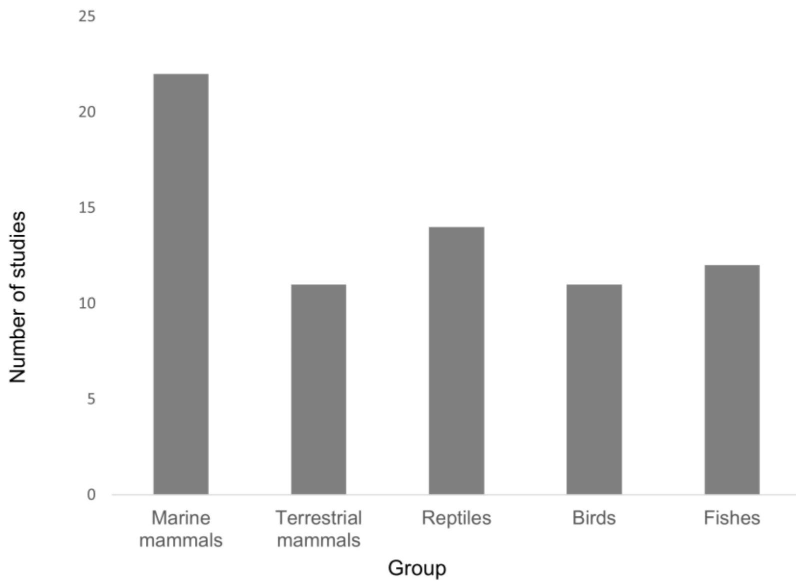

Fig. 3. Number of studies for group using UAV/ Fig. 3. Cantidad de estudios por grupo de fauna silvestre utilizando vehículos aéreos no tripulados.

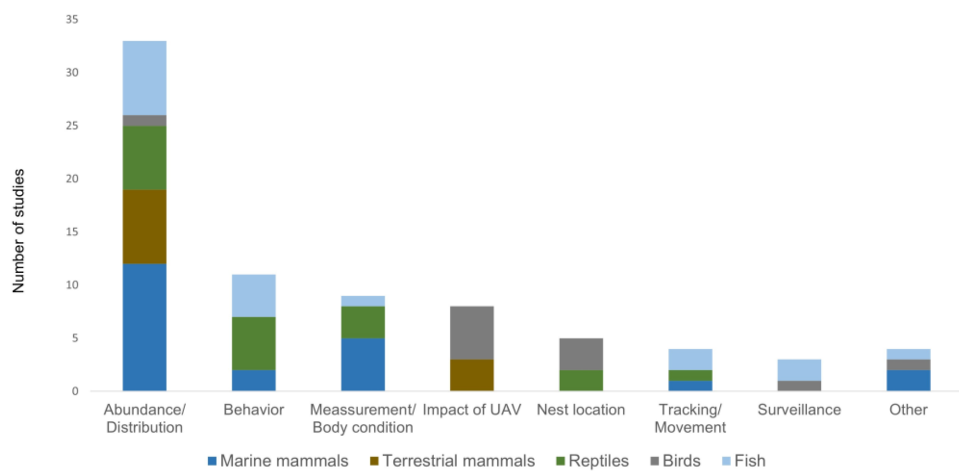

Fig. 4. Focus of studies on the wildlife groups/ Fig. 4. Enfoque de los estudios por grupo de vida silvestre.

The great utility of drones in the field of conservation and wildlife was found in all articles except in one, where the authors established that the use of UAV for monitoring macropod populations are inefficient, expensive and an inaccurate alternative to manned aerial surveys of wildlife (Gentle et al., 2018), that because of the cost associated with procuring a UAV, the operating crew, safety preparations and processing of data. The advantages of the use of UAV are the low cost, ability to reach sites of difficult access, need for little logistics, less risk for the researcher, greater field of vision, obtaining photographs and videos for further review; the disadvantages are the short time of flight, difficulty to use them in places with a lot of wind, dependent on the weather (rain), effects on the behavior of the fauna if you fly very close to it, legal restrictions depending on each country.

Most of the studies were carried out using rotor-based UAVs (60 studies), follow by fixed-wind UAVs (13 researches), and only two studies used tethered blimps for wildlife survey. Multispectral, near infrared and thermal sensors has been incorporated in the use of UAVs, the first article using sensors in this review was in 2015 for maritime surveillance, monitoring marine fauna and debris (Brooke et al., 2015).

Use of drones in the wildlife research

Use of drones for the study of wildlife habitat

To study the populations of wildlife, it is necessary to know the environment in which they develop; we cannot study wildlife without contemplating their habitat, since both biotic and abiotic factors influence it (vegetation, soil, reliefs, location of bodies of water, among others). Numerous studies have been carried out in which drone technology has been applied to obtain orthophotos (georeferenced terrain images) and low-spatial high-resolution digital elevation models (Westoby et al., 2012; Johnson et al., 2014) with which can measure coverage of an ecosystem, locate key habitats, identify areas of conflict. Using orthophotos, allometry of the trees (height, crown diameter) can be obtained and forest biomass can be calculated (Reyes-Palomenque, 2018).

Obtaining high-resolution digital elevation models requires modern geospatial technologies, such as LiDAR (Light Detection and Ranging) and TLS (Terrestrial Laser Scanning). However, these technologies have limitations, such as their high cost and the requirement of high logistics to carry out the mappings. Through the photographs obtained using drones, a method called "Structure of Motion" (SfM for its acronym in English, Structure from Motion) (Micheletti et al., 2015; De la Llata-Quiroga 2023) and through specialized software for image processing, which can be free software (CloudCompare) or paid software (Agisoft Metashape, Pix4D), orthophotos can be generated, and very high-resolution spatially-high-resolution digital elevation models.

Studies have been carried out for the mapping of coastal habitats. In November 2016, in the Sandy Cove (Arellana Bay) at 2 km north of Giglio Porto (Tuscany, Italy) a study was carried out using a small propeller drone (Quanum Nova CX-20) and a digital camera to map marine phanerogam *Posidonia oceanica*, which is the most widespread sea grass in the Mediterranean Sea (Milazzo et al., 2004), it reduces coastal erosion and offers a nursery area for many species of fish and invertebrates (Francour, 1997). It was shown that the drones are adequate to map the upper limits of seagrasses at small scales (1-5 km), and with high resolution, they could even detect small areas of dead grass, which had not been detected by satellite images (Ventura et al., 2017).

Monitoring of wildlife

Wildlife surveys are essential to understand the dynamics, population status and response to climate variability (Hodgson et al., 2017). Drones are used to conduct censuses of populations in a more efficient way, since it is possible to reach places of difficult access, you can locate individuals that would not be located from the ground, either because they are behind obstacles such as rocks, or in difficult sites to observe from the ground (Ezat et al., 2018; Butcher et al., 2019; Colefax et al., 2019; Kelaher et al., 2019; Aota et al., 2021; Barreto et al., 2021; Francis et al., 2022; Huang et al., 2022). Some examples of the use of drones in wildlife monitoring are the following studies:

Monitoring of marine fauna

In the last decade, UAVs have begun to be used to monitor marine fauna, since it can cover a larger area of monitoring, and photographs can be obtained, which can be revised in more detail later (Hodgson et al., 2013; Kiszka et al., 2016; Dawson et al., 2017; Hensel et al., 2018; Gorkin et al., 2020; Giacomo et al., 2021; Mitchell et al., 2022; Rowe et al., 2022). To the west of Australia in Shark Bay, a study was conducted using a ScanEagle fixed-wing drone, with a mounted digital SLR camera, to conduct dugong (*Dugong dugong* Müller, 1776) monitoring (Hodgson et al., 2013). With the aerial photographs taken they detected 627 dugongs, in addition to identifying whales, dolphins and turtles. The turbidity of the water was the only environmental variable that affected the sighting of dugongs.

UAVs have been used to obtain information about the spatial and temporal movement of marine fauna at high resolutions (Raoult et al., 2018; Colefax et al., 2020; Mesquita et al., 2022). The benefit of this approach is that no direct interaction with the fauna occurs, the behaviors and the movements would not be affected by human interactions, and it is cost-effective. With what is demonstrated that censuses of marine fauna can be realized using drones. Nevertheless, there are some limitations, such as battery run time and pilot fatigue as this methos requires constant flight inputs and concentration (Raoult et al., 2018).

Pinniped census

Using a multirotor drone (Phantom 3) equipped with a 12-megapixel camera, a census of a population of California sea lions (*Zalophus californianus* Lesson, 1828) was carried out in Los Islotes, Baja California, México (Adame et al., 2017). In which the traditional method (using binoculars from a boat to make the census) was compared with the method using drones. The results obtained showed that with the traditional method there is an underestimation in the population of sea lions. Using drones could detect individuals that were not detected from the boat, as there were individuals who were behind rocks.

River dolphin monitoring

The monitoring of river dolphins in shallow waters is carried out from canoes, however, dolphins emerge for very short periods and show very little of their body when they surface, which presents a difficulty for monitoring (Fürstenau et al., 2017). Fürstenau et al. (2017) compared the method used from canoas with the use of UAV for the monitoring of river dolphins (*Inia araguaiaensis* Hrbek, Farias, Dutra and da Silva, 2014) in the State Park of Cantão, in the Amazon rainforest, Brazil. The visual counts detected on average <75% of the dolphins recorded by the UAV. With the aerial method, more individuals were detected, demonstrating that it is a more reliable technique than visual canoe monitoring.

Identification of nests

One of the data needed to measure the productivity of a population is to measure reproductive and nesting success (Sardà-Palomera et al., 2012). There are challenges to the study of nests because they are in places that are difficult to access (such as swamps, treetops), and which generally require the use of high logistics and several days of searching. Using drones, it is possible to obtain georeferenced data from the location of the nests (Sardà-Palomera et al., 2012; Elsey and Trosclair, 2016; Brisson-Curadeau et al., 2017), it requires little time to perform the search for nests and represents a useful alternative to prevent security risks associated with the search of nests in marshy sites or difficult to access.

Identifications of bird of prey nests (*Pandion haliaetus* Linnaeus, 1758; *Haliaeetus leucocephalus* Linnaeus, 1766; *Buteo regalis* Gray, 1844 and *Buteo jamaicensis* Gmelin, 1788) have been made using drones, accurately and safely (Junda et al., 2015), thanks to the high resolution of the digital cameras carried by the drones. They have been able to make approaches and count the number of eggs inside the nests. The advantage of being able to count the eggs is that, knowing a percentage of the content of the nests of the population, the number of individuals in the whole population could be inferred (Steenhof and Newton, 2007).

In difficult to access areas that present logistical challenges, in addition to being dangerous obstacles for observers (such as semi-flooded and swampy forests with high grasses), drones have been used to identify crocodile nests, *Crocodylus porosus* Schneider, 1801 in mixed tropical habitats, *Alligator mississippiensis* Daudin, 1801 in coastal marshes (Elsey and Trosclair, 2016; Evans et al., 2015) showing success when comparing this method with the use of manned aerial vehicles (helicopters), observing the same percentage of nests.

In mammals, nest identification studies have also been carried out, chimpanzee nests have been identified (van Andel et al., 2015) proving that in open-canopy forests, drones have great potential as a rapid assessment tool for detecting nests and the presence of chimpanzees. In places where the nests are in closed canopy forests, and under the trees, the drones may have limited applicability, since it is difficult to detect the nests by means of aerial images (van Andel et al., 2015).

Morphology and measurement of individuals

The use of drones has become more common in the field of marine sciences for measurements of marine mammals. Using drones there is possible to make long and wide measurements of cetaceans (Durban et al., 2015, 2016; Burnett et al., 2019), pinnipeds (Krause et al., 2017), reptiles (Myburgh, 2021; Piacenza et al., 2022) with great effectiveness, being a non-invasive technology that allows us to obtain photographs at a lower altitude than with a manned aircraft.

Using drones, it is possible to obtain repeated estimates of the length and width of cetaceans to monitor their changes in growth and body condition over time, without affecting them. This is done by flying the drone from the boat and positioning it above the individual at a certain height, photographs are taken, which are then processed in a software (Adobe Photoshop) to perform the measurement of the individual in a precise way, considering different variables such as the height of flight and inclination of the photograph (Christiansen et al., 2014). From photographs obtained by drones, in 2016 the body condition of humpback whales (*Megaptera novaeangliae* Borowski, 1781) was evaluated in four reproductive classes to deduce the energy cost faced by each class during the breeding season and to know how it influences population dynamics (Christiansen et al., 2016).

In 2017 estimates of body mass and condition of pinnipeds (leopard seals, *Hydrurga leptonyx* Blainville, 1820) were made using drones, in the Antarctic Peninsula, on the north coast of Livingston (Krause et al., 2017). Measurements of body size and mass are fundamental for the management and conservation of the pinniped population, since it is an indicator of ecosystem health, metrics such as body length and mass provide information on age, physiology (Kooyman, 1989), feeding ecology of marine mammals (Webb et al., 1998).

The use of drones to make mass estimates is an alternative to manual measurement that involves physical captures that entail a risk both for the pinnipeds and for the people who will perform the measurements. In addition, use of drones can be useful to differentiate the sex of the species, as in the case of the marine turtle *(Caretta caretta* Linnaeus, 1758) in which adult males of females were distinguished in a breeding area, using drones to obtain information on the measurement of turtle tails (morphological characteristics) and behavioral differences between sexes (Schofield et al., 2017).

Wildife health

Advances in aerial drone technology offer new opportunities to study and monitor the health of individuals. Studies have been conducted to evaluate the respiratory health of humpback whales (*M. novaeangliae*) by collecting blow samples. Often the samples of whale blows are obtained by approaching the whale in a small boat and holding a pole of approximately seven meters, with a collector plate over the blowhole (Hunt et al., 2014) which presents a security risk for researchers and the whales. Recently the use of UAVs to collect non-invasively samples of the blows of the whales has been proved (Acevedo-Whitehouse et al., 2010; Apprill et al., 2017). Using this method, it was possible to determine the respiratory microbiome of humpback whales and identify possible pathogens in individuals. The use of drones represents an advantage to be able to obtain samples of blows from the whales in a non-invasive way.

Behavior

Recently, UAVs have been used to study the behavior of wildlife, primarily on marine fauna (Bevan et al., 2016; Schofield et al., 2017; Tapilatu et al., 2017; Rieucau et al., 2018; Torres et al., 2018; Adams et al., 2020), they can be used to analyze and quantify interactions between individuals, probability of success mating attempts (Schofield et al., 2017) and record courtship and mating behavior (Bevan et al., 2016). The use of UAVs provides the opportunity to observe free-ranging sharks in their habitat and quantify their behavior and movements (Rieucau et al., 2018). Three studies have used drones to analyze the scavenging behavior of crocodiles and sharks (Gallagher et al., 2018; Lea et al., 2018; Tucker et al., 2021) and in other study they have been used to document hatchling movements of Leatherback Sea turtles (*Demochelys coriacea* Vandelli, 1761) during sea finding behavior and initial swimming behavior (Tapilatu et al., 2017).

The advantages of the UAVs for the studies of behavior include high-resolution video platform located at an optimal angle of observation, they provided three times more observational capacity than boat-based observations alone and it’s a cost-effective method (Schofield et al., 2017; Torres et al., 2018). The primary weakness of UAV is the limited flying time, since some behaviors can occur over many hours, environmental factors can limit the use of UAV for documenting behaviors and UAV flights can be limited to daylight hour (Tapilatu et al., 2017: Rieucau et al., 2018).

Poaching

Due to the increase in poaching and the loss and degradation of habitat, more and more species are threatened (Linchant et al., 2015), thus it is necessary to carry out regular monitoring to prevent this from happening. Drones have been used to prevent poaching of threatened and endangered species such as the black rhinoceros (*Diceros bicornis* Linnaeus, 1758) and the white rhinoceros (*Ceratotherium simum* Burchell, 1817), monitoring wildlife and hunting hunters in the area (Mulero-Pázmány et al., 2015), also drones can be used for monitoring conservation efforts in mountain areas during winter (Weber and Knaus, 2017). For this purpose, digital cameras, HD video cameras and thermal cameras have been used. The thermal cameras are used during the morning and during the night, when it is difficult to observe with the digital cameras in HD. The use of drones has proven its effectiveness and usefulness in monitoring the wildlife. However, there is not much information about the use of drones in the control of poaching.

Thermal sensors

Thermal cameras have passive sensors sensitive to the infrared band of the electromagnetic spectrum (Gade and Moeslud, 2014). They capture the infrared radiation emitted by bodies; infrared radiation is displayed in a color code of temperature, obtaining a thermal image of individuals. Several works have used digital cameras with thermal sensors mounted on drones for the identification and monitoring of wildlife (Brooke et al., 2015; Gonzalez et al., 2016; Sykora-Bodie et al., 2017; Gentle et al., 2018; Witczuk et al., 2018; Brunton et al., 2019; Carrasco-Escobar et al., 2019; Kays et al., 2019; Witt et al., 2020). Thermal sensors have been used to prevent damage caused to wildlife during harvest periods in agriculture (Christiansen et al., 2014; Witczuk et al., 2018) since thousands of animals die or are injured by agricultural machinery during harvesting, thanks to the use of thermal cameras it is possible to detect the wildlife that is hidden inside the crops and reduce their mortality.

Wildlife disturbances due to the use of drones and recommendations to avoid these disturbances

It has been shown that drones can cause disturbances to certain species when the necessary measures and precautions are not taken (Borsellino and Rebolo, 2017; Ditmer et al., 2015; Brunton et al., 2019; Rebolo-Ifrán et al., 2019; Schroeder et al., 2020). In marine birds, it has been seen that some species get dispersed when they are close to drones, and that a period of five minutes with a 20 m distance from the individuals is necessary for them to become accustomed to small drones before censuses can be taken (Brisson-Curadeau et al., 2017).

It has been reported that a takeoff 50 m away from some species such as penguins (*Aptenodytes patagonicus* Miller, 1778) can cause a warning reaction in individuals (Rümmler et al., 2016), another study recommends a takeoff 100 meters away from the species (Weimerskirch et al., 2018). In addition, it has been reported that, flying even four meters away, some species of birds seem not to change their behavior, such as wild flamingos (*Phoenicopterus*) and *Tringa nebularia* Gunnerus, 1767, which are known to have a high sensitivity to disturbances. It has been shown that the speed of approach, color and repeated approaches of the drone have not had significant impacts on the reactions of some birds (Weimerskirch et al., 2018). However, the angles of approach have marked impacts on the species.

In some countries (such as Canada and the United States), drones are only allowed up to a flight height of 120 m above the ground, where most birds are found. Territorial birds of prey can suffer disturbances when drones fly close to their nests, birds have been shown to increase their behavior when the drone approaches vertically (Lambertucci et al., 2015; Vas et al., 2015; Frixione and Salvadeo, 2021), perhaps because it is associated with a predator attack. However, its effects continue in investigation. There is little information about the disturbances that are caused to wildlife by using drones.

As precautionary measures when using drones, it is recommended to land and detach the drones at 100 meters or more from the birds, adjusting the approach distance according to the species (Lambertucci et al., 2015). Flying within the line of sight, at a certain height as specified by the regulations of the country where you are located, in most countries it is prohibited to fly at night, near people or near infrastructures and areas of government (Hodgson et al., 2017). In countries where there is no regulation, you are invited to fly with caution, regular equipment service and proper maintenance must be provided. Assessing the climatic conditions before flying the drone is fundamental, the biggest problems are caused when the wind is higher than 8 km/h for most of the drones (Weber and Knaus, 2017), this varies with the type of drone, so you must check the specifications of each one and avoid flying in unfavorable weather conditions.

It can be concluded that the UAVs are a low-cost tool, very effective for the study of wildlife. The technology of UAVs is increasing, developing more and more, with higher resolution cameras, drones with longer flight time and greater resistance to wind, its use has great potential for the study of wildlife. The advantages of the fixed wing drones are that they fly much faster than multirotor drones, and you can cover large worksites, but they cannot hover and require too much space. Multirotor drones are better in small spaces, they can hover over specific area to capture more information. It is recommended to evaluate the study that you want to carry out to later choose the type of drone that is most suitable for that study, since each type of drone has its advantages in certain areas and review the legal requirements for its use depending on each country.

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The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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