The effect of unmanned aircraft systems on predatory bird species

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A comparison between drone and other known wildlife disturbing agents

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Preface

I conducted this study to assess the effects of drone use on predatory bird species and compared them with other disturbing factors to determine if current laws that forbid drone use in nature reserves are based on correct assumptions. This literature study serves as my graduation thesis. I would like to thank my coach, Roy Veldhuizen, for assisting me during this process by providing feedback, and Kars Klein Wolterink for designing the front page.

Sander van den Broek
Zwolle, the Netherlands, July 2020

Samenvatting

Drones worden steeds vaker gebruikt door hobbyisten, voor het maken van video's en foto's, maar ook door wetenschappers in werkvelden als dierenecologie. Echter zijn de effecten van drones op wilde dieren niet goed beschreven in de huidige beschikbare literatuur.

Verschillende andere storende bronnen en de effecten op wilde dieren zijn wel breed beschreven in de literatuur. Deze storende bronnen onderscheiden zichzelf van andere met bron specifieke eigenschappen. Een aantal studies heeft het effect van drones op verschillende diergroepen onderzocht, maar er zijn geen onderzoeken die deze effecten op roofvogels hebben onderzocht. Het doel van dit onderzoek is om de effecten op roofvogels van de al beschreven storende bronnen te vergelijken met het effect van drones, aan de hand van een verzameling van beschikbare literatuur.

Veel onderzochte storende bronnen zijn: menselijke aanwezigheid, wegen, voertuigen, ontbossing en klimaatverandering. Ontbossing en klimaatverandering wordt niet besproken omdat deze niet te vergelijken zijn met drones. De storende eigenschappen van de gevonden storende bronnen die een rol speelden in het storen van wilde dieren zijn: fysieke grootte, naderende snelheid en geluid.

Geluid bleek een van de eigenschappen die het meest storende effect had op wilde dieren. Voornamelijk wanneer de bron van het geluid niet zichtbaar was voor het dier. De fysieke grootte van een storende bron speelt ook een rol in het storende effect. Een fysiek grote storende bron legt nadruk op het verschil in grootte met het dier. Dit resulteert in een groter storend effect.

Een storende bron kan kortstondige- of langdurige effecten veroorzaken. Alle effecten die niet langer aanwezig waren dan een dag werden beschouwd als kortstondig, bijvoorbeeld het vluchten voor een roofdier. Effecten die langer aanwezig bleven werden beschouwd als langdurig effecten, zoals fysieke schade of obstructie van het leefgebied. Voertuigen en de aanwezigheid van mensen veroorzaakten voornamelijk kortstondige effecten. Wegen veroorzaakten voornamelijk langdurende effecten. Roofvogels bleken extra gevoelig voor geluid, maar minder gevoelig voor fysieke grootte en naderende snelheid.

De conclusie is dat de effecten van drones erg vergelijkbaar zijn met de effecten van menselijke aanwezigheid en voertuigen met betrekking tot naderende snelheid en geluid, maar niet in fysieke grootte. Het is aannemelijk dat drones hierom soortgelijke effecten te veroorzaken als menselijke aanwezigheid en voertuigen. Overeenkomsten tussen de effecten van wegen en drones zijn niet gevonden.

Abstract

Unmanned aircraft systems or drones are becoming increasingly more popular, as well amongst hobbyists as for scientific research. They provide new ways for artists to creatively express themselves and make certain studies in fields as wildlife ecology much easier to execute. However, the effect of drones on wildlife is barely described in the literature available today.

There are multiple disturbing agents of which the effect on wildlife has been researched and published. These disturbing agents differentiate themselves from other with specific disturbing characteristics. There are some studies that researched the effect of drones on different animal groups, but there have been no studies that have researched the effect of drones on predatory bird species. This study aims to compare the effect of the already researched disturbing agents on predatory bird species with the effect of drones, using available literature.

Commonly described disturbing agents that were found were on-foot human presence, roads, vehicles, deforestation, and climate change. As deforestation and climate change were not or hardly comparable to drones, they were not further discussed. The disturbing characteristics of the disturbing agents that were found to have the most effect on wildlife were physical size, approaching speed and emitted noise.

Emitted noise was found to be the most influencing factor for disturbance on wildlife, especially if the animal is visually obstructed from the source of the noise. The physical size of a disturbing agent can also play a large role in the amount of disturbance on an animal. A larger disturbing agent can emphasize the size difference for an animal and also increase the loom rate, which results in more disturbance.

The disturbing agents can have either short-lasting or long-lasting effects. All effects that did not last longer than a day were considered short-lasting, for example anti-predator behaviour as fleeing. Effects that stay present for a longer period of time were considered as long-lasting effects such as physical harm or habitat obstruction. On-foot human presence and vehicles mostly caused short-lasting effects. Roads mostly caused long-term effects. Predatory bird species were found to be extra sensitive to noise, but less sensitive to physical size and approaching speed.

In conclusion, drones were found similar to on-foot humans and vehicles in terms of emitted noise and approaching speed, but different in physical size and are likely to cause similar effects. No similarities were found between the effect of drones and the effect of roads.

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1. Introduction

The use of small unmanned aircraft systems (also known as drones) for scientific research has grown quite a lot since 2010 as the technology keeps improving, making drones smaller and more affordable (Phys, 2017). Especially in fields as wildlife ecology, drones prove to be valuable assets by providing remote-sensing data at fine spatial and temporal scales, where traditional methods could not (Anderson et al., 2013; Christie et al., 2016; Hodgson et al., 2016). Although the use of fixed-wing airplanes and helicopters are effective for covering large research areas, they are expensive, known to disturb wildlife, and are the number one cause of work-related deaths among biologists (Christie et al., 2016). With all this in mind it is expected that drone use among scientists will further replace traditional methods in the coming years (Christie et al., 2016).

The non-commercial use of drones, as leisure flying, racing and amateur photo and videography, is becoming increasingly more popular (Engadget, 2019). In 2018 this growth increased to 170 percent, surpassing the predicted 44 percent growth by officials (Federal Aviation Administration, 2019). Drone Industry Insight, a market research agency, predicts the global value of the drone industry to be doubled to 38 billion by 2024 (Drones, 2019).

Many countries have developed drone laws to regulate drone use and guarantee the safety of the drones' surroundings (EASA Europa, 2019; Drone Traveller, 2019; UAV Coach). Common rules used worldwide, include an altitude limit, no flying in the dark, no flying over groups of people, roads, buildings, and no flying in close proximity to other aircrafts or airports (Kadaster; UAV Coach). Many more rules can apply and there are different rules for certain heavier drones.

New European drone laws, published in June 2019, enforce new drones to be individually identifiable (EASA Europa, 2019). This new set of European laws aim to replace country specific laws to enable drone users to follow the same set of rules seamlessly across borders. Patrick Ky, Executive Director of EASA said the following about these new laws: "*Europe will be the first region in the world to have a comprehensive set of rules ensuring safe, secure and sustainable operations of drones both, for commercial and leisure activities. Common rules will help foster investment, innovation and growth in this promising sector*" (EASA Europa, 2019).

Since January 2017, drone laws in the Netherlands have prevented drone pilots to fly above Natura 2000 biogeographical regions (Drone-nieuws, 2016). A set network of 165 smaller and larger nature reserves within the Netherlands, connected to harbour the natural state of conservation of protected plants and animals, forthcoming of European guidelines (Alterra; European Commission Europa, 2019; Ministerie van Infrastructuur en Waterstaat, 2018). Six of these nature reserves are common breeding grounds for many migrating and overwintering bird species (Overheid Nederland, 2016). Therefore, aside from specific exceptions, these areas are forbidden to enter year-round, which affectively also forbids the use of drones (Overheid Nederland, 2016). The use of model aircrafts within these areas is forbidden because the shadow casting could be similar to the silhouette of a predatory bird and thereby disturb breeding, resting or foraging birds (Overheid Nederland, 2016). The common helicopter like drones are, by this law, considered to have this same effect (Overheid Nederland, 2016). As per why drones specifically are forbidden to be used in the 159 remaining areas is not clearly stated by the article of law (Overheid Nederland, 2019).

The influencing factors, as well as the actual effect of drones on wildlife have not been completely identified, because drones are a relatively new development and thereby lack a broad scientific base (Jenni-Eiermann et al., 2017). However, there have been many studies on the effects of other wildlife disturbances. Such as animal responses to manned aircrafts and helicopters (Jenni-Eiermann et al., 2017; Efroymson et al., 2001), on-foot human presence (Tablado et al., 2017) and terrestrial vehicles (Jaeger et al., 2005; D'Amico et al., 2016). Effects vary from physiological reactions to reduction in fitness but may also lead to the avoidance of specific areas which could fragment the viability of populations (Jenni-Eiermann et al., 2017). These studies indicate that the effects are not just caused by the presence of the disturbing agent but mainly by the characteristics of it (Jenni-Eiermann et al., 2017; Tablado et al., 2017; Stankowich et al., 2005). Such as the size, speed, emitted noise, distance, and angle of approach (Jenni-Eiermann et al., 2017). Together these affect the level of risk perceived by the animal (Jenni-Eiermann et al., 2017; Tablado et al., 2017).

Drones share these disturbing characteristics but in completely different levels. Which begs the question as to how drones compare to other disturbing agents when it comes to influencing various bird species. It is important to have an answer to this question to write fair laws on the regulation of drone use, whether it is scientific or non-commercial use, in nature reserves. This study aims to answer this question, with the focus on predatory bird species, by comparing similarities and differences between drones and other disturbing agents by utilizing previously conducted studies. The main research question, "How does the effect of drones on predatory bird species compare to other known disturbing agents?", will be answered by asking the following sub-questions; "Which disturbing agents are known to have short and/or long-lasting negative effects on bird species?", "What are the similarities and differences between the currently known disturbing agents?" and "How do these similarities and differences differentiate in effect on predatory bird species?".

Direct effects from disturbing agents on bird species are expected to be fight or flight responses (Jenni-Eiermann et al., 2017; Tablado et al., 2017; Stankowich et al., 2005). Longer or larger disturbances are in some cases expected to affect spatial use, which would result in animals avoiding a certain area. (Jenni-Eiermann et al., 2017; Tablado et al., 2017) It is expected that the differences between disturbing agents will mainly be physical size, approaching speed, approaching angle, emitted noise, distance, etc (Tablado et al., 2017). Despite these many differences it is expected that all disturbing agents will initially induce similar anti-predator responses but will differ in severity (Tablado et al., 2017; Stankowich et al., 2005). Drones are expected to have similar, but less severe, effects on animals as other disturbing agents, as the disturbing characteristics are not as extreme (Jenni-Eiermann et al., 2017).

2. Material & Methods

To answer the main- and the sub research questions a literature study was conducted. In this chapter the methods used to find the required studies and other sources will be clarified. The search terms that were used will be listed below. Furthermore, the way in which acquired studies were analysed will be explained.

2.1 Method

Multiple search engines were used to find the sources that were used to write this study. The main search engine used to find news related, law documents, or other non-scientific sources was Google. Google Scholar was used to find scientific studies related to the topic. Some scientific sources were found by reading the references of previously used studies. The use of studies from Science Direct, Wiley Online and Springer was possible due to the access supplied by Aeres University. Mostly English terms were used to find the used sources, however, to find law documents of the Netherlands the Dutch language was used. In some occasions Google Translate was used to find synonyms for specific words.

The gathered information from sources was either directly included in the study or saved to a separate document to be used later. The links to all sources were first copied down and later transcribed following the APA rules.

2.2 Library

The search terms used to find the required sources are listed in table 1.

Search engine	**Search term**
Google	Hoeveel natura 2000 gebieden zijn er
	Natura 2000 drones
	Drone laws worldwide
	European drone laws
	Wet natuurbescherming
	Drone laws the Netherlands
	Overzichtkaart drone Kadaster
Google Scholar	Wildlife disturbance
	Drone stress wildlife
	Drone effect wildlife
	Animal fear responses
	Human presence wildlife stress
	Punctual behaviour animals
	Drone effect nature reserves

2.3 Criteria

As drones have only become publicly accessible in the recent years, it was not necessary to specifically focus on during what year a drone related study was executed. Non-scientific sources were only used if they referred their source of information and was only accepted from widely known websites. Some specific, news related, sources were confirmed by finding other sources that supported the information or by reading the referred sources. Information that would not contribute to study was not included.

2.4 Analysis

The title and abstract were read to specify if the found studies were useful. If these two aspects held any information relevant to this study, the introduction and conclusion were read. The results and discussion were only read if specific information from it was required. Sometimes the search function was used to quickly find certain terms within a study. When useful information was found it was written down to be used later in the results chapter.

3. Results

In this chapter all the results necessary to answer the research sub-questions will be presented. In 3.1 commonly documented disturbing agents and their effects on wildlife will be divided up in short- and long-lasting effects. An effect is considered short-lasting if it does not affect the animal for more than a day. These results will be further discussed in chapter 4.

3. Sub-question one

In this sub-chapter the results required to answer the question “Which disturbing agents are known to have short-lasting and/or long-lasting negative effects on bird species? “will be shown. A factor is labelled disturbing if it damages an animal’s health, or affects their distribution, abundance, reproduction, survivorship, genetic composition, or habitat use (Kerlinger et al., 2013). A factor is also considered to be disturbing if it causes a detectable change in behaviour (Kerlinger et al., 2013; Richardson et al., 1997). These known disturbing agents either cause a short-lasting effect, such as a flight response to an emitted noise, or a long-lasting effect, such as a busy road closing off a habitat (Jaeger et al., 2005; Blumstein, 2003 & Blumstein et al., 2003).

3.1.1 Short-lasting effects

Short-lasting effects that disturbing agents can have on birds and other forms of wildlife include anti-predator behaviour, bursts of physiological stress, temporary area avoidance and observable changes in behaviour (Bokony et al., 2009). A stressor causes a bird to flee if it is perceived as a possible threat. There are multiple factors that influence whether something is perceived as a threat or a non-threat, including approaching speed, physical size, scent, and noise. One of the most important factors to the flight response however is the distance at which the animal starts to perceive the possible threat.

3.1.2 Long-lasting effects

When faced with a more severe or threatening disturbing factor, animals may experience long-lasting effects. Showing altered behaviour is a response of wildlife to a disturbance. Long-lasting effects include, long-lasting altered behaviour, altered fitness, a change in productivity of the individual. But also, effects on a population or community level, as changes in abundance, distribution, and species composition (Kerlinger et al., 2013; Tablado et al., 2017).

One of the obvious causes would be physical harm (Papouchis et al., 2001). When an animal gets physically harmed not only does it lower the animal’s survivability by reducing its fitness. It may also negatively affect the animal’s ability to find food and water and the reproduction rate by making it harder to move and find a mate.

Area avoidance is another long-lasting effect, mostly induced by regular or constant disturbance from a certain disturbing factor. A typical example would be area avoidance caused by a busy road. In a previously conducted research, in the woodlands in the Netherlands, the density of a breeding bird population had a reduction of up to 98% close to roads. They found that the visibility of cars had little to no effect on the population, but noise seemed to be the number one cause of this regression (Reijnen et al., 1995).

On a global scale it was found that as the human footprint increases, an animals nocturnality increases. A study by Gaynor (2018) indicated an average increase in nocturnality by a factor of 1.36 in response to human disturbance.

3.1.3 Described disturbing agents

Commonly described wildlife disturbing agents are on-foot human presence, vehicles, roads, deforestation, and climate change (Jaeger et al., 2005; D'Amico et al., 2016; Tablado et al., 2017). As deforestation and climate change are not similar to drones and are more large-scale disturbing agents, further discussion will be limited to on-foot human presence, vehicles, and roads.

On-foot human presence

To reduce human impacts on wildlife, wildlife managers often develop buffer zones. Buffer zones are predefined areas that stand in between animal habitats and human disturbances (Blumstein, 2003; Blumstein et al., 2003). During the development of these buffer zones wildlife managers often make use of the 'flight initiation distance' (FID) (Blumstein, 2003; Blumstein et al., 2003). This is the distance at which an animal starts to flee as a reaction to an approaching predator (Blumstein, 2003; Blumstein et al., 2003). Many variables have shown to influence FID, including disturbance source, approaching distance, site specific variables and approaching speed, but also depends on variables related to the animal itself, such as type of animal, life-history and state and level of aggregation (Mulero-Pázmány et al., 2017; Blumstein et al., 2003). Blumstein (2003) found that the FID can also be specific to species.

Another measurement of animal tolerance towards human approaches is the distance at which an animal starts to exhibit alert behaviours, also known as the alert distance (Ferández-Juricic et al., 2001; Ferández-Juricic et al., 2002). Just as FID, there are multiple variables that influence the alert distance. One of which is Habitat structure. Bird tolerance to human approach, and so the alert distance increased where there was more cover or were more escape options available (Ferández-Juricic et al., 2001). The alert distance is also specific to species, with smaller species being more tolerant to human approaches then larger ones. The difference between alert and flight distance acts as a buffer in which a bird's reaction may vary depending on the behaviour of the approaching human. The alert distance is therefore deemed to be a more conservative measurement than FID (Fernández-Juricic et al., 2002; Ferández-Juricic et al., 2001; Blumstein et al., 2003; Blumstein, 2003). Figure 1 shows a schematic representation of the difference between the alert distance and flight initiation distance.

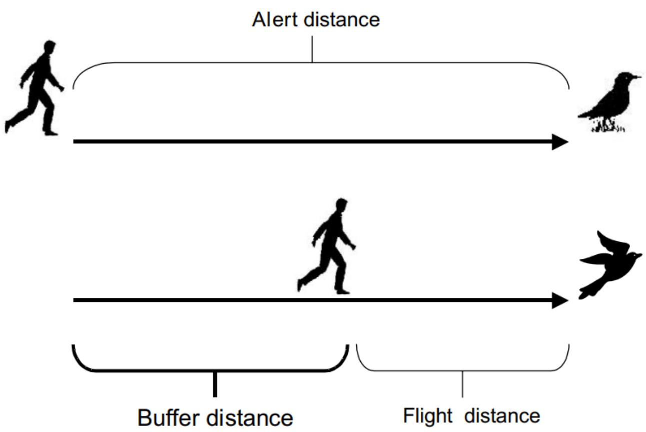

Figure 1: Schematic representation of buffer distance, which is the difference between alert and flight distances (Fernández-Juricic et al., 2002)

Vehicles and roads

A study in Utah found that bighorn sheep are more likely to flee from on-foot humans than approaching vehicles (Papouchis et al., 2001; Jaeger et al., 2005). They suspect this to be because of the following three reasons. Hikers move less predictable than vehicles and often approach the animals directly. Secondly, vehicles appear relatively static, especially compared to body motions associated with animal and human movement and may therefore not be perceived as a threat. Because of this it may also be difficult for animals to gauge the speed of an approaching vehicle, which make them harder to evade. Lastly, vehicles lack an organic scent and may therefore not deter animals as strongly as on-foot humans or animals (Papouchis et al., 2001).

It is common for population densities to decrease when they are adjacent to roads (Reijnen et al., 1995; Papouchis et al., 2001). A study carried out in woodlands in the Netherlands investigated the effect of car traffic on the breeding density of birds and found a reduction in population amongst 26 out of 43 researched species (Reijnen et al., 1995). When the visibility of the cars was controlled the reduction of population density was much higher in plots where there was a lot of noise than plots where there was little noise. When the emitted noise was controlled there was no difference in population density between plots with high and low visibility of the road. They therefore argue that noise emitted by the vehicles is the largest factor that causes this reduction in population density (Reijnen et al., 1995).

3.2 Sub-question two

In this sub-chapter the following question will be answered "What are the similarities and differences between the currently known disturbing agents?". All disturbing agents have unique characteristics that differentiate them from others and so have different effects on wildlife. As noted before commonly described characteristics are physical size, approaching speed and emitted noise (Jaeger et al., 2005; Christie et al., 2016; Mulero-Pázmány et al., 2017; Blumstein et al., 2003; Fernández-Juricic et al., 2002). Other characteristics that may influence the effect or its severity is the regularity or consistency of the disturbing agent. If a certain disturbing agent only gets in contact with an animal once it will most likely only result in short-lasting effects. However when a disturbing agent gets into contact with an animal on a regular basis, as a busy road or on-foot humans in a park, it will sooner result in long-lasting effects such as area avoidance and habitat reduction (Mulero-Pázmány et al., 2017; Blumstein, 2003; Reijnen et al., 1995).

Physical size

The physical size of an approaching subject (e.g. a person or vehicle) plays a role in the perceived danger of an animal (Stankowich et al., 2005). The perceived risk increases as the approaching subject physical size gets larger (Stankowich et al., 2005). The larger size will emphasize the size difference between the possible threat and the animal and increases the loom rate. 'This is the rate of change of the angle subtended by the predator at the prey's eye' (Stankowich et al., 2005).

The size differences between the previously listed disturbing agents are apparent. Approaching vehicles are significantly larger than approaching humans. Especially in width and depth.

Approaching speed

There is a large difference between the approaching speed of on-foot humans and vehicles. A human's speed ranges from 5 km/h up to 9 km/h when walking and while running may vary from 15 km/h to 25 km/h on average (Mohler et al., 2007; Levine et al., 1999). A vehicle approaching speed can vary anywhere from 10 km/h up to 200 km/h if a given road support such speeds.

An increased approaching speed of a possible threat increases the perceived danger for the affected animal (Jaeger et al., 2005; Christie et al., 2016; Mulero-Pázmány et al., 2017).

Emitted noise

The amount of noise emitted by a disturbing agent has a big effect on an animals ability to perceive it from a distance, but also plays a role in the actual disturbance of wildlife (Jaeger et al., 2005; Reijnen et al., 1995). When a disturbing agent, such as a road, emits a lot of noise animals will keep their distance, leading to area avoidance and possible habitat size reduction (Reijnen et al., 1995). This noise avoiding behaviour is very common among bird species in the Netherlands (Reijnen et al., 1995).

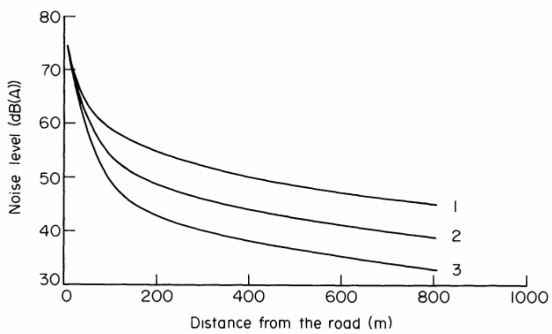

Figure 2: Estimation of the noise load of car traffic along a highway with 50 000 cars per day and a speed of cars of 120 km/h based on Moerkerken & Middendorp (1981) and Huisman (1990). 1 = open field; 2 = proportion of woodland along the road 05; 3 = proportion of woodland along the road 1 0 (Reijnen et al., 1995)

As shown in figure 2, the noise level can reach up to 60db at a distance of 200m from a road with 50.000 cars passing a day, at an average speed of 120km/h. (Reijnen et al., 1995). In comparison, a normal human conversation between humans at an average conversation distance is about 60db

3.3 Sub-question three

In this sub-chapter the question "How do these similarities and differences differentiate in effect on predatory bird species?" will be answered. Previously mentioned disturbing agents will have different effects on different animal species. In this sub-chapter human presence, vehicles and roads, and their influence on predatory bird species will be discussed.

Human presence

Human vicinity has a large effect on multiple predatory bird species, even more so than other animal groups or species (Richardson et al., 1997; Holmes et al., 1993). To outdoor recreationists the effect of their activities on wildlife and particularly predatory birds may seem minimal. But activities like rock climbing or other sports where communication through shouting is common, like football or other team sports, can have severe effects on nesting raptors (Richardson et al., 1997). These noises can keep predatory birds away from their nests which can lead to parent birds missing feedings, or to overheating or chilling of the eggs, but may also prevent the parent birds from protecting their eggs or younglings from predators (Richardson et al., 1997).

Some Peregrine falcons (*Falco peregrinus*) have shown to be extremely sensitive and sometimes refuse to breed if humans have been in their nest's vicinity (Richardson et al., 1997). Ferruginous hawks (*Buteo regalis*) may desert their nests if the adults themselves are exposed to human activity during the incubation period (Richardson et al., 1997). The disturbance of these species during these critical moments can be fatal to embryos and younglings.

These impacts of human activities are often also dependent on if the predatory birds can visually perceive it and can therefore be reduced by visually shielding the animals from these activities (Richardson et al., 1997).

Vehicles & Roads

Like suggested for other animal groups, predatory birds seem to be less sensitive to vehicle disturbance than on-foot human disturbance. Holmes (1993) suggested that most of their researched animal species were less likely to flee from approaching vehicles than pedestrians. Similar behaviour has been noted for bald eagles (*Haliaeetus leucocephalus*) and various species of waterfowl (Holmes et al., 1993; Richardson et al., 1997). Humans approaching are perceived as a bigger threat, and thus disturbance, than vehicles, which approach at faster speeds. (Holmes et al., 1993).

It was found that Rough-legged hawk (*Buteo lagopus*) individuals that were nested near a road started to exhibit anti-predator behaviour at greater distances than individuals nested further away from a road (Holmes et al., 1993). Suggesting that road vicinity can influence its behaviour over longer periods of time. American kestrels (*Falco sparverius*), Prairie falcons (*Falco mexicanus*), and Ferruginous hawk (*Buteo regalis*) individuals that nested high off the ground exhibited anti-predator behaviour at shorter distances than other individuals of the same species nested closer to the ground (Holmes et al., 1993). These findings suggest that the tolerance towards disturbing agents decreases when the disturbing agent is within a closer vicinity to the animal (Holmes et al., 1993).

4.Discussion

In this chapter the results from chapter 3 will be interpreted. Alongside with a review of the research method and an evaluation of the scope of the study.

4.1 Results interpretation

In the results section the commonly described disturbing agents and their effects on certain animal groups have been described and compared. Hereafter it is described how these disturbing agents affect certain predatory bird species. To assess the possible disturbing effect of drones on predatory bird species the disturbing factors of the described disturbing agents will be compared to similar factors in drones. This comparison will be based on the collected literature to answer the sub-questions and the main research question, respectively.

The described disturbing agents have short-lasting and/or long-lasting effects on wildlife. Long-lasting effects have only been found where a constant disturbance was present, for example the constant influence of a busy road in an animal's vicinity. Short-lasting effects have only been found to be the result of disturbing agents as on-foot human presence. These short bursts of anti-predator behaviour or similar sudden changes in behaviour are also described in some studies that researched animal responses to drones (Mulero-Pázmány et al., 2017; Christie et al., 2016).

The short-lasting effects caused by disturbing agents as on-foot human presence are depended on multiple factors from disturbing agents, as well as factors from the affected animal. These factors influence the type of animal response as its severity. One of these factors is the physical size of the disturbing agent compared to the physical size of the affected animal. Larger sized disturbing agents were found to cause negative effects more frequently than smaller sized disturbing agents, based on an increasing FID with larger disturbing agents. This increased effect larger disturbing agents have on wildlife is caused by the increased loom rate which increases the perceived danger for the affected animal. The approaching speed of a possible threat is another factor that influences the animals perceived risk. When the approaching speed increases, so does the perceived risk. However, it is also found that it can be rather difficult for animals to gauge the speed of approaching objects that move relatively static compared to humans or predatory species, such as vehicles or drones. When approaching bird species with drones, the approaching speed did not make a significant difference (Vas et al., 2015). This is likely due to the previously stated fact that animals find it hard to gauge the speed of static moving objects. Noise emission of a disturbing agent is one of the most important factors that influence the animal's perception of risk. An increase of noise emission was found to increase the perceived risk, especially when the disturbing agent could not visibly be perceived by the animal.

Predatory bird species are found to react more severely to these disturbing agents than other species. Mainly the emitted noise and visibility of the disturbing agents causes the predatory birds to exhibit anti-predator or abnormal behaviour. Activities where communication through shouting is common are known to have severe effects on nesting predatory birds as it can keep them from their nests. These activities can lead to parents missing feeding moments and prevent them from protecting their younglings from predators. Thus, a high amount of emitted noise can be catastrophic to predatory bird species. The ability to visibly perceive a disturbing agent is another important factor of the perceived risk the animal experiences. It was found that when predatory bird species were visually shielded from human activities, the negative impact of said activities can be reduced.

The disturbing factors in drones are similar to that of other disturbing agents. However, the intensity of these factors can differ greatly among different types of drones. Especially physical size and the amount of emitted noise is greatly depended on what type of drone is used. The most commonly used drones for leisure flying are electric-powered drones. Other use cases sometimes require the use of fuel-powered drones, a type of drone that is commonly larger, and generates more noise, than electric-powered drones (Mulero-Pázmány et al., 2017). As shown in figure 3 wildlife has a higher probability of exhibiting a reaction towards fuel-power drones than electric-powered drones, this difference is deemed to be caused by the difference noise level both drones emit and the difference in size (Mulero-Pázmány et al., 2017). A fuel-powered drone generates an average of 85db at a 6m distance and have an average wingspan of 3m (Hodgson et al., 2013). In comparison, a common electric-powered drone, used for leisure flying, generates an average noise level of 75db at a 1 to 2-meter distance and have an average size of about 30cm (Dronethusiast, 2020).

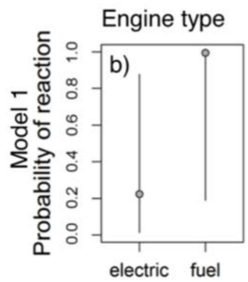

Figure 3: Mean probability of wildlife reaction with 95% CrI according to drone engine type (b). (Model: 0 = no reaction vs. 1 = reaction [either alert or active; N = 167]; (Mulero-Pázmány et al., 2017)

It was found that larger bird species were more likely to react to drones than smaller ones (Mulero-Pázmány et al., 2017). This is likely due to a wider range of awareness that larger birds have (Mulero-Pázmány et al., 2017). However, is it speculated that wildlife is not directly affected by the noise level a disturbing agent emits, but rather by the fluctuation of noise levels (Mulero-Pázmány et al., 2017).

4.2 Scope of the study

This study focusses on the effect of drones on predatory bird species. The effects found apply to predatory bird species worldwide and can thus be relevant to many use cases, such as wildlife management, scientific studies or as a basis for legal frameworks. However, as the effects are generalized to predatory species as a group, effect severity or frequency can be specific to habitat location, species, or even individual predatory birds.

4.3 Review and validity of research method

The results this study is based on are acquired through a literary study. The validity of this study can be confirmed because the same results will be found if the same sources were to be used.

To assess the effect of drones on wildlife, the characteristics of drones were compared with the characteristics of other disturbing agents. However as of now, the effects of the already broadly described disturbing agents are still being questioned.

Certain aspects that are researched in this study lack a broad scientific base. For example, there are few field studies that research the effect of unmanned aircraft systems on wildlife in general, let alone predatory bird species. The studies that do research this topic make little or no distinction between quadcopter drones, commonly used for leisure flying, and winged unmanned aircraft, which are mostly used for scientific research. The characteristics, and therefore the effects on wildlife, of these two types of drones may drastically vary. Because of this lacking scientific base, a distinction between quadcopter drones and winged unmanned aircraft could also not be made in this study.

5. Conclusion

The sub-questions and main research question will be answered in this chapter. The goal of this study was to assess the disturbing effect of drones on predatory bird species, by comparing drones to other known disturbing agents based on available literature.

5.1 Answers to the sub-questions

Sub-question 1: "Which disturbing agents are known to have short- and/or long-lasting negative effects on bird species?"

Commonly described wildlife disturbing agents are on-foot human presence, vehicles, roads, deforestation, and climate change. On-foot human presence and vehicles mostly have short-lasting negative effects on bird species. Where the placement of roads mostly has long-lasting negative effects.

Sub-question 2: "What are the similarities and differences between the currently known disturbing agents?"

The mentioned disturbing agents differentiate themselves with their disturbing factors such as approaching speed, physical size, and emitted noise. On-foot human presence has a relatively small physical size and emits an amount of noise that can be disturbing to wildlife. Vehicles have a large physical size that can be threatening to wildlife and emits a high amount of noise that is known to disturb wildlife. Roads, especially ones with lots of high-speed traffic, emit a high amount of noise that can reach far into wildlife habitats and is known to decrease the population density. The approaching speed of on-foot humans can vary and is only considered a large factor in disturbance when humans run towards animals. The approaching speed of vehicles differs per area. It is described that animals may find it difficult to gauge a threat's speed when it moves relatively static compared to movements associated with animal movements and predators. Which is the case for vehicles and drones.

Sub-question 3: "How do these similarities and differences differentiate in effect on predatory bird species?"

The short-lasting effects that disturbing agents have on many animal species are often more severe on predatory bird species and can often lead to catastrophic long-lasting effects. When humans are in the vicinity of a predatory bird it may often scare it away and can refrain it from coming back to the nest while the humans are still present. This can lead to the death of fledglings. They are scared off by both the sounds that humans produce and by visually perceiving them. Predatory bird species are less sensitive to vehicle disturbance than other bird species or other animal groups. Nesting close to roads can however lead to long-lasting effects on an individual's behaviour, as it was found that certain individuals that were nested close by a road started to exhibit anti-predator behaviour at greater distances than individuals nested further away from a road.

5.2 Answer to the main research-question

The main research question is "How does the effect of drones on predatory bird species compare to other known disturbing agents?"

Depending on the type of drone that is used, fuel- or electric-powered, the amount of emitted noise may vary. However, at close ranges, both types can generate an amount of noise that is disturbing to wildlife. Both type of drones can reach speeds similar to cars, which may have an effect on wildlife. However as stated before, animals find it difficult to gauge the speed of an object that moves relatively static. This may also apply to drones just as it does to cars and other vehicles.

As the use of drones, whether its leisure flying or for scientific studies, will most likely never be as constant of a disturbing agent as roads, they are considered to have no long-term effects on wildlife, including predatory bird species.

The emitted noise by drones will have the same or similar effects on predatory bird species as the noise emitted by other disturbing agents. The animals will get scared away from their nests and can be forced to stay away while the drone is audibly present. With the large size difference between drones and other vehicles it is not possible to state with any certainty that the effect of a visually present drone will have the same effect as a visually present vehicle. However, as visually shielding predatory bird species from disturbing agents proved to be effective for limiting the disturbance, this can also be true for drones.

5.3 Recommendations

To further asses the effect of drones on predatory bird species, but also on wildlife in general, it would be advisable to do a field study where the effect of disturbing agents is measured, including the effect of different drone types. To harbour the most conclusive results this study should be executed in the natural habitat of different predatory bird species. Since literature argues that drones are a potential disturbance, conducting this kind of research is not ethical.

To limit the disturbance of drones on predatory bird species with legal frameworks, it is suggested to prevent the use of drones within areas where predatory bird species are known to nest.

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