

EVALUATING THE POTENTIAL UTILITY OF DRONES TO DETER BIRDS FROM  
AREAS OF HUMAN-WILDLIFE CONFLICT

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**Title**

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**MASTER OF SCIENCE**

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## ABSTRACT

Predator-prey dynamics shaped the evolution of morphological and behavioral adaptations that foraging animals use to detect and avoid predators. Wildlife managers can potentially exploit antipredator behavior when attempting to deter animals from areas of human-wildlife conflict. A promising new tool in the field of wildlife damage management is the unmanned aircraft system (UAS; or drone), which might be able to overcome the mobility limitations of other deterrent strategies. The main objective of my study was to determine the behavioral response of blackbirds (Icteridae) to three drones, using a predator model, a standard fixed-wing, and a multicopter as candidate platforms. I evaluated the behavioral response of individual, captive red-winged blackbirds (*Agelaius phoeniceus*) to the three drones approaching at direct and overhead trajectories, and I evaluated their efficacy on eliciting escape and resource-abandonment behavior in free-ranging blackbird flocks.

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## **DEDICATION**

I dedicate this thesis to my parents, who never question my pursuit of happiness:

chasing animals for low wages, often in far off places.

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## LIST OF ABBREVIATIONS

AD.....	Alert Distance
AGL .....	Above Ground Level
APHIS .....	Animal and Plant Health Inspection Service
ATOC.....	Aviation Safety, Training, and Operations Center
FAA.....	Federal Aviation Administration
FID .....	Flight Initiation Distance
FPS .....	Frames Per Second
JND .....	Just Noticeable Difference
NWRC.....	National Wildlife Research Center
PPR .....	Prairie Pothole Region
RC .....	Radio Controlled
UAS.....	Unmanned Aircraft System
USDA.....	United States Department of Agriculture
WS.....	Wildlife Services

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## CHAPTER 1: INTRODUCTION

There is growing evidence that animals respond to human disturbance (e.g., moving vehicles, walking pedestrians) using behavior strategies adapted to avoid natural predation risk (Frid, & Dill, 2002; Blumstein, & Fernández-Juricic, 2010; Lima et al., 2015). This risk-disturbance hypothesis (Frid, & Dill, 2002) allows wildlife managers to predict how wildlife will respond to anthropogenic disturbance using economic models based on antipredator behavior (Ydenberg, & Dill, 1986; Bejder et al., 2009; Bernhardt et al., 2010). Consequently, the antipredator behavior of animals can potentially be exploited to optimize efficacy of wildlife management tools (e.g., visual deterrents; Blackwell et al., 2016). For example, efficacy of visual deterrents could be increased by incorporating characteristics of natural predators (e.g., shape, pattern, size), allowing wildlife managers to enhance the predation risk an animal assesses toward unnatural stimuli (DeVault, Blackwell, & Belant, 2013; Blackwell et al., 2016).

If the energetic costs of devoting time to antipredator behavior (i.e., scanning and monitoring) outweigh the fitness-benefits provided by a resource patch, given alternative resource patches are available and the animal has knowledge of these resources, an animal may decide to leave an area entirely (Frid, & Dill, 2002; Bejder et al., 2009). Theoretically, wildlife managers could enhance the predation risk perceived by target species, and ultimately encourage wildlife to abandon a resource patch in zones of human-wildlife conflict (Blumstein, & Fernández-Juricic, 2010; Blackwell et al., 2016). Effectively manipulating the predation risk perceived by target species will require a clear understanding of how the species detects, assesses, and ultimately avoids threats (Blumstein, & Fernández-Juricic, 2010).

For an animal to survive, it must meet its energetic demands by foraging while avoiding predators. Early detection is a crucial step to surviving predator encounters (Tyrrell, &

Fernández-Juricic, 2015). The distance at which prey are able to detect approaching threats depends on the interaction between an animal's sensory systems and the time dedicated to detecting predators, otherwise known as vigilance (Beauchamp, 2015). For many years, foraging and vigilance were deemed exclusive in models of antipredator vigilance, but Lima and Bednekoff (1999a) challenged the assumption that nonvigilant animals, or animals foraging with their head down, are unable to detect predators. They instead suggested that animals alternate between low-cost, low-quality vigilance (i.e., head down foraging, head close to food) with high-cost, high-quality vigilance (i.e., head up posture, head away from food; Lima, & Bednekoff, 1999a).

Although some animals can detect predators in a head-down posture, the probability of detection is much higher when the head is up (Lima, & Bednekoff, 1999a; Tisdale, & Fernández-Juricic, 2009). Predator detection probability decreases by 65% in European starlings (*Sturnus vulgaris*) as individuals shift from a head-up vigilance posture to a head-down foraging posture, suggesting the blind area above and behind the head limits an individual's visual coverage and detection window (Tisdale, & Fernández-Juricic, 2009). Visual acuity can also influence predator detection (Blackwell et al., 2009; Tisdale, & Fernández-Juricic, 2009). Blackwell et al. (2009) defined the detection window of mourning doves (*Zenaida macroura*) and brown-headed cowbirds (*Molothrus ater*) by assessing the relationship between threat-detection, avoidance, and species-specific visual properties (e.g., visual fields and visual acuity). These authors found that the mourning dove, a species with better visual acuity and wider visual fields than the brown-headed cowbird, detected approaching vehicles more quickly than the brown-headed cowbird (Blackwell et al., 2009). These studies emphasize the importance of incorporating species-

specific visual properties when assessing antipredator response of avifauna toward disturbance stimuli (see Tyrrell, & Fernández-Juricic, 2015).

Following predator detection, animals face a sequence of behavioral decisions that can improve their likelihood of surviving an impending attack (Lima, & Dill, 1990; Cooper, & Blumstein, 2015). Individuals might signal to the predator or to nearby conspecifics by alarm calling or other behaviors (Edelaar, & Wright, 2006; Devereux et al., 2008; Beauchamp, 2015), and if the threat persists, decide to flee or remain (Ydenberg, & Dill, 1986). The obvious benefit of escaping predators is survival, but prey that successfully flee from predators do so at a cost (Ydenberg, & Dill, 1986). The cost of fleeing may include lost foraging or mating opportunities, a weakened territory defense, or other activities that would otherwise provide fitness benefits (Ydenberg, & Dill, 1986; Blumstein, 2003; Cooper, & Blumstein, 2015).

Following exposure to predator attacks, an animal may alter its behavior to accommodate a new level of perceived predation risk (Devereux et al., 2006; Jones, Krebs, & Whittingham, 2007). European starlings increased scan intervals (i.e., head up duration) and decreased interscan intervals (i.e., head down duration) following exposure to a simulated raptor attack (Devereux et al., 2006). Similarly, chaffinches (*Fringilla coelebs*) increased head-turning rate and waited longer to return to foraging following exposure to a cat model when compared to a non-threatening object (Jones, Krebs, & Whittingham, 2007). Enhancing perceived predation risk could potentially decrease the foraging efficiency of animals as they allocate more time to vigilance behavior and less time to foraging (Bednekoff, 2007; Ferrari, Sih, & Chivers, 2009).

Lima and Bednekoff (1999b) developed a risk allocation model to predict how animals alter their behavior under different scenarios of predation risk. The model predicts that animals optimize the tradeoff between vigilance and foraging by increasing vigilance (i.e., decreasing

foraging) during periods of increased predation risk and decreasing vigilance (i.e., increasing foraging) during periods of low predation risk (Lima, & Bednekoff, 1999b). The model assumes that an animal consumes a fixed-amount of food per day to meet its energetic demands, and the animal can afford to temporarily reduce foraging effort during brief moments of high predation risk without risking starvation (Lima, & Bednekoff, 1999b; Ferrari, Sih, & Chivers, 2009). This risk allocation hypothesis may not apply to all foragers however, as some prey species are capable of scanning for predators while simultaneously manipulating food items (Lima, Zollner, & Bednekoff, 1999; Cresswell et al., 2003).

Generally, studies evaluating animal reactions to approaching threats have used alert distance and flight-initiation distance as metrics of perceived risk (Cooper, & Blumstein, 2015). Alert distance (AD) indicates the distance animals begin to overtly focus attention toward monitoring an approaching threat (Fernández-Juricic, Jimenez, & Lucas, 2001; Cooper, & Blumstein, 2015), and is defined as the distance between the approaching stimuli and a focal individual when the latter's behavior changes from a relaxed state to an alert vigilant state (Fernández-Juricic, Jimenez, & Lucas, 2001; Blumstein et al., 2005). In passerines, this behavior can be indicated by neck extension, sudden head-up scanning movements, crouching, and feather compression (e.g., Blackwell et al., 2009; DeVault et al., 2015; Doppler et al., 2015). Until recently, AD had been used as an indicator of detection distance (Blumstein et al., 2005), but recent studies that evaluated the visual perception of birds suggest detection distance and AD can be divergent (Tyrrell, & Fernández-Juricic, 2015).

For example, Blackwell et al. (2009) estimated the distance mourning doves and brown-headed cowbirds are capable of resolving an object occurs at around 1,000 m. During vehicle approach however, both species became alert between 70 – 100 m, suggesting animals may



detect a threat but delay behavior transitions until full attention becomes necessary (Blackwell et al., 2009; see also Blumstein, & Fernández-Juricic, 2010; Tyrrell, & Fernández-Juricic, 2015). Recently, alert behavior has been suggested as denoting the beginning of a period of high-quality risk assessment toward an approaching threat and prior to escape (Cresswell et al., 2009; DeVault et al., 2015), while overall risk assessment may begin before an obvious change in behavior (Tyrrell, & Fernández-Juricic, 2015).

Flight initiation distance (FID) is the distance between prey and an approaching threat at which the prey initiates escape (Ydenberg, & Dill, 1986; Cooper, & Blumstein, 2015). Ydenberg and Dill (1986) developed a quantitative model to predict FID. This economic model predicts prey should flee from a predator when the cost of remaining (i.e., loss of fitness due to predation) equals the cost of fleeing (i.e., loss of fitness due to abandoning foraging opportunities; Ydenberg, & Dill, 1986). According to the model, animals will initiate flight at farther distances when predation risk increases (Ydenberg, & Dill, 1986). Blumstein (2003) modified this model to include three zones of distance relative to the prey animal. In the farthest zone, a predator may be too far away to be detected or may be detected but not yet perceived as threatening. In the intermediate zone, a predator is assessed as a threat and a prey species will make an escape decision when the cost of fleeing equals the cost of remaining. In the closest zone, a prey species is unable to detect a predator until it approaches to a distance where the cost of remaining exceeds the cost of fleeing, and the prey will flee as soon as possible (Blumstein, 2003). In birds, several factors have shown influence on FID including body size, urbanization, hunting pressure, and habitat structure (Møller, 2015), as well as the presence of conspecifics (Fernández-Juricic, & Schroeder, 2003). Additionally, predator characteristics such as approach speed, size, and directness of approach can lead to increased FID in wildlife (Stankowich, & Blumstein, 2005).

Following the discovery that FID in birds was dependent on the starting distance of an approaching threat (Blumstein, 2003), a new theory was posited, *Flush Early and Avoid the Rush* (FEAR), to predict escape behavior in prey (Blumstein, 2010). The FEAR hypothesis predicts that prey will escape shortly after detecting predators to reduce energetic costs (i.e., reduced foraging efficiency) associated with directing attention towards monitoring a predator approach (Blumstein 2010). According to this hypothesis, enhancing detection distance of an approaching predator or perceived threat could theoretically increase FID in a target species (Cooper, & Blumstein, 2014; Blackwell et al., 2016). For example, increasing the distance wildlife can detect and avoid approaching vehicles might reduce the frequency of animal-vehicle collisions in areas where human traffic and wildlife activity overlap (DeVault et al., 2014; Doppler et al., 2015; Lima et al., 2015; Blackwell et al., 2016).

One example of human-wildlife conflict is the economic loss and safety hazards caused by birds (Conover, 2002). The frequency of aircraft-wildlife collisions increased 7.4-fold from 1990-2015, and over 95% of these collisions involved birds (Dolbeer et al., 2016). New World blackbirds (Icteridae) are frequently involved in aircraft-bird collisions (Dolbeer et al., 2016) and are also recognized as agricultural pests in North America (Linz et al., 2011; Klosterman et al., 2013; Linz, Avery, & Dolbeer, 2017). These two problems are linked, as evident by an event in January 1997 where an aircraft leaving Dallas-Fort Worth International Airport struck over 400 blackbirds attracted to an unharvested wheat field located on airport property (Cleary, & Dolbeer, 2005). Current nonlethal methods used to deter birds from airports and agricultural fields include habitat management, exclusion, chemical repellents, physical deterrents such as pyrotechnics, propane cannons, trained falcons, trained dogs, and radio-controlled aircraft (Cleary, & Dolbeer, 2005; DeVault, Blackwell, & Belant, 2013; Avery, & Werner, 2017).

The efficacy and economic feasibility of these methods, in agricultural settings, depends largely on the biology of the target species, context, and the duration of use (Linz et al., 2011). For example, an assessment of aerial hazing of wild blackbirds with manned aircraft suggested that efficacy depended on the migratory status and annual molt-cycle phase of blackbirds (Handegard, 1988). Molting can impair the flight performance of birds, as shown in European starlings that exhibit reduced level-flight speed, decreased take-off ability, and poor maneuverability when molt was experimentally induced compared to birds with complete molt (Swaddle, & Witter, 1997). Thus, molting birds may seek immediate cover instead of flying to a different location in response to aircraft approach (Handegard, 1988). Ultimately, this method becomes ineffective when the high costs of hiring an aircraft and associated pilots outweigh the benefits of reduced crop damage (Besser, 1978; Linz et al., 2011). Propane cannons, speakers that broadcast distress calls, and predator effigies have also been used to deter birds from airports and crop fields, but the efficacy of these methods is often limited by effective range and mobility of the tools (DeVault, Blackwell, & Belant, 2013; Klug, 2017). These stationary methods are most effective when used infrequently and in multiple locations as animals can quickly habituate to them (Cleary, & Dolbeer, 2005; Avery, & Werner, 2017).

Preventing habituation is crucial to the long-term success of nonlethal wildlife management tools (Conover, 2002; DeVault, Blackwell, & Belant, 2013; Avery, & Werner, 2017). Habituation refers to a decrease in behavioral response to a stimulus over time (Bejder et al., 2009). In an overview of visual deterrent strategies at airports, Blackwell and Fernández-Juricic (2013) recommend that habituation can be reduced by optimizing deterrents to the sensory capabilities and behavior of a target species (see also Fernández-Juricic, 2015). In contrast to habituation, sensitization refers to an increased response toward stimulus over time

(Bejder et al., 2009). Birds approached by model predators have sensitized toward repeated approaches (Lima, & Bednekoff, 1999a; Devereux et al., 2006), and such effects may be elicited through the risk of predation associated with natural predators (Conover, 2002). Additionally, DeVault et al. (2017a) reported possible habituation of rock pigeons (*Columba livia*) to a simulated vehicle approach, but only after exposure to repeated approaches by the actual vehicle. Animals might also show differences in alert and flight responses (i.e., relative to habituation or sensitization evident in the specific behavior) after repeated exposure to human-related disturbances (e.g., simulated vehicle approaches; DeVault et al., 2017b). Wildlife managers should also consider combinations of nonlethal strategies to enhance perceived predation risk (Blackwell, & Fernández-Juricic, 2013). For example, combining stationary speakers that broadcast predator calls with a mobile predator model may help reinforce the predation risk associated with both methods and delay habituation effects (Conover, 2002).

Recently, unmanned aircraft systems (UAS; or drones) have been suggested as a nonlethal method to deter birds from areas of human-wildlife conflict (e.g., airports, vineyards and crop fields; Grimm et al., 2012; Ampatzidis, Ward, & Samara, 2015; Klug, 2017). Drones are useful tools for ecological research and monitoring (Jones IV, Pearlstine, & Percival, 2006; Wich, & Koh, 2018) and are employed in a variety of wildlife management applications including population surveys (Chabot, & Bird, 2012; Sardá-Palomera et al., 2012; Hodgson, Kelly, & Peel, 2013; Vermeulen et al., 2013; Chabot, Craik, & Bird, 2015), wildlife detection (Israel, 2011), anti-poaching efforts (Mulero-Pázmány et al., 2014), and avian nest-monitoring (Junda, Greene, & Bird, 2015; Weissensteiner, Poelstra, & Wolf, 2015). Some producers are hesitant to incorporate drones into standard farming practices because of initial cost (Zhang, & Kovacs, 2012). However, for producers who can experience over 20% crop loss due to bird

damage (Linz et al., 2011), the cost-benefit of purchasing a drone may seem more appealing if it can also function as bird deterrent.

Several studies have evaluated drone disturbance on wildlife (Ditmer et al., 2015; Koski et al., 2015; Moreland et al., 2015; Pomeroy, O'Connor, & Davies, 2015; Rümmler et al., 2016; Barnas et al., 2018), but few have operated drones in a manner to intentionally provoke an escape response (Vas et al., 2015; McEvoy, Hall, & McDonald, 2016; Weimerskirch, Prudor, & Schull, 2018; Wandrie, Klug, & Clark, 2019). Drones can elicit avoidance behavior in birds, suggesting utility as nonlethal hazing tools (Blackwell et al., 2012; Vas et al., 2015; Weissensteiner, Poelstra, & Wolf, 2015; McEvoy, Hall, & McDonald, 2016; Rümmler et al., 2016). If effective, drones could be incorporated into integrated pest management plans to reduce economic loss and safety hazards caused by birds. A drone is unique in that it can overcome mobility limitations, and future technology may include on-board bird-detection systems, extended battery longevity, and fully autonomous flight capabilities (Ampatzidis, Ward, & Samara, 2015). Still, limitations to the efficacy and implementation of a drone as a hazing mechanism exist (Klug, 2017). Previous research has shown that a multicopter drone can approach flocks of mallards (*Anas platyrhynchos*), greater flamingos (*Phoenicopterus roseus*) and common greenshanks (*Tringa nebularia*) to within 4 m without provoking an escape response (Vas et al., 2015). A similar study revealed that birds (e.g., albatross [Diomedidae]) will actively approach a drone to within 5 m (McClelland et al., 2016). These close encounters suggest that in some scenarios, birds may tolerate drone disturbance rather than avoid it.

Wildlife response toward drones may depend on a variety of factors, including vehicle platform, flight dynamics, and the evolutionary history of the intended target species (Mulero-Pázmány et al., 2017; Weimerskirch, Prudor, & Schull, 2018). Birds are capable of assessing

threat levels of multiple aerial predators based on visual cues (Walters, 1990; McEvoy, Hall, & McDonald, 2016), and if identified, these visual signals may be applied to a drone designed for hazing. For example, by approaching groups of waterfowl with various drone platforms, McEvoy, Hall and McDonald (2016) found that birds seemed most disturbed by the fixed-wing platform that closely resembled the shape of an aerial raptor. In contrast to fixed-winged drones, waterfowl displayed a less pronounced disturbance response when approached by two multicopter drones (McEvoy, Hall, & McDonald, 2016). In addition to discriminating between various aerial predators and vehicles, some birds have also shown an ability to evaluate a predator's behavior during threat assessment. Arabian babblers (*Turdoides squamiceps*) do not initiate alarm calls following detection of known predators flying at high altitudes (i.e., migratory behavior), despite alarm calling for encounters with the same predators under riskier scenarios (Edelaar, & Wright, 2006). These observations indicate the threat perception by birds toward both flying vehicles and predators can depend on flight dynamics and form, and wildlife managers can potentially exploit both aspects of predator approach to elicit a desired escape response with drone approach.

### **Research Objectives**

My specific objectives were to understand avian perception and response to drone encounters, while simultaneously identifying features (i.e., visual appearance) and flight dynamics (i.e., approach trajectory) that birds perceive as disturbing. Factors that elicit a higher degree of disturbance can potentially be exploited to enhance drones as hazing tools to disperse and deter flocks of birds from areas of human-wildlife conflict (e.g., airport environments and commercial crop fields). However, results also have implications for wildlife monitoring in that factors that cause greater disturbance should be avoided.

In Chapter 2, I evaluate the behavioral response of individual, captive red-winged blackbirds (*Agelaius phoeniceus*) to three drones: a predator [raptor] model, a generic fixed-wing, and a multirotor approaching at direct and overhead trajectories. Previous antipredator studies have shown that birds differentially respond to manipulated levels of perceived risk. By examining the behavioral decisions (e.g., increased time devoted to monitoring predators, alarm calling, and escape) of individual blackbirds exposed to drone flights, the perceived risk blackbirds associate with drone treatments can be quantified. The seminatural study design minimized several confounding variables that can affect avian responses (e.g., social interactions, food availability, and distractions; Fernández-Juricic, 2015); however, the behavioral responses of captive, individual blackbirds may not reflect the response of free-ranging blackbird flocks, warranting an evaluation of our drones in a field setting.

In Chapter 3, I evaluate the response of free-ranging blackbirds toward the same three drones to understand the efficacy of drones to disperse wild blackbird flocks from commercial sunflower fields. Although red-winged blackbirds make up the majority, free-ranging flocks may also include yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), common grackles (*Quiscalus quiscula*), brown-headed cowbirds, and European starlings, but will hereafter be generally referred to as blackbirds. The field evaluation was important because it simulated an active hazing program, where birds would likely be hazed repeatedly over the course of the blackbird damage season (August to October). Group dynamics and landscape factors experienced by free-ranging blackbirds may diminish effects observed across individual birds tested under controlled conditions, and the field evaluation will reflect the efficacy of drone hazing in an applied context.

Despite several studies that have evaluated the disturbance of wildlife from drones, it remains unclear if animals perceive drones as benign objects that strictly pose collision hazards, potential predators, or confuse both possibilities during encounters (Lima et al., 2015; McEvoy, Hall, & McDonald, 2016). By comparing avian responses to a predator model and drones typically used for monitoring, my research attempts to fill this gap, with important consequences for the future use of drones in conservation ecology and wildlife damage management. In Chapter 4, I discuss conclusions and future research involving the use of drones as wildlife monitoring tools and avian deterrents.

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**CHAPTER 2: TESTING A KEY ASSUMPTION OF DRONE-WILDLIFE  
INTERACTIONS: DO ANIMALS PERCEIVE DRONES AS LOW-DISTURBANCE  
FLYING OBJECTS?**

**Abstract**

Operational guidelines for the use of unmanned aircraft systems (UAS; or drones) in wildlife conservation are beginning to develop despite uncertainties and assumptions surrounding wildlife perception and responses. It is generally assumed wildlife perceive drones as less disturbing than predators based on field studies that have evaluated the behavioral and physiological reactions of wildlife to drones, but controlled studies comparing those responses to predators have not been conducted. We compared avian response to drones typically used for monitoring (i.e., standard fixed-wing or multirotor) versus a predator-shaped drone. We tested the hypotheses that perception of risk would vary by drone platform, and that perceived risk would be highest with direct versus overhead approaches, regardless of drone platform. Specifically, we predicted that approach by the predator model would result in greater or more frequent antipredator responses compared to other drones. In a seminatural setting, we evaluated behavioral response of individual, captive red-winged blackbirds (*Agelaius phoeniceus*) to three drones: a predator model, a standard fixed-wing, and a multirotor, approaching directly or overhead. Blackbirds alerted earlier, alarm-called more frequently, returned to forage later, and allocated more time to vigilance in response to the predator model compared to other drones. Overhead approaches failed to elicit flight in blackbirds across all drones, and no blackbirds took flight in response to the multirotor at either overhead or direct trajectories. Wildlife response toward drones depend on a variety of factors, including vehicle platform, flight dynamics, species, and context. We demonstrated that individual red-winged blackbirds do not perceive a

multirotor as threatening as a simulated raptor attack posed by our predator model. When operated responsibly, multirotor drones may be suitable and convenient wildlife-monitoring tools that can minimize distress to birds when compared to conventional survey methods, but questions remain as to their efficacy as deterrents in wildlife damage management scenarios.

**Keywords:** *Agelaius phoeniceus*, antipredator behavior, disturbance, frightening devices, hazing, human-wildlife conflict, perceived predation risk, UAV, visual deterrent, wildlife monitoring

## **Introduction**

Recently, unmanned aircraft systems (UASs; or drones) have gained popularity as wildlife monitoring tools (Chabot, & Bird, 2015; Linchant et al., 2015; Wich, & Koh, 2018), which has led to multiple species being exposed to a novel flying object. When compared to traditional wildlife survey methods such as manned aircraft flights, drones have been deemed to cause negligible disturbance on wildlife (Chabot, & Bird, 2015; Christie et al., 2016; Wich, & Koh, 2018). However, physiological (e.g., increased heart rate; Ditmer et al., 2015; Weimerskirch, Prudor, & Schull, 2018) and escape responses (McEvoy, Hall, & McDonald, 2016; Bevan et al., 2018) can occur during low-altitude flights. Therefore, it remains unclear whether or not animals perceive drones as benign flying objects.

Of the studies that have measured physiological and behavioral reactions of wildlife to drones, birds appear to be the most sensitive taxa when compared to large terrestrial mammals and fully-aquatic species (Mulero-Pázmány et al., 2017). In instances where birds display amplified avoidance or agonistic behaviors in response to drone encounters, it is often implied that birds perceive or confuse the drone as a legitimate predator (Vas et al., 2015; Weissensteiner, Poelstra, & Wolf, 2015; McEvoy, Hall, & McDonald, 2016; Rümmler et al., 2016; Mulero-Pázmány et al., 2017; Bevan et al., 2018). For example, Vas et al. (2015) reported

a greater frequency of escape among birds in response to vertical descents of a drone when compared to shallower approach angles, and suggested birds may have perceived the former approach as a predator attack.

Our goal was to test whether birds perceive drones as low-disturbance flying objects. Conceptually, we defined low-disturbance as a behavioral response that would be substantially less pronounced than that given to a potential predator. We used two drones typically used for wildlife monitoring (i.e., multirotor and standard fixed-wing) as well as a drone with the shape of a predator (hereafter, predator model). The latter has been used in the past to successfully generate antipredator behaviors (Blackwell et al., 2012). Having a predator model allowed us to establish baseline behavioral responses under conditions of high disturbance and comparison to the other two drones, which were assumed to generate lower disturbance.

We conducted a seminatural experiment to evaluate the responses of individual birds to either direct or overhead approaches of three drones: a predator model, standard fixed-wing, and multirotor. We used the red-winged blackbird (*Agelaius phoeniceus*) as the model species because they behaviorally respond to both simulated predators (Yasukawa, Whittenberger, & Nielsen, 1992) and drones (Wandrie, Klug, & Clark, 2019). Furthermore, there have been few studies that evaluated drone disturbance on passerines (Weissensteiner, Poelstra, & Wolf, 2015; Wandrie, Klug, & Clark, 2019). The seminatural experiment allowed us to control for multiple confounding factors that previous studies on drones have not been able to do (Vas et al., 2015; McEvoy, Hall, & McDonald, 2016), such as, identify individual birds, control food-deprivation time, and achieve large sample sizes with single exposures per individual (but see Barnas et al., 2018). All of which provided us with a powerful method to understand avian responses to drones at the individual level. We used two approach trajectories because we wanted to assess a baseline

response to a scenario that represented high risk and high disturbance (i.e., direct approach), but such an approach is unlikely to occur during typical wildlife-monitoring protocol, thus we also included the overhead approach.

Operational guidelines and recommendations for drone-monitoring protocols are being developed (Hodgson, & Koh, 2016; Mulero-Pázmány et al., 2017; Wich, & Koh, 2018), despite the uncertainties surrounding wildlife perception to drone exposure. For example, it remains unclear if animals perceive drones as benign objects that strictly pose collision hazards, potential predators, or confuse both possibilities during encounters (Lima et al., 2015; McEvoy, Hall, & McDonald, 2016). Our study attempts to fill this gap, with important consequences for the future of drones in conservation ecology and wildlife management. If animals show a lower degree of disturbance-related responses to drones compared to the predator model (i.e., supporting the current assumption), drones used as tools for monitoring and surveying may not negatively impact wildlife.

However, if animals show a similar (or higher) degree of disturbance-related responses to drones than to the predator model (i.e., contradicting the current assumption), conservation practitioners should reconsider using drones for “close-up” monitoring missions (Chabot, & Bird, 2015) such as hovering near avian nests (Potapov et al., 2013; Junda, Greene, & Bird, 2015; Weissensteiner, Poelstra, & Wolf, 2015) and exercise caution when conducting flights over species of conservation concern (Thapa et al., 2018). Additionally, pronounced negative responses to drones would open up opportunities to use drones to deter birds from areas of human-wildlife conflict (e.g., vineyards, crop fields, and airports; Ampatzidis, Ward, & Samara, 2015; Klug, 2017). Addressing this knowledge gap is urgent for limiting undue distress to animals exposed to drone flights (see Frid, & Dill, 2002; Mulero-Pázmány et al., 2017).

## **Hypotheses**

We predicted that blackbird responses to drones would differ based on platform qualities, which included differences in sound, contrast, color, shape and size of the vehicles. More specifically, we predicted that birds would perceive the predator model as a legitimate predatory threat (Blackwell et al., 2012; McEvoy, Hall, & McDonald, 2016) and as a result, birds exposed to it would exhibit amplified response behaviors when compared to birds exposed to the fixed-wing and multirotor. We also predicted that responses would be more pronounced for direct versus overhead approaches (Lima, & Bednekoff, 2011; Møller, & Tryjanowski, 2014).

## **Methods**

### ***Unmanned Aircraft Systems (Drones)***

We compared three drones: a drone modeling the form of an aerial predator (USDA-APHIS-WS ATOC, Cedar City, UT, USA), a standard fixed-wing (FT Explorer; Flight Test, New Philadelphia, OH, USA), and a multirotor (DJI Phantom 4 Pro; DJI, Shenzhen, China; Figure 2.1). The predator and fixed-wing models have similar lengths, wingspans of 1,430 mm, and are identical in structural material (i.e., brown foam). The multirotor is white in color and 350 mm in diagonal length. We disabled the factory-installed lights on the multirotor to prevent the effect of light on antipredator behavior (Blackwell et al., 2009; Blackwell et al., 2012; Doppler et al., 2015).

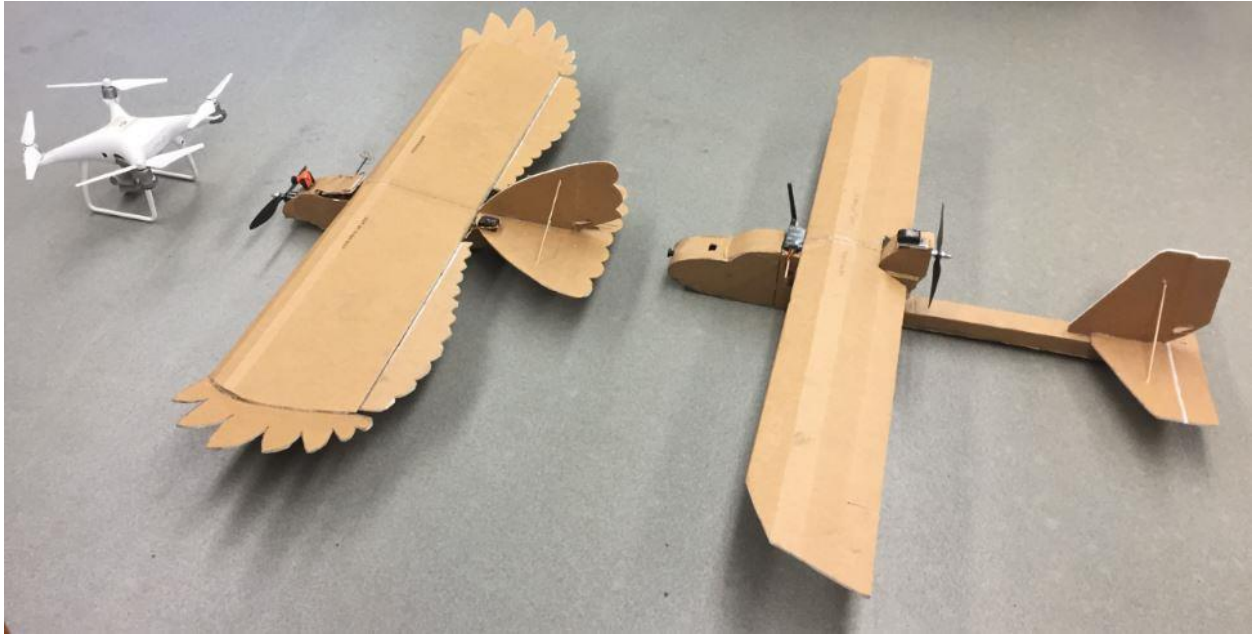


Figure 2.1. Drone platforms included a DJI Phantom 4 Pro (multirotor), predator model, and a standard fixed-wing.

### ***Animal Maintenance***

The 100 male red-winged blackbirds used in this study were captured in Colorado, USA and transferred to permanent housing at the Red River Zoo Aviary in Fargo, North Dakota, USA. Blackbirds were color-banded and housed in group enclosures under a natural light:dark cycle from March – October 2017. No more than 20 individuals were permanently housed together across 4 small enclosures (2.4 x 2.4 x 2.4 m), and no more than 50 individuals in a single large enclosure (4.8 x 4.8 x 2.4 m). We fed the birds a mix of millet, cracked corn, milo, sunflower and safflower seeds *ad libitum*. On occasion, we supplemented the diet with dehydrated mealworms, sweet corn, and suet cakes.

### ***Experimental Arena***

We conducted our seminatural study in an agricultural field at the North Dakota State University Agronomy Seed Farm in Casselton, ND, USA (46°52'59"N, 97°14'06"W), where the experimental arena was outdoors. The experimental arena (305 x 27.5 m) was bordered by

sunflower (1.5 m tall) and included a launch point, an approach path devoid of visual obstructions (i.e., vegetation height <30 cm), and a bird enclosure (Figure 2.2A). We visually screened the pilot (C.C.E), visual observer, and area behind the enclosure during trials using ~2 m tall screens. The enclosure was a 12.7 mm polypropylene net over a steel frame (3.7 x 3.7 x 2.7 m) with two compartments and a landscape fabric floor. One compartment served as the focal compartment, where we provided a perch and food tray 1.7 m above ground level (AGL). We placed the perch directly behind the food tray to control bird location during trials. The adjacent compartment housed two companion blackbirds to reduce stress behaviors in the focal bird, but we visually obstructed this compartment to drone approaches. The compartments allowed visual and auditory, but not physical contact between blackbirds. Prior to trials, we secured a 7-cm section of corn to the food tray in the focal compartment to motivate foraging during trials. Five cameras (GoPro HERO5 Black; GoPro, San Mateo, CA, USA) recorded blackbird behavior and drone approach (60 frames s<sup>-1</sup>; Figure 2.2A).



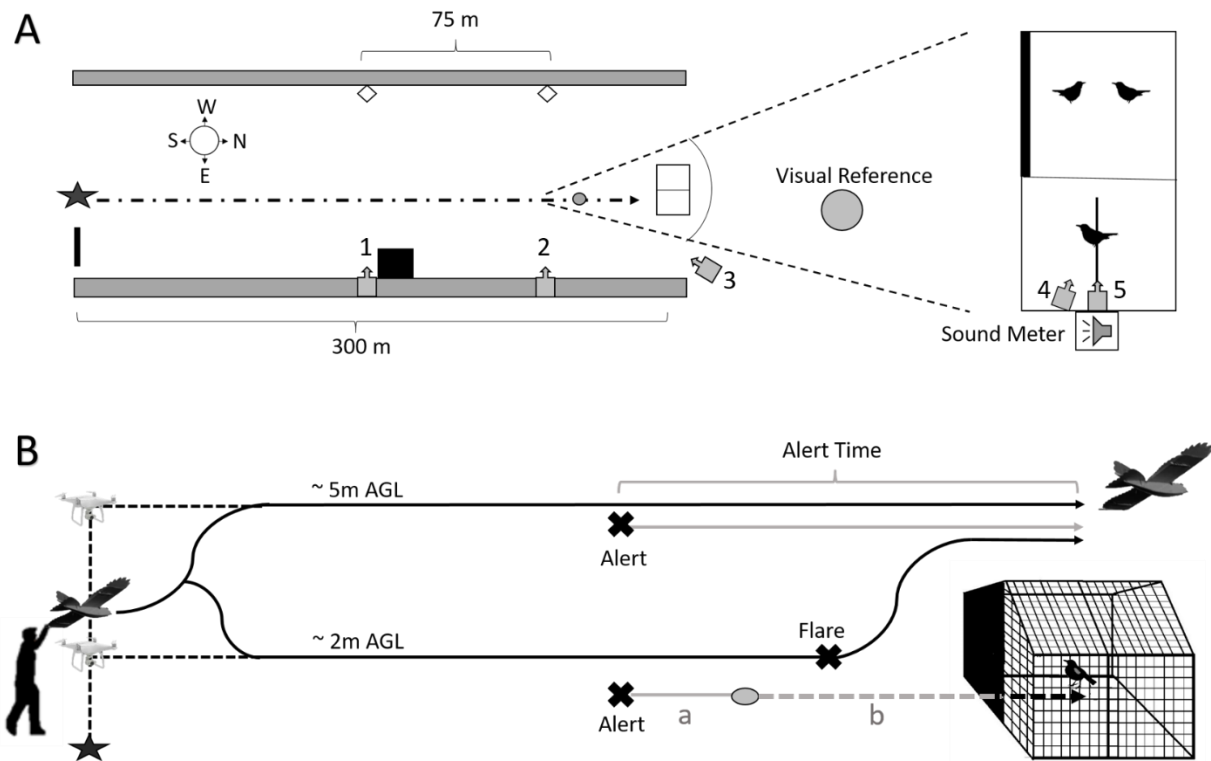


Figure 2.2. Experimental arena and drone approach path. (A) Overhead view of experimental arena including launch site (star), pilot blind (square), launch assistant blind (black vertical rectangle), sunflower (gray horizontal rectangles), visual markers (white diamonds), drone approach path (dotted arrow line) and cameras (gray arrow boxes). The area around the enclosure holding the focal and companion birds is magnified for clarification. A disc used for visual reference was located 10.3 m away from the perch. We measured drone speed by recording the time required for each drone to travel 75 m between visual markers opposite cameras 1 and 2. Camera 3 recorded drone position relative to the enclosure. Cameras 4 and 5 recorded blackbird behavior during trials. (B) Drone approach from launch to overpass. We launched the predator model and fixed-wing windward by hand. We hovered the multirotor to the appropriate treatment altitude and accelerated directly toward the enclosure. During direct approaches, the drone flared upward prior to colliding with the enclosure. Overhead approaches did not flare. We measured alert time and flight-initiation time for direct approaches using the time required for the drone to reach the visual reference located 10.3 meters away from the perch from the moment the bird responded (a) and projected the time required for the drone to travel an additional 10.3 meters (b). We then added (a + b) to estimate response time for direct approaches. Figure not to scale.

### ***Trials***

We exposed 87 male, red-winged blackbirds to a single drone flight (i.e., one flight per bird). We conducted trials between 07 August and 12 September 2017, from 0720 to 1200 hr

under calm weather conditions (i.e., no precipitation and average wind speed  $<14 \text{ km hr}^{-1}$ ). We placed two companion blackbirds in the enclosure at the beginning of each day, and provided food and water *ad libitum*. Companion birds were randomly selected each morning from a stock of 13 individuals, housed separately from focal individuals. Companion birds experienced multiple trials per day (i.e., 3-8). We food-deprived focal birds for 25-30 hours to motivate foraging behavior during trials, and tested 3-8 focal birds per day. Birds awaiting trials were temporarily housed in solitary enclosures, within a climate-controlled vehicle parked outside the flight arena.

During trials, we released a blackbird into the focal compartment. Once the focal bird foraged for 30 seconds, we performed a flight treatment. Flight treatments required coordination between the pilot and visual observer. The pilot (C.C.E) operated drones from a blind located near the center of the flight path (Figure 2.2A). The visual observer was located behind a screen near the launch point, and once a focal bird began foraging, exited to hand-launch the predator model or fixed-wing. In contrast, the multirotor did not require a hand-launch, and was already on the ground at the launch point, when the focal bird began foraging. We launched the predator model and fixed-wing windward and quickly reoriented flight direction toward the enclosure. In contrast, we hovered the multirotor and accelerated directly toward the enclosure (Figure 2.2B). Thus, all drones were visually exposed to the focal bird prior to launch.

We had two independent factors: drone platform and trajectory. Drone had three levels (i.e., predator model, fixed-wing, and multirotor). Trajectory had two levels (i.e., direct and overhead). Consequently, we had six treatments (1. direct predator model, 2. overhead predator model, 3. direct fixed-wing, 4. overhead fixed-wing, 5. direct multirotor, and 6. overhead multirotor). The drones travelled fluidly above the enclosure for overhead approaches. In

contrast, the drones flared upward ~6 m prior to the enclosure for direct approaches, and proceeded to fly up and over the enclosure (Figure 2.2B). After the drone went over the enclosure with the bird, we circled the drone back to the pilot location for landing. After the approach, we recorded the behavior of the birds and stopped recording 30 seconds after the focal bird resumed foraging. We recorded ambient sound intensity (dB) using a digital sound meter (Extech Model 407732, Extech Instruments Corp., Nashua, NH, USA) located at perch height next to the enclosure (Figure 2.2A). After each approach, we recorded ambient temperature (12.3 – 34.7°C) and average wind speed (0.0 – 13.9 km hr<sup>-1</sup>) using a Skymaster SM-28 weather meter (Speedtech Instruments, Great Falls, VA, USA) and ambient light intensity (115.01 – 883.5  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) with a Li-Cor (Lincoln, NE, USA) LI-250 Light Meter and LI-190SA Quantum Sensor.

### ***Red-winged Blackbird Visual Perceptual Modeling***

The visual detection of each drone by blackbirds may be influenced by differences in object brightness (achromatic) and color (chromatic) contrast between the drone and the visual background (Fernández-Juricic et al., 2012). To account for these differences, we used a visual contrast model based on that by Vorobyev and Osorio (1998) to estimate how male, red-winged blackbirds discriminated the drones against the ambient background of our field site (see Blackwell et al., 2012; Fernández-Juricic et al., 2013; Doppler et al., 2015). This contrast model, which incorporates object reflectance, background reflectance, ambient light conditions, and species-specific visual system properties, has been successfully applied to predict perception of avifauna toward aircraft (Blackwell et al., 2012; Doppler et al., 2015). The model calculates chromatic and achromatic contrast in “just noticeable differences” (JND) units (e.g., Siddiqi et al., 2004; Fernández-Juricic et al., 2012). When JND values are greater than 3, the visual stimuli

are predicted to be easily distinguishable from the environmental background (Fernández-Juricic et al., 2012). Greater values of JND reflect increasing conspicuousness of an object relative to the visual background (Siddiqi et al., 2004; Doppler et al., 2015).

### ***Behavioral Response Metrics***

We used BORIS (version 5.1.0; Friard, & Gamba, 2016) to analyze video footage. A single observer (C.C.E) measured blackbird behavioral responses to treatments: vigilance, alert time, whether a bird alarm called, whether a bird initiated fight, flight-initiation time, and latency to resume foraging. We did not include trials where the behavioral response occurred during or after a piloting error (e.g., drone made contact with the enclosure or significantly deviated from the flight path prior to the overpass).

We recorded the focal bird vigilance behavior for 30 seconds both immediately before and after drone flights. Specifically, we measured the proportion of time with the head-up (i.e., head above the horizontal plane of the body) while foraging. We examined vigilance patterns at 0.10x playback speed (60 fps) and began evaluation when the bill made initial contact with the food. Thus, all observations began while the focal bird was in a head-down position and ended 30 seconds later. We omitted birds from analysis that did not forage for a full 30 seconds, perched in a manner that was not comparable to other birds (e.g., perched directly on food tray), or that did not return to forage within 5 minutes following drone flights.

We recorded alert time as the time (seconds) required for the drone to reach the point above the perch (hereafter perch) from the moment at which the bird became alert (Figure 2.2B). We defined alert responses as a transition from a general (e.g., foraging, preening, loafing, or scanning) to an alert behavior directed toward the drone (e.g., sudden head-up, increased rate of head movement, neck extension, feather compression or crouching). During direct approaches,

we flared the drone to avoid collision with the enclosure, whereas overhead approaches did not require a flare. Thus, using the calculated drone speed for each trial, we projected the time required for the direct approaches to reach the perch after the flare, had the drone been allowed to continue travelling directly forward into the enclosure (see Figure 2.2B). We recorded whether the focal bird alarm called during drone flights.

We recorded whether birds initiated flight in response to drone approaches. If a bird initiated flight, we also recorded flight-initiation time (s) as the time required for the drone to reach the perch from the moment at which the focal bird initiated flight (i.e., departure from perch). Alert behaviors preceded each flight response suggesting the behavior was in response to the approaching drone. For direct approaches, we used the projection method mentioned previously to calculate flight-initiation time (see Figure 2.2B). We recorded the time (s) it took the focal bird to resume foraging from the moment the drone passed directly above the perch. We did not consider birds that took longer than 5 minutes to return foraging.

We calculated ground speed for each flight using the time required for the drone to pass between cameras located 75 m apart along the approach path (Figure 2.2A). Across drones, speeds  $\pm$  SD ( $\text{m s}^{-1}$ ) were similar ( $F_{2, 84} = 1.09$ ,  $P = 0.340$ ; predator model:  $13.76 \pm 1.84$ ; fixed-wing:  $13.14 \pm 1.78$ ; multicopter:  $13.75 \pm 1.91$ ). We calculated approach time from the moment the drone began accelerating forward to the moment it passed above the perch. Approach times  $\pm$  SD (s) were also similar across drones ( $F_{2, 84} = 0.40$ ,  $P = 0.669$ ; predator model:  $25.86 \pm 4.94$ ; fixed-wing:  $25.71 \pm 3.89$ ; multicopter:  $24.94 \pm 3.29$ ). We did not calculate exposure time prior to launch (i.e., total time each drone was visually exposed to birds), but considered this effect by evaluating focal bird vigilance before drone approach.

## *Analyses*

We considered responses observed in each trial as independent because we only exposed a single bird to a given treatment once (i.e., one drone flight per bird). We evaluated the effects of drone platform, trajectory, and the interaction between platform and trajectory as fixed effects. We also considered some potential confounding factors: sound intensity, wind speed, ambient temperature, food deprivation time, ambient light intensity, drone speed, and approach time per trial. After examining independence among candidate effects (Table 2.1), our final model included drone platform, trajectory, ambient light intensity, drone speed, and the interaction between drone platform and trajectory. We also included flight (i.e., if the bird escaped drone approach by flying) as a predictor variable in the latency to resume foraging model given that birds choosing to take flight would take longer to resume foraging.

We used general linear models to model alert time, flight-initiation time, latency to resume foraging, and vigilance. We examined model residuals and  $\log_{10}$ -transformed alert time, flight-initiation time, and latency to resume foraging to meet model assumptions. We used generalized linear models with logit link functions to model the probability of focal birds alarm calling and the probability of focal birds initiating a flight response (binomial distribution). All statistical analyses were conducted using R (version 3.4.3; R Core Team, 2017) using type II sums of squares. We calculated least squared means, Tukey's HSD (honest significant difference) tests for multiple comparisons, and predicted probabilities via the "lsmeans" package in R (Lenth, 2016). Results are presented as least squares means  $\pm$  SE unless stated otherwise. We also present means  $\pm$  SE for untransformed raw data when appropriate.

Table 2.1. We used general linear models and correlations to assess independence and collinearity among candidate fixed effects.

		<i>df</i>	<i>F</i>	<i>P</i>
Sound Intensity	Platform	2,80	<b>27.73</b>	<b>&lt;0.001</b>
	Trajectory	1,80	<b>4.34</b>	<b>0.040</b>
	Platform x Trajectory	2,80	0.41	0.667
Drone Speed	Wind Speed	1,79	<0.01	0.944
	Wind Direction	3,79	<b>8.76</b>	<b>&lt;0.001</b>
	Wind Speed x Wind Direction	3,79	2.36	0.078
				<i>r</i>
Drone Speed vs. Approach Time				-0.77
Ambient Light Intensity vs. Temperature				0.76
Ambient Light Intensity vs. Food Deprivation Time				0.68
Food Deprivation Time vs. Temperature				0.62

Note: Sound intensity recorded at the enclosure was inherent to platform and trajectory. Wind direction contributed to variable drone speeds across trials, with downwind and crosswind approaches being faster than windward approaches. We included drone speed in the model, given predator speed can influence antipredator behaviors (Stankowich, & Blumstein, 2005), and birds may respond to approaching vehicles using a spatial, rather than temporal margin of safety (DeVault et al., 2015). Temperature, food deprivation time, and ambient light intensity were correlated. We included ambient light intensity in the model as it can impair vision in birds, potentially hindering detection and escape responses (Fernández-Juricic et al., 2012).

## Results

### *Drone Characteristics*

Blackbirds likely discriminated each drone using achromatic contrasts, but were also able to readily distinguish drones chromatically from the ambient conditions of our field site (Figure 2.3). Under both sunny and cloudy conditions, contrast values for the multirotor are lower compared to the predator model and fixed-wing (Figure 2.3). Furthermore, drones varied by sound intensity recorded next to the enclosure (Table 2.1). The multirotor (LSmean  $\pm$  SE dB;

54.0 ± 0.58) was louder than the predator model (50.6 ± 0.56,  $t_{80} = 4.33$ ,  $P < 0.001$ ), but quieter than the fixed-wing (56.3 ± 0.54,  $t_{80} = 2.88$ ,  $P = 0.014$ ) during approaches. The fixed-wing was louder than the predator model ( $t_{80} = 7.38$ ,  $P < 0.001$ ).

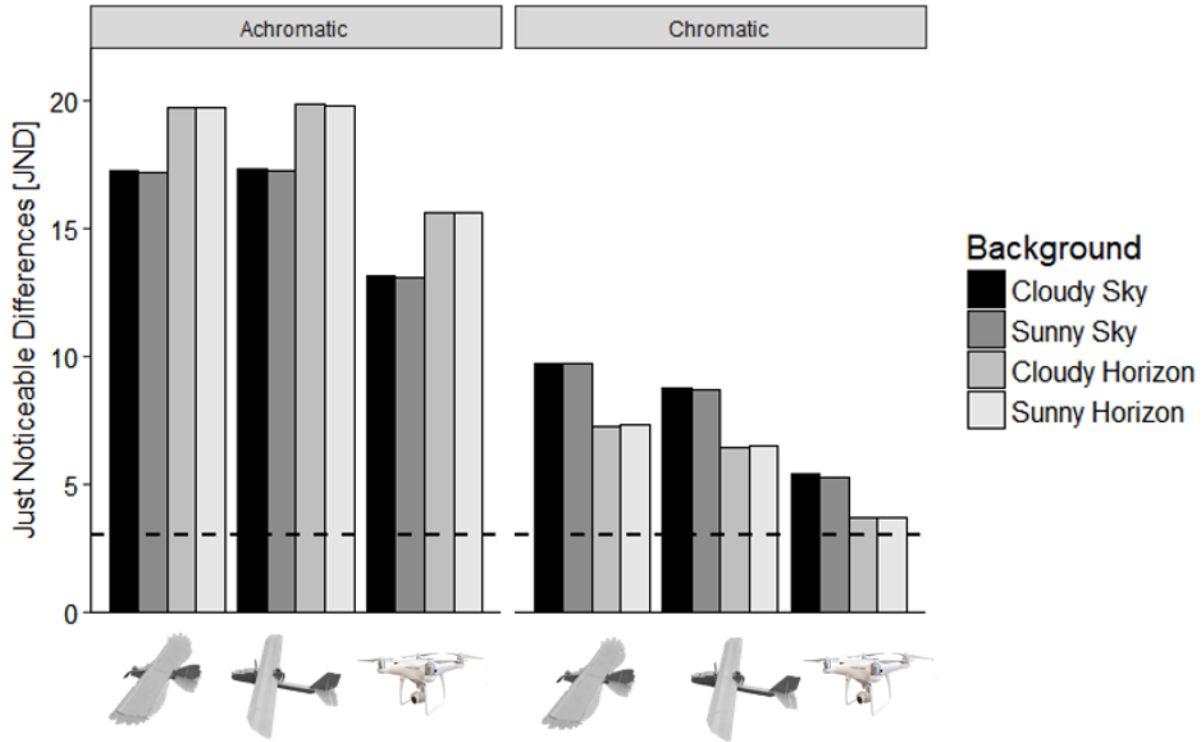


Figure 2.3. Chromatic and achromatic contrast values for the drones under sunny and cloudy ambient light conditions were calculated using visual system properties of the red-winged blackbird. Units are just noticeable differences (JND). JND >3 (dashed line) indicate the drone was salient against background conditions.

### **Behaviors**

We considered 87 individuals that were foraging or loafing on the perch at the onset of alert behavior, regardless of orientation in the following analysis. However, as we were unable to control orientation and feeding patterns for all birds, we also provide conservative results including only 76 blackbirds that were both foraging (i.e., not loafing) and facing forward during drone approaches (see Appendix, Table A1 and A2).



When quantifying baseline vigilance prior to drone approaches, but while drones were visible to blackbirds from the launch point, we observed a significant response to drone platforms ( $F_{2,72} = 4.84$ ,  $P = 0.011$ ). Prior to approaches, blackbirds exposed to the predator model foraged with a greater time spent vigilant (mean proportion spent head-up  $\pm$  SE;  $0.44 \pm 0.03$ ), when compared to both the fixed-wing ( $0.34 \pm 0.03$ ;  $t_{72} = -2.58$ ,  $P = 0.031$ ) and multirotor ( $0.33 \pm 0.03$ ;  $t_{72} = -2.82$ ,  $P = 0.017$ ).

Alert time ( $\log_{10}$  scale) significantly varied by drone platform (Table 2.2; Figure 2.4). Blackbirds became alert approximately 2 times earlier in response to the predator model (mean  $\pm$  SE seconds before the drone reached the perch;  $15.6 \pm 1.5$ ) compared to the fixed-wing ( $7.5 \pm 1.3$ ;  $t_{79} = -4.80$ ,  $P < 0.001$ ) and approximately 8 times earlier compared to the multirotor ( $1.9 \pm 0.25$ ;  $t_{79} = -9.83$ ,  $P < 0.001$ ). Blackbirds alerted approximately 4 times earlier to the fixed-wing compared to the multirotor ( $t_{79} = 5.11$ ,  $P < 0.001$ ).

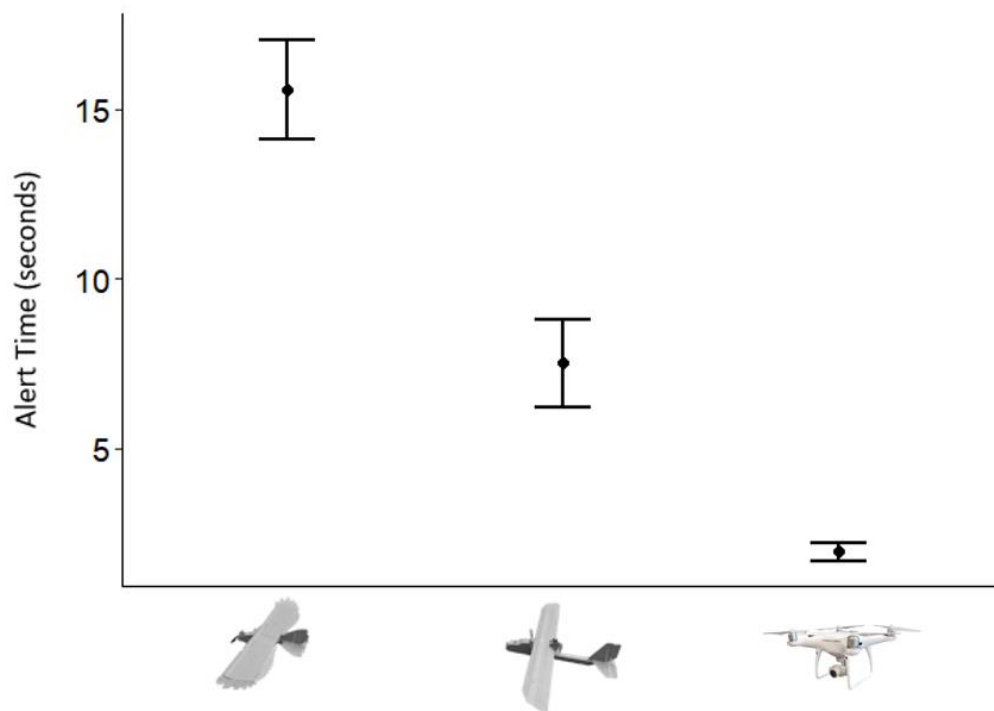


Figure 2.4. Red-winged blackbirds alerted earlier in response to the predator model (mean  $\pm$  SE seconds before the drone reached the bird) compared to the fixed-wing and multirotor.

Blackbirds alarm called more frequently in response to direct approaches compared to overhead approaches, and alarm called more frequently in response to the predator model when compared to the fixed-wing and multirotor (Figure 2.5). Blackbirds vocalized either “check” or “cheer” calls in response to drones, but the “cheer” call only occurred during direct predator model approaches. “Check” calls are one of the most frequent vocalization observed in red-winged blackbirds, and used in a variety of behavioral contexts (Beletsky, Higgins, & Orians, 1986). “Cheer” calls are given most frequently in alarming situations, and higher-pitched cheer calls have been linked to the detection of flying hawks (Beletsky, Higgins, & Orians, 1986). Intermittently, companion birds vocalized “check” calls during trials, but an overt behavioral reaction by focal individuals was not observed (i.e., the focal bird continued to forage). Focal birds vocalized both “cheer” and “check” calls singularly, but only the “check” call occurred in a rapid sequence as the blackbird flushed the perch.

Table 2.2. Responses of blackbirds to drones ( $\log_{10}$  alert time,  $\log_{10}$  flight initiation time, and  $\log_{10}$  latency to resume foraging).

	<i>df</i>	<i>F</i>	<i>P</i>
<b>Log<sub>10</sub> Alert Time</b>			
Platform	2, 79	<b>48.79</b>	<b>&lt;0.001</b>
Trajectory	1, 79	2.54	0.115
Platform x Trajectory	2, 79	1.24	0.296
Ambient Light Intensity	1, 79	2.80	0.098
Drone Speed	1, 79	1.19	0.278
<b>Log<sub>10</sub> Flight Initiation Time</b>			
Platform	1, 11	1.54	0.241
Ambient Light Intensity	1, 11	0.49	0.557
Drone Speed	1, 11	0.36	0.497
<b>Log<sub>10</sub> Latency to Resume Foraging</b>			
Platform	2, 66	<b>15.48</b>	<b>&lt;0.001</b>
Trajectory	1, 66	0.11	0.737
Platform x Trajectory	2, 66	0.02	0.984
Ambient Light Intensity	1, 66	0.45	0.505
Drone Speed	1, 66	0.30	0.584
Flight	1, 66	<b>12.18</b>	<b>&lt;0.001</b>

Note: Results derived from general linear models. Degrees of freedom differ between response variables based on behavior criteria for each response.

Only a single bird alarm-called in response to the multirotor treatment (Figure 2.5). Thus, we omitted the multirotor treatment from the analysis. When evaluating only the predator model and fixed-wing treatments, we found the probability of a bird alarm calling was significantly affected by drone platform and trajectory (Table 2.3), with a 55% probability of a blackbird alarm calling in response to the predator model compared with 14% for the fixed-wing. We also found an effect of trajectory (Table 2.3), with a 63% probability of a blackbird alarm calling in response to direct approaches compared to 10% for overhead approaches.

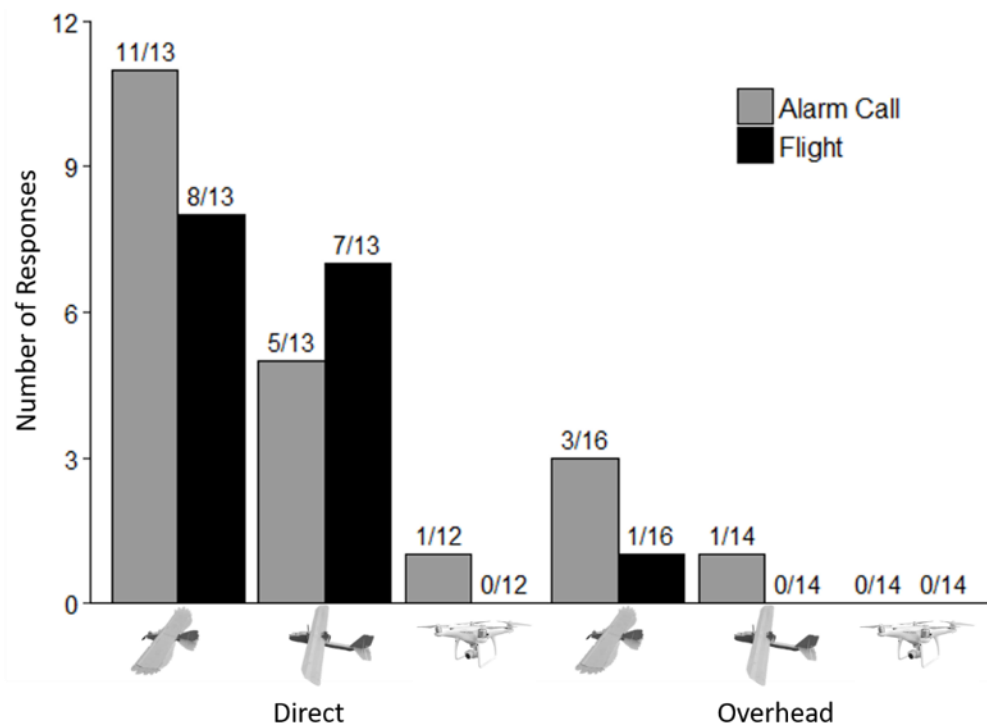


Figure 2.5. Number of birds that alarm called and initiated flight in response to predator model, fixed-wing, and multirotor under direct and overhead trajectories.

No birds initiated flight in response to the multirotor treatment, and only a single bird initiated flight in response to all overhead approaches (Figure 2.5). Thus, we omitted multirotor and overhead treatments from the analysis. When evaluating only direct approaches of the predator model and fixed-wing, we did not observe an effect of drone platform on the probability

of a blackbird initiating flight; however, we observed a significant effect of ambient light intensity (Table 2.3). The probability of a blackbird escaping in response to the direct predator model and fixed-wing decreases from ~80% to ~20% as ambient light intensity increases from 115 to 884 ( $\mu\text{mol m}^{-2} \text{s}^{-1}$ ). For blackbirds that initiated flight, we did not observe any significant effects of drone platform, drone speed, or ambient light intensity on flight-initiation time ( $\log_{10}$  scale; Table 2.2).

Table 2.3. Responses (alarm call and flight) of blackbirds to the predator model and fixed-wing. Results derived from generalized linear models.

	$\chi^2_1$	<i>P</i>
Alarm Call (n = 56)		
Platform	<b>8.20</b>	<b>0.004</b>
Trajectory	<b>16.51</b>	<b>&lt;0.001</b>
Platform x Trajectory	0.42	0.520
Ambient Light Intensity	0.36	0.549
Drone Speed	3.64	0.056
Flight (n = 26)		
Platform	0.14	0.705
Ambient Light Intensity	<b>5.27</b>	<b>0.022</b>
Drone Speed	0.41	0.520

Note: We omitted the multirotor treatment from both models due to only one bird alarm calling and no birds taking flight. We omitted the overhead trajectory treatment from the flight model due to only one bird taking flight in response to overhead predator model.

Latency to resume foraging ( $\log_{10}$  scale) significantly varied by the bird's flight response and drone platform (Table 2.2; Figure 2.6). Blackbirds returned to forage approximately 3 times later following predator model approaches (mean  $\pm$  SE seconds after the drone passed above the perch;  $56.8 \pm 9.7$ ) compared to the fixed-wing ( $18.8 \pm 4.4$ ;  $t_{66} = -5.16$ ,  $P < 0.001$ ) and approximately 5 times later compared to the multirotor ( $12.1 \pm 2.8$ ;  $t_{66} = -4.14$ ,  $P < 0.001$ ). There was no significant difference between the fixed-wing and multirotor ( $t_{66} = -0.726$ ,  $P = 0.749$ ).

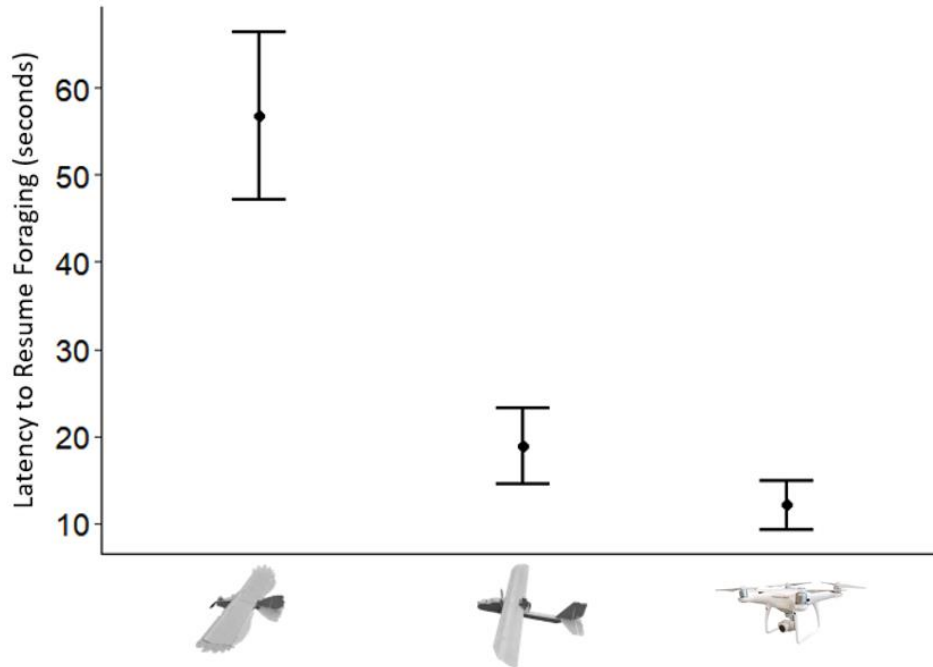


Figure 2.6. Red-winged blackbirds resumed foraging later (mean  $\pm$  SE seconds after the drone passed above the enclosure) in response to the predator model compared to the fixed-wing and multirotor.

Following flights, we found a significant difference in vigilance effort by blackbirds in response to drone platform ( $F_{2, 59} = 4.78$ ,  $P = 0.012$ ; Figure 2.7), but not trajectory ( $F_{1, 59} = 0.17$ ,  $P = 0.679$ ) or an interaction between platform and trajectory ( $F_{2, 59} = 1.16$ ,  $P = 0.321$ ). While foraging, blackbirds exposed to the predator model spent a greater proportion of time vigilant (mean  $\pm$  SE proportion head-up;  $0.49 \pm 0.03$ ) compared to the fixed-wing ( $0.37 \pm 0.03$ ;  $t_{59} = -2.51$ ,  $P = 0.039$ ) and the multirotor ( $0.36 \pm 0.04$ ;  $t_{59} = -3.03$ ,  $P = 0.010$ ). There was no significant difference between the fixed-wing and multirotor ( $t_{59} = 0.53$ ,  $P = 0.855$ ).

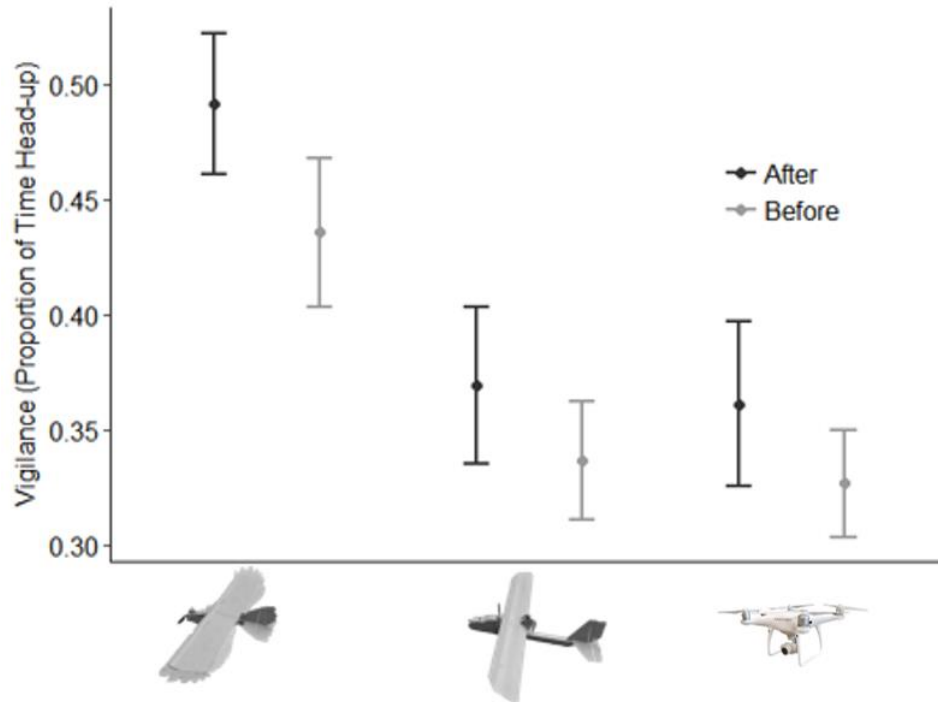


Figure 2.7. While foraging, red-winged blackbirds were more vigilant (mean  $\pm$  SE proportion of time spent head-up) in response to the predator model compared to the fixed-wing and multirotor, both before and after drone approaches. Each drone was visible to blackbirds prior to launch.

## Discussion

As predicted, blackbirds showed more pronounced responses toward the predator model compared to the other drones. Between the predator model and fixed-wing, differences were likely attributable to the predator silhouette given the size, color, and contrast of the two drones were similar. Specifically, from the perspective of perception, each drone was readily detectable to red-winged blackbirds both chromatically and achromatically. As far as the effect of sound, blackbirds alerted earliest to the predator model, despite it being the quietest drone; evidence that sound did not prompt the initial alert response. Further, prior to approach, but while drones were visible, blackbirds foraged with greater vigilance while exposed to the predator model compared to the other drones. This finding suggests blackbirds might have detected and discriminated the appearance of our stationary drones from a distance of 300 m and delayed overt alert reactions

until the drone began forward movement. Detection at this distance is plausible. For instance, Blackwell et al. (2009) examined the visual acuity of two avian species and estimated the distance mourning doves (*Zenaida macroura*) and brown-headed cowbirds (*Molothrus ater*) are capable of distinguishing an object from the background occurs around 1,000 m. Blackbirds showed an elevated vigilance response during predator model exposure compared to fixed-wing exposure, despite both drones being perceptually identical in contrast (i.e., JND <1) and similar in size; further evidence that visual cues (e.g., contour) likely determined the predation risk blackbirds associated with the drones.

Also, we contend that the predator model, despite being a drone, effectively mimicked a raptor. Classic research by Lorenz (1939) and Tinbergen (1939) first demonstrated release of innate responses in prey birds to avian predator shape via models. Similar responses have been observed across free-ranging taxa (Conover, 1979; Boag, & Lewin, 1980) and in seminatural experimental settings (Blackwell et al., 2012). In addition, predator models, conspecific effigies, and robots have been effectively deployed to examine mobbing behavior (Shalter, 1978), predation risk (Devereux et al., 2006; Jones, Krebs, & Whittingham, 2007), sensitization of animals to predators for reintroduction (McLean, Hölzer, & Studholme, 1999), and as avian repellents or deterrents (Blackwell, & Fernández-Juricic, 2013; Avery, & Werner, 2017).

In confirmation of our prediction, blackbirds were more likely to escape and alarm call in response to direct compared to overhead approaches (Figure 2.5). Directionality is a component of perceived risk in predator-prey scenarios (Møller, & Tryjanowski, 2014; Mulero-Pázmány et al., 2017) and has been confirmed experimentally (Blackwell et al., unpublished data). Escape and alarm call responses occurred less frequently during overhead flights, supporting observations where wildlife perceive drones as less disturbing at greater altitudes (McEvoy, Hall,

& McDonald, 2016; Rümmler et al., 2016; Bevan et al., 2018; Weimerskirch, Prudor, & Schull, 2018). However, trajectory had no effect on alert behavior (Table 2.2), indicating a 3-m increase in flight altitude did not diminish the time blackbirds devoted to monitoring the approaching drones. Future studies should identify minimum flight altitudes in combination with launch distances that prevent antipredator responses in wildlife, however responses might be drone-specific (McEvoy, Hall, & McDonald, 2016) and dependent on species (Mulero-Pázmány et al., 2017; Weimerskirch, Prudor, & Schull, 2018).

With direct approaches of both the predator model and fixed-wing, the probability of a blackbird initiating flight decreased as ambient light intensity increased. One explanation for this is the “disability glare hypothesis”, where high levels of ambient light can impair vision, potentially hindering detection and escape responses among birds (Fernández-Juricic et al., 2012). In birds, ambient light intensity has been shown to influence reactions to predation risk (Fernández-Juricic, & Tran, 2007; Fernández-Juricic et al., 2012) and approaching vehicles (Blackwell et al., 2009) and should be considered when evaluating responses to predator-prey scenarios. Ambient light intensity can also affect the ability of birds to visually resolve airborne threats (Blackwell et al., 2012; Beauchamp, 2017) and could affect avian responses to drones.

Our results suggest that individual blackbirds do not perceive a multirotor commonly used for wildlife monitoring (i.e., DJI Phantom; Wich, & Koh, 2018) as threatening as a simulated predator. Similar to other studies using a DJI Phantom to approach birds (Vas et al., 2015; McClelland et al., 2016; McEvoy, Hall, & McDonald, 2016; Weimerskirch, Prudor, & Schull, 2018), we found a limited antipredator response of individual blackbirds toward this drone (but see Weissensteiner, Poelstra, & Wolf, 2015). Similarly, Vas et al. (2015) approached flocks of greater flamingos (*Phoenicopterus roseus*), common greenshanks (*Tringa nebularia*),



and mallards (*Anas platyrhynchos*) with a Phantom, and were able to approach the majority of flocks to within 4 m without provoking an escape response. This popular multirotor drone might be a suboptimal option when used alone as an avian deterrent, but if operated with discretion, remains a suitable and convenient wildlife-monitoring tool that can minimize behavioral distress (but see Ditmer et al., 2015; Weissensteiner, Poelstra, & Wolf, 2015; Weimerskirch, Prudor, & Schull, 2018) to birds when compared to alternative drone platforms.

### **Management Implications**

Our data suggests drones designed to mimic aerial raptors can effectively elicit amplified behavioral responses when compared to generic fixed-wings or multirotors. Although the fixed-wing elicited greater behavioral responses than the multirotor, the platforms also varied in multiple physical attributes (e.g., size, color, sound output), complicating conclusions that one general drone type (i.e., multirotor versus fixed-wing) is less disturbing than another. We suggest future research assess wildlife responses to multirotors and generic fixed-wings having similar characteristics. We support protocol recommendations outlined in (Mulero-Pázmány et al., 2017), where wildlife managers deploying drones for monitoring should maximize altitude when possible, and avoid using drones with predator attributes.

Our results have management implications for areas human-wildlife conflict; specifically, the economic loss caused by birds through crop predation, and safety hazards caused by birds in airport environments (Conover, 2002; DeVault, Blackwell, & Belant, 2013). Current nonlethal methods used to deter birds from airports and agricultural fields include habitat management, exclusion, chemical repellents, and deterrents such as pyrotechnics, propane cannons, effigies, and acoustic devices that play distress calls (Cleary, & Dolbeer, 2005; DeVault, Blackwell, & Belant, 2013; Avery, & Werner, 2017). Drones can overcome the mobility limitations faced by

other deterrent strategies and can be deployed quickly to a specific location when needed (Grimm et al., 2012; Klug, 2017). However, multirotors and standard fixed-wings might be suboptimal when used as avian frightening devices. Drones with predator attributes might perform better, but only in scenarios when target species (e.g., blackbirds) perceive aerial raptors as lethal predators.

Furthermore, our data suggests that wildlife managers should not evaluate the efficacy of drones deployed for wildlife hazing solely by their ability to provoke an escape response, but rather the potential to enhance the perceived risk of an area. In our study, blackbirds spent more time vigilant and returned to forage later when exposed to the predator model compared to the other drones. Both metrics suggest that drone exposure can decrease the foraging efficiency of birds as they dedicate an increased effort to vigilance. Reducing the foraging efficiency of birds can potentially decrease economic losses due to crop depredation and encourage birds to abandon areas where foraging efficiency is limited. However, the behavioral responses of captive, individual blackbirds in our study may not reflect the response of free-ranging flocks of blackbirds, warranting evaluation of our drones in a field setting.

Many questions remain regarding the use of drones for wildlife hazing. Future studies should evaluate the effects of speed, size, and color of drones on wildlife escape responses (Vas et al., 2015). Additionally, installing or modifying drone lighting systems tuned to the sensory capabilities of target species may improve detection and escape responses (Blackwell, & Fernández-Juricic, 2013; Fernández-Juricic, 2015). For example Blackwell et al. (2012) and Doppler et al. (2015) found that lighting on radio-controlled aircraft enhanced alert behavior in Canada geese (*Branta canadensis*) and brown-headed cowbirds respectively. Other possibilities may include equipping drones with on-board sound speakers that interfere with flock

communication (Swaddle et al., 2016) or play distress or predator calls, or on-board firearms that discharge nonlethal projectiles toward pest-species (Chabot, & Bird, 2015). Future technology may also allow drones to be modified with on-board mechanisms to directly spray non-lethal chemical repellents at flocks (Ampatzidis, Ward, & Samara, 2015). This strategy would create a negative stimulus for a greater proportion of the flock to experience, potentially countering the dilution of risk within flocks (see Krause, & Ruxton, 2002). Evaluating drones as potential hazing mechanisms is a novel concept, and the rapidly evolving technology of drones suggest a promising future for integrating these unique tools into global pest management strategies.

## References

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## **CHAPTER 3: EVALUATING THE UTILITY OF DRONES TO DETER PEST BLACKBIRDS FROM SUNFLOWER FIELDS**

### **Abstract**

Crop depredation by blackbirds (Icteridae) results in significant economic losses to the United States sunflower industry (~ \$7 million annually), and a solution to effectively reduce damage remains elusive. We explored the potential utility of unmanned aircraft systems (UASs; or drones) as hazing tools to deter foraging blackbirds from commercial sunflower fields. We evaluated the hazing efficacy of three drones: a predator model mimicking the form of an aerial raptor, a standard fixed-wing of similar size, and a multirotor. Multirotor drones are relatively easy to fly and are a multi-functional tool for agricultural use, however, they may not be an effective avian deterrent, due to a lack of similarity in appearance with natural predators. Free-ranging blackbird flocks initiated flight upon every drone approach; however, the probability of a blackbird flock abandoning a field was dependent on field size and flock size, rather than the specific drone deployed. In an applied setting, the performance of drones as frightening devices will likely depend on a combination of platform selection, duration of use, context, and species.

### **Introduction**

Throughout the Prairie-Pothole Region (PPR) of the Northern Great Plains, red-winged blackbirds (*Agelaius phoeniceus*), common grackles (*Quiscalus quiscula*), and yellow-headed blackbirds (*Xanthocephalus xanthocephalus*) congregate in large post-breeding flocks that can number over 100,000 individuals (Linz, & Hanzel, 1997; Linz et al., 2011). Collectively, these species reach a post-breeding population of about 75 million individuals throughout the PPR, and their migration overlaps with the ripening of commercially-grown sunflower (Linz et al., 2011). Sunflower seeds are an important food resource for many migrating birds, as the seeds contain

fats and proteins necessary to fuel energetic demands posed by feather molt and long-distance flights (Besser, 1978). Consequently, annual blackbird damage to sunflower exceeds US \$3.5 million (Linz et al., 2011; Klosterman et al., 2013), and individual producers can experience field damage surpassing 20% crop loss (Klosterman et al., 2011), far beyond the threshold considered economically acceptable (Linz, & Homan, 2011). After reviewing the history of blackbird damage management strategies, Linz et al. (2011) identified the mobility of blackbird flocks as the greatest challenge to current efforts, and conceded a cost-effective solution remains elusive.

Effective avian deterrents may require a disturbance that shifts the costs of remaining in a resource patch (e.g., crop field) beyond the costs of fleeing (Ydenberg, & Dill, 1986), a challenge that may depend on a variety of factors including perceived predation risk, patch-quality, and the availability and knowledge of other foraging areas on the landscape (Frid, & Dill, 2002; Avery, 2003). If the energetic costs of devoting time to antipredator behavior (i.e., scanning and monitoring) outweigh the fitness-benefits provided by a resource patch, given alternative resource patches are available and the animal has knowledge of these resources, an animal or group of animals may decide to leave an area entirely (Frid, & Dill, 2002; Bejder et al., 2009). Theoretically, wildlife managers could increase the costs of remaining by enhancing predation risk perceived by target species, and ultimately encourage wildlife to abandon a resource patch in areas of human-wildlife conflict (Blumstein, & Fernández-Juricic, 2010; Blackwell et al., 2016).

Recently, unmanned aircraft systems (UASs; or drones) have gained popularity as wildlife monitoring tools (reviewed in Chabot, & Bird, 2015; Linchant et al., 2015; Wich, & Koh, 2018) and have been suggested as a method to deter birds from areas of human-wildlife conflict (Grimm et al., 2012; Ampatzidis, Ward, & Samara, 2015; Klug, 2017). Drones can elicit

escape behavior in birds (Blackwell et al., 2012; McEvoy, Hall, & McDonald, 2016; Weimerskirch, Prudor, & Schull, 2018) and can overcome mobility limitations faced by other deterrent strategies (Grimm et al., 2012; Klug, 2017). Furthermore, managers or producers can deploy a drone to a specific location within minutes and can reach the interior of large crop fields (4-250 ha) that are otherwise inaccessible for tool deployment. Wildlife managers have used multirotor drones to harass birds, but reports of efficacy are so far anecdotal (Lilleboe, 2015; Curtis et al., 2016), or drones were not operated in a manner to maximize disturbance (see Wandrie, Klug, & Clark, 2019). In contrast to multirotors, some companies offer bird-control services using drones that mimic the appearance and flight behavior of falcons, and their use has already been adopted at airports (Rosenberg, 2017). However, it remains unclear what features (e.g., shape, contrast, size, speed, or flight maneuvers) optimize drones for hazing, and how responses to these features differ across taxa and species (Mulero-Pázmány et al., 2017; Weimerskirch, Prudor, & Schull, 2018).

McEvoy, Hall and McDonald (2016) approached groups of waterfowl with various drone platforms and found that birds seemed most disturbed by the drone that resembled the shape of an aerial raptor. In contrast, waterfowl displayed a limited disturbance response when approached by two multirotor platforms in the same study (McEvoy, Hall, & McDonald, 2016). In addition, we found that individual, captive red-winged blackbirds exhibited greater antipredator responses when exposed to a predator-shaped drone when compared to a standard fixed-wing and multirotor (see Chapter 2). These studies indicate that drones designed to mimic aerial raptors can effectively elicit amplified antipredator behaviors in birds when compared to drones typically used for monitoring (i.e., generic-fixed wings and multirotors), but their use to

deter free-ranging birds from areas of human-wildlife conflict has not been empirically tested (but see Wandrie, Klug, & Clark, 2019).

### **Objectives and Hypotheses**

We tested whether a predator-shaped drone would be more effective at dispersing blackbirds from commercial sunflower fields, when compared to drones typically used for monitoring (generic fixed-wings and multirotors). We hypothesized that blackbird flocks would differentially respond to the drone platforms, and escape responses would involve fleeing. Using flight initiation distance (FID) as our metric of perceived risk (Ydenberg, & Dill, 1986), we predicted that FID of flocks would be greater in response to the predator model compared to the other drones. Additionally, when pursued using targeted, low-altitude flights we predicted blackbird flocks would abandon fields in less time or more frequently in response to the predator-shaped drone compared to the other drones.

### **Methods**

We conducted our study in the PPR of North Dakota, an area with a historically large red-winged blackbird population (Nelms et al., 1999; Peer et al., 2003). From 16 September to 25 October 2017, we conducted drone flights within 32 sunflower fields, ranging in size from 4 – 250 ha (mean  $\pm$  SD ha;  $62.33 \pm 57.27$ ). We conducted flights when blackbirds were observed actively foraging on sunflower fields and the pilot (C.C.E) obtained permission from landowners to conduct flights. Thus, we did not distribute effort uniformly across field sizes, but instead opportunistically sampled a gradient of field sizes occurring on the landscape. Sunflower fields occurred in a heterogeneous matrix of agricultural land cover types, including pasture, soybean, corn, barley, and harvested fields, interspersed with human development (e.g., farmsteads and roads), shelterbelts (i.e., rows of trees) and cattail (*Typha* spp.) dominated wetlands (USDA

NASS, 2018). If we operated within a single field multiple times, we used a different, randomly selected drone and allowed 6 days to pass between subsequent flights. Flock composition likely changed throughout the season due to population turnover with incoming migrant birds and flock mixing at roosting sites (Linz et al., 1991), however, blackbirds were unmarked, so we cannot exclude that we approached individual blackbirds multiple times. That said, we considered our methods as comparable to an active hazing program, where birds would likely be hazed repeatedly over the course of the damage season (August to October) for repeatedly short time periods over the course of the day.

Upon locating a blackbird flock, (C.C.E) visually estimated flock size (range 150 – 6000 birds; mean  $\pm$  SD;  $1288 \pm 939$ ). Compared to aerial-photo counts, visual estimates of large bird flocks by human observers are often inaccurate (Erwin, 1982; Boyd, 2000; Frederick et al., 2003). However, we feel confident that our estimates were consistent relative to other flocks observed throughout the season, thus any overall effect of flock size in our analysis should reflect a true biological effect.

### ***Flight Initiation Distance***

Escape behavior, specifically FID, can be influenced by the starting distance of an approaching threat (Blumstein, 2003). We used a rangefinder and compass to estimate the location of the flock, by targeting the nearest bird as a proxy for the flock edge. Calculations resulted in launch distances (i.e., starting distance) ranging from 74 – 401 m (mean  $\pm$  SD m;  $202 \pm 73.94$ ). Using FID as our metric of perceived risk (Ydenberg, & Dill, 1986), we launched a randomly selected drone (predator model, fixed-wing, or multirotor) and approached free-ranging blackbird flocks directly (5-10 m AGL) until they initiated a flight response. We attempted to control altitude; however, uneven terrain and high wind gusts resulted in slight

variations. Once we observed a flock escape response, we stopped the drone approach and returned the drone to the pilot location. We scored an escape response as the moment when >50% of the birds within a flock became airborne, which was always a conspicuous event (i.e., dense group of birds). We collected drone coordinates via an onboard GPS for every moment in flight, which we used to pinpoint drone location when the flock initiated flight. Studies using terrestrial vehicles to approach animals have dropped objects from the vehicle to mark FID (see DeVault et al., 2014), however, that method would have been logistically difficult in this scenario. Instead, we used Google Earth to calculate the horizontal distance between the drones and flock location when the flock initiated flight, giving us an estimate of flock FID (Figure 3.1). Our calculations of FID depended on accurate estimates of flock location. Variable flock sizes, uneven terrain, and complex land cover made estimating flock dimensions (e.g., edge, center, diameter) challenging. As such, our estimates of flock FID are subject to error.

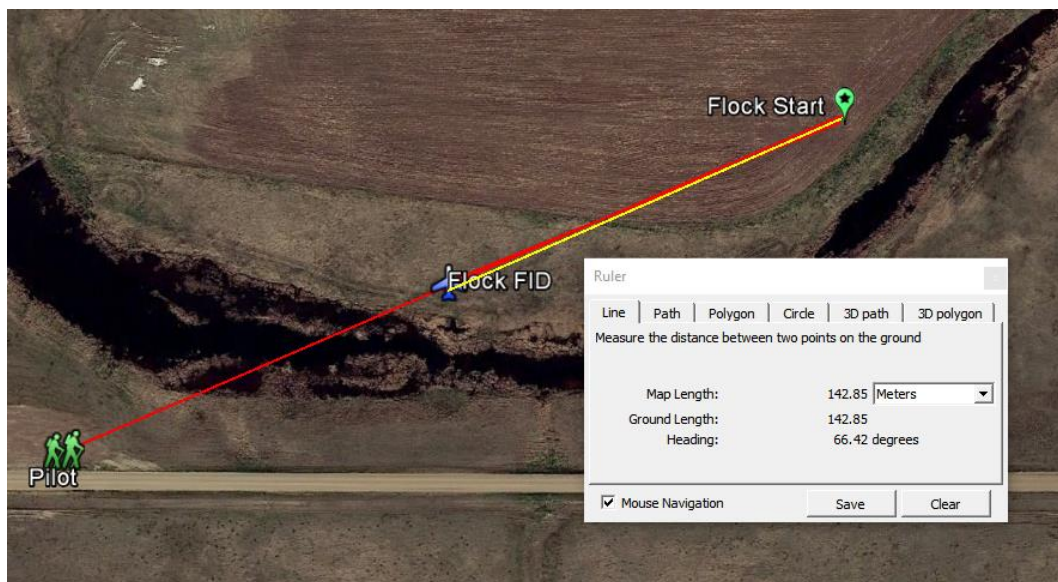


Figure 3.1. We used Google Earth to estimate flight-initiation distance of blackbird flocks in response to drone flights. Here, “Pilot” indicates our launch location, “Flock Start” indicates the flock’s initial location, “Flock FID” indicates the drone’s location at the moment the flock initiated flight.



### *Hazing Flights*

Following FID trials, we allowed blackbirds to resume foraging behavior (i.e., land on sunflower), before approaching the same flock again and performing aggressive flight maneuvers (e.g., swooping, diving, herding) with the intent of motivating the flock to leave the sunflower field. Due to battery constraints, these flights were limited to approximately 120 seconds, and we scored whether the entire flock exited the sunflower field as a binary response. Generally, hazing trials required advanced piloting maneuvers (i.e., repetitive turning). Thus, if we conducted an FID trial, but the pilot (C.C.E) determined flocks were too distant to safely maneuver the drone for hazing, we did not conduct hazing trials. We recorded ambient air temperature (1.1 – 24.9°C), ambient light intensity (98.58 – 932.20  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ), and average wind speed (0.3 – 28.5  $\text{km hr}^{-1}$ ) during each trial.

### *Statistical Analysis*

We treated each blackbird flock as an experimental unit, and used general linear models assess the effect of drone platform on our estimates of FID, for which we assumed a Gaussian distribution. We including starting distance as an independent continuous variable, due to the predicted relationship between starting distance and FID (Blumstein, 2003).

We used a generalized linear model, binomial distribution, and a logit link to assess the effect of drone platform on the probability of a blackbird flock abandoning a field in response to hazing. We also considered the potential effects of field size and flock size on perceived risk and treated both variables as continuous independent variables. All statistical analyses were conducted using R (version 3.4.3; R Core Team, 2017) using type II sums of squares.

## Results

### *FID Trials*

Every blackbird flock initiated flight in response to 60 FID trials. We did not consider two trials for analysis, due to confirmed GPS error. We observed a significant effect of drone platform ( $F_{2, 54} = 11.8, P < 0.001$ ; Figure 3.2) and starting distance ( $F_{1, 54} = 15.2, P < 0.001, r = 0.33$ ) on estimated FID. Blackbird flocks initiated flight at shorter distances (LSmean  $\pm$  SE) in response to the multirotor ( $50.83 \pm 7.48$ ) compared to the fixed-wing ( $102.52 \pm 8.28; t_{54} = 4.59, P < 0.001$ ) and predator model ( $89.87 \pm 8.21; t_{54} = 3.51, P = 0.003$ ). There was no significant difference between the predator model and fixed-wing ( $t_{54} = -1.09, P = 0.527$ ).

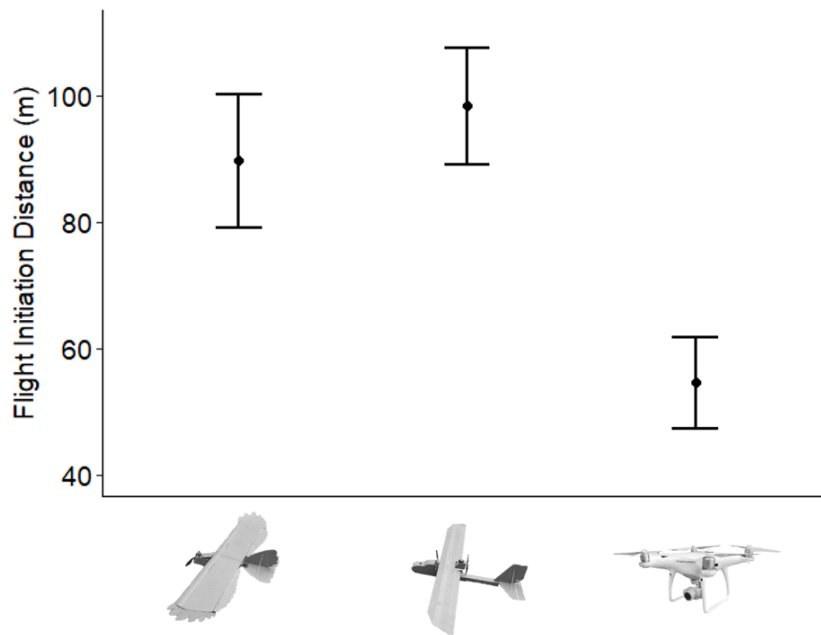


Figure 3.2. Blackbird flocks initiated flight at shorter distances (mean  $\pm$  SE) in response to the multirotor compared to the predator model and fixed-wing.

### *Hazing Trials*

We conducted hazing trials on a total of 53 blackbird flocks, and motivated 9 flocks to abandon fields. We did not observe a significant effect of drone platform on field abandonment

( $x^2 = 3.46$ ,  $P = 0.177$ ), but we observed a significant effect of field size ( $x^2 = 10.47$ ,  $P = 0.001$ ) and estimated flock size ( $x^2 = 7.53$ ,  $P = 0.006$ ), but no significant interaction of field size and estimated flock size ( $x^2 = 0.03$ ,  $P = 0.873$ ). Based on our data, the probability of a flock abandoning a field in response to 2-minute drone flights begins at about 50% and decreases as field size increases and estimated flock size increases, independently (Figure 3.3).

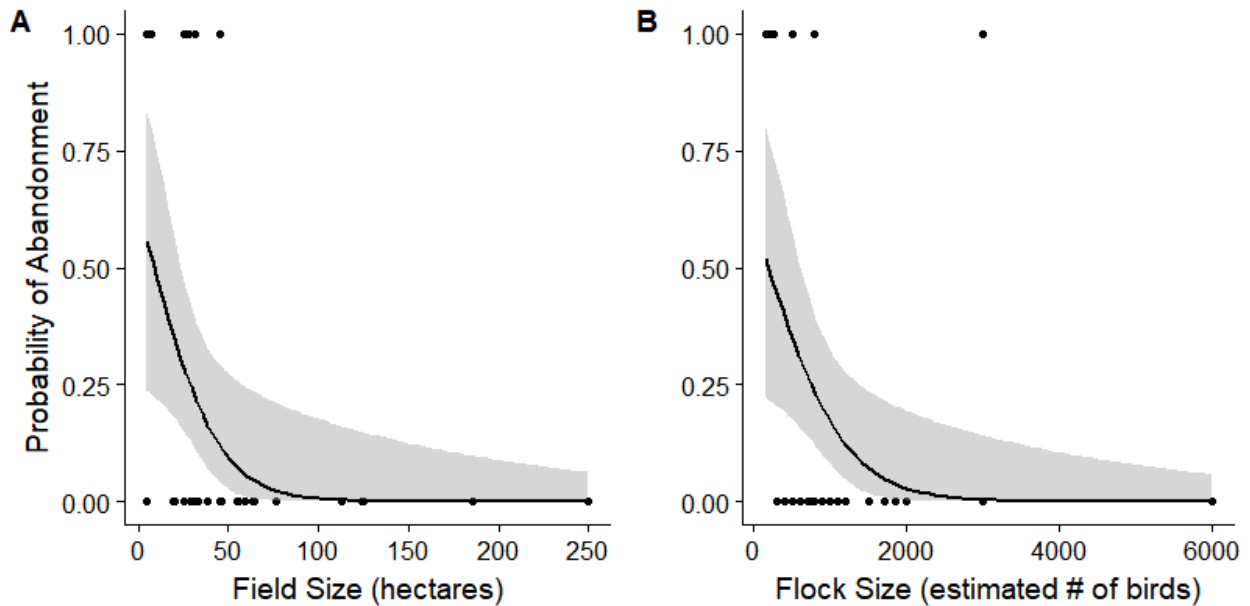


Figure 3.3. The probability of blackbird flocks leaving the field in response to drone hazing (N=53) decreases with increasing field size and increasing flock size. Shaded area indicates 95% confidence interval.

## Discussion

Based on our estimates of flock FID, blackbird flocks initiated flight earlier in response to the predator model and fixed-wing compared to the multirotor, a finding supported by the results of our seminatural study (see Chapter 2). Flocks may have perceived the predator model and fixed-wing drones as more threatening than the multirotor, detected the multirotor later into the approach sequence, or a combination thereof. Interestingly, every flock responded to drone approaches by taking flight. In contrast, Wandrie, Klug and Clark (2019) found that no blackbird

flocks showed a flight response during approaches by a fixed-wing drone flying 52 m AGL, and several flocks showed no flight response during approaches by a multirotor flying 15 or 30 m AGL. Although we used different drone platforms, this suggests blackbird flocks perceive drone approaches at lower altitudes (i.e., 5 to 10 m AGL) more disturbing than approaches at higher altitudes (i.e., >15 m AGL).

The probability of a flock abandoning fields depended on estimated flock size and field size, but not drone platform. In regard to flock size, larger groups of prey may take advantage of dilution effects, whereby prey realize they have “safety in numbers” when a predator can only capture a single individual among many (Krause, & Ruxton, 2002). Thus, the chances of an individual prey being captured decreases as group size increases, and larger groups may tolerate predation pressure that a smaller group would not (Krause, & Ruxton, 2002). Group size has been observed to influence wildlife reaction distances to drones (Vas et al., 2015; Mulero-Pázmány et al., 2017), and future studies should identify species-specific group size thresholds where effects of drone disturbance stabilize, despite increasing numbers of individuals (see Laursen, Kahlert, & Frikke, 2005).

In regard to field size, the effect is likely due to scale, timing, and duration of drone flights. Depending on their location, blackbirds will need to travel considerable distances (i.e. >500 m) to exit the airspace above large fields in response to hazing. Furthermore, during September and October, blackbirds might suffer impaired flight performance due to feather molt, and may seek cover instead of flying (Handegard, 1988; Swaddle, & Witter, 1997). Over a span of approximately 120 seconds, drone hazing was largely ineffective at encouraging blackbird flocks to abandon sunflower fields. Longer flight durations may be necessary to effectively disperse blackbird flocks; however, contracting drone services or independently operating drones

will likely cost producers money and time, warranting a cost-benefit analysis (see Linz et al., 2011).

Linz et al. (2011) identified two management strategies that might influence the efficacy of hazing blackbirds with drones: 1) some producers currently plant large fields as a strategy to spread blackbird damage over a greater area; and 2) producers are encouraged to leave an unplanted route to the interior of the field, providing increased access to deploy deterrent strategies. Based on our data, the performance of drones as a hazing tool might work better on smaller fields when compared to larger fields. Perhaps planting sunflower across smaller tracts, alternating with a less attractive food resource crop (see Linz, & Klug, 2017) may create a landscape that is less energetically profitable to blackbirds, giving flocks less incentive to tolerate disturbance pressure applied by drones. However, this assumes that other foraging opportunities exist on the landscape and blackbirds are aware of these opportunities. For example, blackbirds depredating a sunflower field will likely tolerate disturbances if the field is isolated from other foraging opportunities of similar nutritional value (Avery, 2003; Linz, & Klug, 2017). For this reason, sunflower growers strategically synchronize plantings to reduce the potential for staggered crop stages, as early and late-maturing fields may be susceptible to blackbird predation due to lack of alternative fields. Access points into the field interior will also allow a drone pilot to launch drones closer to the flock's location. This will improve a drone pilot's ability to maintain close contact with blackbird flocks without flying the drone beyond visual line of sight; a current restriction prohibited by the U.S. Federal Aviation Administration.

Biologically, one might argue that our predator model failed to effectively mimic a raptor from the perception of free-ranging blackbirds. Throughout the study period, we observed multiple interactions between raptors and blackbird flocks. Raptors observed on multiple

occasions included merlins (*Falco columbarius*), Cooper's hawks (*Accipiter cooperii*), red-tailed hawks (*Buteo jamaicensis*), and northern harriers (*Circus hudsonius*). Raptors observed on a single occasion included a turkey vulture (*Cathartes aura*), prairie falcon (*Falco mexicanus*), and peregrine falcon (*Falco peregrinus*). We observed two separate occasions where a merlin and a Cooper's hawk approached a foraging blackbird flock and caused the flock to abandon the field. In contrast, we also observed a merlin actively consuming a deceased blackbird, while a flock actively foraged within 50 m. We also witnessed active attacks of Cooper's hawks on blackbird flocks, where the flock remained on the sunflower crop following the attack. Interestingly, the presence of northern harriers and red-tailed hawks appeared ineffective at deterring blackbirds from sunflower fields or displacing them from a roosting site. For example, on one occasion we observed a red-tailed hawk perched among roosting blackbirds (i.e., same tree). These observations indicate that flock response to raptors will likely be species-specific, and this phenomenon has been observed in other predator-prey scenarios involving birds (Walters, 1990; Edelaar, & Wright, 2006).

Additionally, the behavioral response of blackbird flocks to our drones appeared visually similar to the manner in which flocks responded to northern harriers, in that they generally created a rift in the flock, but the blackbirds did not move very far beyond what was necessary to avoid contact or collision (Figure 3.4, 3.5). Although our observations are opportunistic and anecdotal, it appears large, migratory blackbird flocks tolerate the predation risk associated with local raptors, suggesting a single drone resembling a predator or passive raptor management to increase predator presence (i.e., predator perches or nest boxes; Kay et al., 1994; Kross, Tylianakis, & Nelson, 2012) is unlikely to deter blackbird flocks from sunflower fields. However, like drone disturbance, efficacy might depend on field size and flock size.

Ultimately, the performance of drones as avian deterrents will likely depend on drone platform, duration of use, context, and species. We suggest that future research include assessments of stimuli that might enhance perceived risk posed by drones, including evaluations of salient on-board lighting (Blackwell et al., 2012; Doppler et al., 2015; Fernández-Juricic, 2015), evaluation of multiple drones used in coordination, or negative stimuli (e.g., lasers, nonlethal projectiles, chemical repellents; Ampatzidis, Ward, & Samara, 2015; Chabot, & Bird, 2015) used in coordination with drones and assessments of efficacy in different contexts (e.g., day roosts, night roosts, foraging areas, and water retention ponds).



Figure 3.4. Blackbird flock response to incoming predator model.





Figure 3.5. Blackbird flock response to an apparent attack by a northern harrier (*Circus hudsonius*) located near the center (circled) of the photograph.

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## CHAPTER 4: CONCLUSIONS AND FUTURE DIRECTIONS

Our results demonstrate two prominent conclusions: 1) individual male, red-winged blackbirds (*Agelaius phoeniceus*) do not perceive different drone platforms as equally disturbing and 2) the perceived risk of individual blackbirds may be diluted within groups of conspecifics. In the seminatural study, individual blackbirds became alert later, alarm called and escaped less frequently, resumed foraging earlier, and spent less time vigilant while foraging in response to the multirotor compared to a simulated raptor attack posed by our predator model. Blackbirds also showed more pronounced responses toward the predator model compared to the fixed-wing, indicating that differences were unlikely attributed to drone size, color, and contrast alone. These data suggest that wildlife managers can manipulate the perceived risk associated with drones by applying or modifying visual aspects of the airframe. However, group dynamics and landscape factors experienced by free-ranging wildlife (e.g., blackbirds) may diminish the effects observed across individuals tested under controlled conditions.

We support protocol recommendations outlined in (Mulero-Pázmány et al., 2017), where wildlife managers deploying drones for monitoring should maximize altitude when possible, and avoid using drones with predator attributes. The authors also recommend that operators should launch 100-300 m away from the animals or study area to reduce disturbance (Mulero-Pázmány et al., 2017). Our results indicate that wildlife (e.g., blackbirds) might perceive drones as disturbing, even at distances of 300 m. Future studies should identify launch distances in combination with minimum flight altitudes that prevent antipredator responses in wildlife, however responses might be drone-specific (McEvoy, Hall, & McDonald, 2016) and dependent on species (Mulero-Pázmány et al., 2017; Weimerskirch, Prudor, & Schull, 2018).

Future technology will likely increase the efficacy of drones to deter wildlife from areas of human-wildlife conflict. For example, Ampatzidis, Ward and Samara (2015) conceptually designed an autonomous drone capable of detecting pest bird flocks, moving to the flock's active location, and spraying birds directly with a nonlethal chemical repellent. The next phase of this strategy should determine application strategies and if drones can approach bird flocks to a distance where liquid spray makes contact with birds. Using a drone in combination with negative stimuli (e.g., chemical repellents, lasers, nonlethal projectiles) might counter dilution effects within flocks (see Krause, & Ruxton, 2002) if the stimuli directly impacts a larger number of individuals.

If wildlife do not perceive drones as particularly disturbing or threatening, but will move short distances to avoid collision, drones could potentially be used to “herd” wildlife (e.g., ungulates, bird flocks) away from areas of concern (Paranjape et al., 2018), or move animals to allow for more efficient deployment of alternative management tools (e.g., propane cannons, firearms, capture devices, or decoy crops). Alternatively, wildlife managers could use a drone to ferry other deterrents to the problem location. For example, a drone could carry and activate pyrotechnics in close proximity to problematic wildlife species where access by wildlife managers would otherwise be difficult (e.g., within large crop fields). Drones that mimic the appearance and flight dynamics of falcons, operated by mechanically flapping wings, have also been engineered to deter birds (Folkertsma et al., 2017), and their use has already been adopted by airports (Rosenberg, 2017). This strategy might deter species that perceive raptors as lethal predators, but might not work on larger species such as geese (Anatidae) or vultures (Cathartidae) (see Blackwell et al., 2012; DeVault et al., 2014).

Ultimately, wildlife managers should weigh the monetary costs associated with drone flights against the benefits provided by reduced bird presence. For example, a single bird-aircraft strike involving a red-tailed hawk (*Buteo jamaicensis*) resulted in repair costs exceeding U.S. \$1 million, and between 1990 – 2015, the average repair costs per wildlife-strike that resulted in aircraft damage equates to approximately \$165,000 per incident (Dolbeer et al., 2016). In contrast, a bioenergetic model based on red-winged blackbird consumption of commercial sunflower seeds indicates that a single male red-winged blackbird eats roughly 0.009 kg of seed daily (Peer et al., 2003). Accordingly, a flock of 2,000 blackbirds foraging in a sunflower field for the 6-week period sunflower is most vulnerable to depredation, is expected to consume approximately 756 kg of seed (Peer et al., 2003). At 2017 prices (\$17.35/cwt; \$0.34/kg; National Sunflower Association, 2018), this equates to approximately \$257 in damage. However, a flock of 50,000 birds over the same period might cause \$6,426 worth of damage. Thus, the cost-effectiveness of deploying drones to deter and disperse birds from areas of human-wildlife conflict will depend on context and scale, and may not be solvent for every wildlife-damage scenario.

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## APPENDIX

Table A1. Responses of 76 blackbirds to drones ( $\log_{10}$  alert-time,  $\log_{10}$  latency to resume foraging, and  $\log_{10}$  flight initiation time).

	<i>df</i>	<i>F</i>	<i>P</i>
<b>Log<sub>10</sub> Alert-Time</b>			
Platform	2, 68	<b>44.19</b>	<b>&lt;0.001</b>
Trajectory	1, 68	<b>4.95</b>	<b>0.029</b>
Platform x Trajectory	2, 68	1.81	0.172
Ambient Light Intensity	1, 68	1.56	0.217
Drone Speed	1, 68	2.78	0.100
<b>Log<sub>10</sub> Flight Initiation Time</b>			
Platform	1, 7	2.57	0.153
Ambient Light Intensity	1, 7	0.06	0.812
Drone Speed	1, 7	0.49	0.518
<b>Log<sub>10</sub> Latency to Resume Foraging</b>			
Platform	2, 58	<b>14.69</b>	<b>&lt;0.001</b>
Trajectory	1, 58	0.57	0.452
Platform x Trajectory	2, 58	0.06	0.939
Ambient Light Intensity	1, 58	0.68	0.414
Drone Speed	1, 58	0.26	0.612
Flight	1, 58	<b>11.24</b>	<b>&lt;0.001</b>

Note: We omitted birds from analyses that were not foraging during the drone approach, or birds that foraged but faced backwards or sideways relative to the incoming drone. Results derived from general linear models. Degrees of freedom differ between response variables based on behavior criteria we considered for each response.

Table A2. Responses (alarm call and flight) of 76 blackbirds to the predator model and fixed-wing.

	$\chi^2_1$	<i>P</i>
Alarm Call (n = 46)		
Platform	<b>7.67</b>	<b>0.006</b>
Trajectory	<b>10.82</b>	<b>&lt;0.001</b>
Platform x Trajectory	0.85	0.356
Ambient Light Intensity	0.22	0.641
Drone Speed	1.81	0.178
Flight (n = 22)		
Platform	0.11	0.740
Ambient Light Intensity	2.19	0.139
Drone Speed	0.04	0.848

Note: We omitted birds from analyses that were not foraging during the drone approach, or birds that foraged but faced backwards or sideways relative to the incoming drone. Results derived from generalized linear models. We omitted multirotor trials from both models due to only one bird alarm calling and no birds taking flight. We omitted overhead trials from the flight model due to only one bird taking flight in response to overhead predator model.

Table A3. Results of general linear models with the fixed-wing set as the reference (i.e., the intercept).

Effect	Mean	SD	Estimate	SE	<i>t</i> value	<i>P</i>
<b>Log<sub>10</sub> Alert Time (seconds)</b>						
(Intercept)	0.80	0.34	0.953	0.308	3.098	<b>0.003</b>
Direct Multicopter	0.28	0.33	-0.538	0.136	-3.941	<b>&lt;0.001</b>
Direct Predator Model	1.11	0.30	0.311	0.134	2.323	<b>0.023</b>
Overhead Trajectory	0.57	0.49	-0.252	0.132	-1.908	0.060
Ambient Light Intensity	.	.	<0.001	<0.001	1.673	0.098
Drone Speed	.	.	-0.024	0.022	-1.091	0.278
Multicopter x Overhead Trajectory	0.09	0.34	0.092	0.193	0.477	0.635
Predator Model x Overhead Trajectory	1.11	0.33	0.289	0.188	1.538	0.128
<b>Log<sub>10</sub> Latency to Resume Foraging (seconds)</b>						
(Intercept)	1.12	0.57	0.527	0.428	1.229	0.223
Direct Multicopter	0.90	0.49	0.072	0.198	0.365	0.717
Direct Predator Model	1.78	0.27	0.628	0.180	3.485	<b>&lt;0.001</b>
Overhead Trajectory	0.77	0.61	-0.066	0.195	-0.338	0.737
Ambient Light Intensity	.	.	<0.001	<0.001	0.670	0.505
Drone Speed	.	.	0.015	0.028	0.550	0.584
Flight	.	.	0.597	0.171	3.490	<b>&lt;0.001</b>
Multicopter x Overhead Trajectory	0.90	0.29	0.047	0.262	0.178	0.859
Predator Model x Overhead Trajectory	1.46	0.42	0.027	0.248	0.111	0.912
<b>Vigilance Before Approach (Proportion)</b>						
(Intercept)	0.34	0.13	0.337	0.027	12.674	<b>&lt;0.001</b>
Multicopter	0.33	0.12	-0.010	0.038	-0.262	0.794
Predator Model	0.44	0.16	0.099	0.038	2.583	<b>0.012</b>
<b>Vigilance After Approach (Proportion)</b>						
(Intercept)	0.39	0.16	0.187	0.161	1.158	0.252
Direct Multicopter	0.30	0.12	-0.091	0.069	-1.311	0.195
Direct Predator Model	0.51	0.12	0.118	0.074	1.597	0.116
Overhead Trajectory	0.35	0.17	-0.031	0.067	-0.474	0.637
Multicopter x Overhead Trajectory	0.41	0.19	0.131	0.095	1.377	0.174
Predator Model x Overhead Trajectory	0.48	0.16	0.010	0.098	0.105	0.917
Ambient Light Intensity	.	.	<0.001	<0.001	1.315	0.194
Drone Speed	.	.	0.010	0.011	0.898	0.373

Note: Boldface type indicates significance for  $\alpha < 0.05$ .