AN EVALUATION OF THE SOCIAL PERCEPTIONS AND BIOLOGICAL EFFICACY OF UNMANNED AIRCRAFT SYSTEMS FOR AVIAN-AGRICULTURE CONFLICT

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Mallory Gyovai White

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Environmental & Conservation Sciences

November 2021

Fargo, North Dakota

North Dakota State University
Graduate School

Title

AN EVALUATION OF THE SOCIAL PERCEPTIONS AND BIOLOGICAL EFFICACY OF UNMANNED AIRCRAFT SYSTEMS FOR AVIAN-AGRICULTURE CONFLICT

By

Mallory Gyovai White

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Page Klug
Chair

Timothy Greives

Paulo Flores

Approved:

11-15-21
Date

Craig Stockwell
Department Chair

ABSTRACT

North Dakota sunflower producers face a dilemma when it comes to blackbirds (Icteridae). Migrating flocks produce localized damage to production, which results in some farmers with no bird issues, while others face total economic losses. A dynamic and humane crop protection tool is necessary to reduce blackbird damage in this broad-scale agriculture setting, as damage is actively occurring, while considering the protected status of blackbirds. This study examined a novel tool, unmanned aircraft systems (hereafter, UAS), through the lens of a social evaluation of farmers' opinions and the biological impact on blackbird flock behavior. Farmers were very willing to allow a variety of UAS operations on their property, but willingness was dependent on age, farming generation, prior blackbird damage and preventative efforts. Time of day and flock size were important factors for perception of risk toward UAS by blackbird flocks, and 52% of the flocks abandoned due to UAS hazing.

ACKNOWLEDGMENTS

This project is possible because of an entire team of people, supporting me every step of the way. Research is seldom a solo experience, and this project is living proof. I would first like to thank my advisor, Dr. Page Klug, for the encouragement, support, and genuine involvement over the last 2.5 years. I have accomplished so much in such a short timeframe because of her mentorship and guidance. I would also like to thank my committee, Dr. Timothy Greives and Dr. Paulo Flores, for providing me feedback and making time for any and all of my questions. I would like to thank Dr. Craig Stockwell for his continued and ever-present support of students in the Environmental and Conservation Sciences Program.

There are so many people to thank for their assistance along the way. They have poured over R-code, collaborated with me, taught me, and given me the best feedback. I owe you all so much: Bonne Clark, Alli Schumacher, Jessica Duttenhefner, Isaac Carbajal, Morgan Donaldson, Emily Kotten, Jess Lindstrom, Christine Cornish, The Bullpen, Emilee Briggs, Dr. Garrett See, Kurt Williams, Dr. Rebecca Young, Team Bird, Dr. Dane Mataic, Dr. Jay Boulanger, USDA-APHIS-Wildlife Services, and The National Sunflower Association and its Board of Directors. I am forever grateful to the farmers who took the time out of their busy schedules to share their experiences and knowledge with me, and for allowing UAS flights on their property.

A special thank you to all my supporters, for keeping me sane: Colin White, Jaryn Allen, Michael Arthur, Heather Griffin, Kweens of the North, Renegade, estate sales of Fargo, and many of my fellow graduate school comrades.

A final thank you goes to my loyal pups. Working from home during COVID-19 transformed them from faithful friends to classmates, coworkers, confidants, and constant shadows. Early mornings or late nights, they were always by my side.

I would like to acknowledge and express my gratitude toward my funding sources: the United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Wildlife Services (WS), National Wildlife Research Center (#7438-0020-CA; QA-3108) and the National Sunflower Association (#P20-03). I would also like to acknowledge funding and scholarships from both the Environmental and Conservation Sciences Program as well as the Biological Sciences Department at North Dakota State University.

The Institutional Review Board at North Dakota State University reviewed all documents prior to their release and indicated the survey protocol as exempt from formal review. Field data collection for this project was approved by the North Dakota State University Institutional Animal Care and Use Committee (Protocol #A20011), and North Dakota Game and Fish Department (Scientific Collection Licenses #GNF05044707, GNF05151858). Unmanned aircraft systems were registered as follows: DJI Agras MG-1P: FA3E9WHATX; DJI Phantom 4 Pro: FA37C3WEER; Mavic Pro: FA3X9FLXKL and flown under the United States Department of Transportation and Federal Aviation Administration Remote Pilot Certificate Part 107 (#4263743). North Dakota State University Research and Creative Activity approved all UAS flight plans.

DEDICATION

To the little girl who always dreamed so big, despite all of your fears.

I am here because of you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AGL ....Above Ground Level

AL ....Ambient Light

APHIS...Animal and Plant Health Inspection Service

CA ....Cattail Acreage

DTE ....Distance to Edge

DTL ....Distance to Launch

FID..Flight Initiation Distance

FP ....Flight Path

FS ....Flock Size

GLM ....Generalized Linear Model

H ....Habitat

JD ....Julian Day

LM ....Linear Model

ND ....North Dakota

NWRC...National Wildlife Research Center

OLR ....Ordinal Logistic Regression

SA ....Sunflower Acreage

SD ....South Dakota

TD ....Time of Day

TFD ....Total Flight Duration

T ....Temperature

UAS...Unmanned Aircraft System

USDA..United States Department of Agriculture

WS...Wildlife Services

W..Wind

CHAPTER 1: BACKGROUND LITERATURE REVIEW

Human-Wildlife Conflict in Agriculture

The conflict between humans and wildlife, especially in the context of agriculture, is interwoven throughout history. Conover (2002) estimated annual wildlife damage to agriculture in the United States at US$4.5 billion, with a variety of species responsible for the damages faced directly and indirectly by agriculture producers. Direct damages, identified by Conover (2002), are the quantifiable economic losses experienced by a producer (i.e., amount of crop eaten or destroyed, and amount of money spent to prevent damage), whereas indirect damages are the lost opportunities that are hard to quantify (i.e., producers who no longer plant a crop or plant less due to wildlife damage). Management tools used to mitigate human-wildlife conflicts in agriculture rely on using an integrative pest management approach and may include the following: lethal removal, fertility control, diversion or evading strategies, habitat modifications, exclusionary devices, chemical repellents, and frightening devices (Linz *et al.* 2017).

In the last 50 years, there have been efforts to evaluate and quantify avian damage to crops, which is a multi-million dollar loss that producers across the U.S. experience every year (Linz *et al.* 2017). The economic loss associated with bird damage to agriculture varies based on crop, region, and extent of damage. Aggregate bird damage to honeycrisp apple (*Malus domestica*), blueberry (*Vaccinium* spp.), cherry (*Prunus* spp.), and wine grape (*Vitis* spp.) crops, in five different states was estimated at US$189 million in 2011, with bird damage identified by a majority of the survey respondents as a significant factor that limits their profitability (Anderson *et al.* 2013). Evaluations of the average cost per acre of bird management in sweet cherries was estimated to be US$127.71, while producers still expected to lose around 13% of their crop to birds, showcasing a need for the continued development of effective management solutions (Elser *et al.* 2016). Quantifying bird damage to agricultural crops is important to effectively implement the appropriate damage management tools (Dolbeer 1981).

Avian-agriculture conflict is often complex, and each issue and its mitigation strategy differ based on the specific species, time period, landscape (Saunders *et al.* 2016). As mentioned, some avian species depredate fruit and grain crops causing substantial disservices, while other avian species offer ecosystem services (i.e., pest control, pollination, feeding on weed seeds) to agroecosystems (Pejchar *et al.* 2018). A study by Gonthier *et al.* (2019), found that avian damage to strawberries (3.2% crop loss) was balanced out by insect damage to strawberries (3.8% crop loss), when comparing a strawberry patch that was exposed to birds compared to a patch covered by exclusionary netting to keep birds out, resulting in a balance of avian services and disservices. However, the lopsided nature of avian disservices to agriculture crops, resulting in damage thresholds that exceed acceptable levels and substantial economic losses for agriculture producers, requires a multi-faceted approach to effectively manage the conflict.

Stakeholder Perceptions of Human-Wildlife Conflict

An important aspect of appropriately addressing human-wildlife conflict is understanding human dimensions: the perceptions, attitudes, and beliefs that humans have towards the conflict they are facing. A survey conducted to better understand apple growers' perceptions of pollinators identified that growers had low knowledge of native bee species, but they were receptive to using more bee-friendly practices (Park *et al.* 2018). Knowledge gaps, and the decisions producers make based on their own biases, are crucial to develop effective new methodologies or techniques meant to be implemented by producers (Kross *et al.* 2018).

Loss in yield due to wildlife is often not recorded but having access to such records could provide essential insight for management practices and agencies tasked with reducing wildlife damage. A study by Conover et al. (2018) surveyed wildlife agency personnel and agricultural personnel (Farm Bureau and Extension) and tracked perceptions of human-wildlife conflict in 1957, 1987, and 2017. Overall, the findings highlighted a perceived increase in human-wildlife conflict in agriculture, an expanding list of nuisance species, and a breakdown in communication between wildlife agencies and agriculture agencies regarding available services (Conover *et al.* 2018). A baseline evaluation of producer perceptions of wildlife damage is essential to fully understand the impact and scale of conflict over time.

Examining both producer and consumer perceptions of human-wildlife conflict in agriculture is also important, especially as consumers are increasingly invested in agricultural practices and environmental impacts. Consumers who were surveyed about a variety of techniques to reduce bird damage to fruit crops revealed a willingness to pay more for products that used nonlethal strategies to mitigate the conflict (Oh *et al.* 2015). Transparency of the financial burden that agriculture producers are subjected to, because of wildlife damage, could create an increase in consumer willingness-to-pay and thus act as a potential mitigation strategy for some specialty crops.

An integrative approach to addressing human-wildlife conflict, achieved by combining biological-based surveys and human-perception surveys, can address knowledge gaps to inform management agencies how to better assist producers (Park *et al.* 2018). Information gathered from surveys, especially those evaluating current practices and producer/stakeholder limitations, can be used to directly influence research objectives set by management agencies (Bruggers *et al.* 2002).

Sunflower Production in North Dakota

Sunflower (*Helianthus annuus* L.), including both confection and oilseed varieties is an economically important crop for the United States, especially in the northern Great Plains. A total of 1,350,600 acres of sunflowers were planted across the United States in 2019, with North Dakota responsible for 535,000 acres (USDA NASS 2020). North Dakota is consistently one of the leading states in sunflower production and has been for decades. The value of sunflower production for 2019 exceeded US$135,000,000 (USDA NASS 2020), despite a challenging growing and harvesting season due to weather. Sunflower producers face a variety of obstacles during a growing season, from insect pests to disease and weather, but a particularly frustrating hindrance to sunflower production in the Prairie Pothole Region of North Dakota are flocks of molting and migrating blackbirds (Icteridae; Linz and Hanzel 2015).

Conservation of a Nuisance Species: Blackbirds (Icteridae)

North America has experienced a net loss of 2.9 billion birds over the last 50 years, according to breeding bird surveys, with blackbirds experiencing an ~44% population decline (Rosenberg *et al.* 2019). While blackbird populations have been decreasing across the eastern and southeastern portions of the United States, an increasing or stable population trend has been observed through the northern Great Plains (Sauer et al. 2017). Keeping in mind the protected status of blackbirds (US Migratory Bird Treaty Act of 1918), alongside the population dynamics within North Dakota and across North America, the sunflower industry faces a particularly complex problem with limited effective management tools capable of reducing damage while simultaneously protecting a native bird species.

Large mixed flocks of migrating blackbirds, mainly composed of red-winged blackbirds (*Agelaius phoeniceus*), but also yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), common grackles (*Quiscalus quiscula*), Brewer's blackbirds (*Euphagus cyanocephalus*), brown-headed cowbirds (*Molothrus ater*), and European starlings (*Sturnus vulgaris*) descend upon the Prairie Pothole Region of North Dakota every year. Fall molt and migration for these blackbird flocks coincides with the ripening of sunflower fields in North Dakota, up until harvest occurs in October and November. The bird damage period to sunflowers begins after ray flower petals have dropped and continues until achenes are fully mature, with the specific timing dependent on planting dates (Cummings *et al.* 1989). The high-fat content of sunflower seeds makes a particularly desirable food source for those migrating blackbird flocks (Linz *et al.* 2017).

Avian-Agriculture Conflict in North Dakota

The conflict between blackbirds and sunflower producers has been a persistent issue in the United States for the past 50 years (Linz *et al.* 2017). Although damage across the sunflower industry is <5%, localized damage sustained by individual producers, especially in the Prairie Pothole Region of North Dakota, can greatly exceed 20% or reach complete loss (Klosterman *et al.* 2013). Although the average percent damage is low, the localized damage produces staggering direct and indirect economic losses for producers. A study by Ernst *et al.* (2019) calculated the average amount of oilseed and confection crop lost in North Dakota from 2009-2013 was 74.36 kg/ha (resulting in an economic loss of $36.43 per hectare) and 81.23 kg/ha (resulting in an economic loss of $53.61 per hectare), respectively. Those direct losses combined by indirect losses, including jobs and opportunities lost, reaches a staggering average of $18.7 million USD per year (Ernst *et al.* 2019).

Since the 1970s, sunflower growers have been using a variety of methods to reduce blackbird damage. Those efforts have included shotguns, pyrotechnics, avian repellents and toxicants, not planting sunflower near roost sites, managing cattail-dominated wetlands, advancing harvest dates, and even planting wildlife conservation food plots (Linz *et al.* 2017). These damage management methods and tools, as well as agriculture techniques, have been tested for their ability to reduce damage with varying efficacy (Linz *et al.* 2011). Using integrated pest management strategies (i.e., using multiple tools and methods simultaneously) has proven beneficial, but there is still a need for innovative tools with increased effectiveness, especially those capable of being effective at broad scales seen in modern-day agriculture (Linz *et al.* 2002). Thus, the search continues for an integrated, adaptive, and dynamic approach to protect crops from avian damage, while considering the protected status of blackbirds.

Novel Tool Development: Unmanned Aircraft Systems

Unmanned aircraft systems (UAS; commonly called drones) have erupted into the scene of wildlife research over the past decade, due to the relatively low cost, easy-to-learn mechanics, and time efficiency compared to traditional monitoring practices (Weissensteiner *et al.* 2015). Most research using UAS in conservation biology is focused on minimizing disturbance while monitoring species, with aspects like UAS approach angle, speed, and platform evaluated to determine which method should be used to reduce impact on wildlife (McEvoy *et al.* 2016; Mulero-Pázmány *et al.* 2017; Vas *et al.* 2015). Some examples of how UAS devices have been used in wildlife research include: locating and photographing whales (Koski *et al.* 2015), distinguishing between sexes of sea turtles (Schofield *et al.* 2017), and conducting rapid population estimates of seabirds (McClelland *et al.* 2016). While monitoring studies are focused on reducing the antipredator behavior of target animals to the approaching drone, the use of drones in wildlife damage management capitalizes on enhancing those responses to disperse target nuisance animals.

Only a few studies on select bird species and in select crops have been conducted using UAS to exploit the antipredator behavior of birds in efforts to reduce human-wildlife conflicts. Two studies have evaluated blackbird behavior in response to drones and have indicated an antipredator reaction in both captive (Egan *et al.* 2020) and free-ranging birds (Egan 2018b; Wandrie *et al.* 2019). Wandrie et al. (2019) found drones flown 50 m above ground level (AGL) did not elicit a behavioral response from blackbird flocks, whereas lower flight altitudes did, providing a standard for aerial observations and diving into the realm of drone hazing research. Egan (2018b) found the probability of a blackbird flock abandoning a sunflower field due to UAS hazing was higher with smaller flocks (<200 birds), where larger flocks potentially took advantage of dilution effects or "safety in numbers". Thus, larger groups may tolerate the presence of a single UAS, requiring novel methods that result in a negative stimulus on a larger proportion of the flock. Another study found that bird presence in vineyards was reduced by deploying a UAS to "chase" flocks, but they recommended increasing the negative stimulus associated with the UAS to improve continuous crop protection (Wang *et al.* 2019). Suggestions for increasing the negative stimulus associated with UAS platforms have included acoustics emitted from the UAS (Wang *et al.* 2019), a fleet of coordinated UAS (Paranjape *et al.* 2018), UAS designs that resembles an avian predator (Egan *et al.* 2020), and precision technology to target nuisance birds in real-time with an avian repellent (Ampatzidis *et al.* 2015).

Research Objectives

The objectives for my research were to evaluate the social perceptions and biological capabilities of UAS for mitigating blackbird-sunflower conflicts. This approach gives us an understanding of the current impact of blackbird damage and the tool use of farmers and explores the acceptability of a novel tool. The field study provides a foundational understanding of large blackbird flock behavior in broad-scale agricultural environments and provides a baseline to evaluate UAS efficacy and direct future research. The results from this study are applicable to other avian-agriculture conflicts that occur on such a broad scale.

In Chapter 2, I evaluate the social perceptions farmers have towards current damage management tools, their willingness-to-pay to mitigate damage, and their willingness to accept novel UAS operations. The most recent survey to address blackbird damage to sunflower farmers occurred in 1997 and did not examine tools or methods used by farmers. The goal of my study is to address that gap by evaluating how farmers, who planted sunflower in 2020, manage blackbird damage, and explore their openness to allow UAS operations on their property.

In Chapter 3, I evaluated the behavioral response of free-ranging blackbird flocks to a UAS approach and extended hazing (10 min) in North Dakota during the bird damage window to sunflower (September to October). The field study is an important complement to the human-dimensions evaluation, given it is necessary to understand if this methodology is effective when applied at broad scales. Many factors could influence flock behavioral responses at this scale, and previous UAS hazing research has focused on much smaller agriculture settings. Thus, we approached the field evaluation in an exploratory manner when relating environmental variables to antipredator responses in large blackbird flocks.

This research approach addresses both sides of the human-wildlife conflict: perceptions of those impacted (humans) and efficacy of a novel mitigation tool (vertebrate pest). It is crucial to combine social and biological studies for human-wildlife conflict management because the complexities of the conflict may need to be addressed in a different manner (Madden and McQuinn 2014). We address knowledge gaps by highlighting those nuances and complexities, while also providing a foundational understanding to the current state of blackbird-sunflower conflict in the Dakotas. In Chapter 4, I suggest future research directions for addressing this conflict and the development of UAS as a mitigation tool.

References

Ampatzidis Y, Ward J, and Samara O (2015) Autonomous system for pest bird control in specialty crops using unmanned aerial vehicles. 2015 ASABE Annual International Meeting, New Orleans, LA, USA.

Anderson A, Lindell C, Moxcey KM, Siemer W, Linz GM, Curtis P, Carroll J, Burrows C, Boulanger J, and Steensma K (2013) Bird damage to select fruit crops: The cost of damage and the benefits of control in five states. *Crop Protection* **52**, 103-109.

Bruggers RL, Owens R, and Hoffman T (2002) Wildlife damage management research needs: perceptions of scientists, wildlife managers, and stakeholders of the USDA/wildlife services program. *International Biodeterioration & Biodegradation* **49**(2), 213-223. doi: https://doi.org/https://doi.org/10.1016/S0964-8305(02)00042-2.

Conover MR (2002) *Resolving human-wildlife conflicts: The science of wildlife damage management*. CRC Press, Boca Raton, FL, USA.

Conover MR, Butikofer E, and Decker DJ (2018) Wildlife damage to crops: Perceptions of agricultural and wildlife leaders in 1957, 1987, and 2017. *Wildlife Society Bulletin* **42**(4), 551-558. doi: https://doi.org/10.1002/wsb.930.

Cummings JL, Guarino JL, and Knittle CE (1989) Chronology of blackbird damage to sunflowers. *Wildlife Society Bulletin* **17**, 50-52.

Dolbeer RA (1981) Cost-benefit determination of blackbird damage control for cornfields. *Wildlife Society Bulletin* **9**, 44-51.

Egan CC (2018) *Evaluating the potential utility of drones to deter birds from areas of human-wildlife conflict*. Environmental and Conservation Sciences (Biological Sciences). North Dakota State University. Fargo, ND USA, p. 93.

Egan CC, Blackwell BF, Fernández-Juricic E, and Klug PE (2020) Testing a key assumption of using drones as frightening devices: Do birds perceive wildlife-monitoring drones as risky? *Condor* **122**, 1-15.

Elser J, Anderson A, Lindell C, Dalsted N, Bernasek A, and Shwiff S (2016) Economic impacts of bird damage and management in us sweet cherry production. *Crop Protection* **83**, 9-14.

Ernst K, Elser J, Linz G, Kandel H, Holderieath J, DeGroot S, and Shwiff S (2019) The economic impacts of blackbird (icteridae) damage to sunflower in the usa. *Pest Management Science* **75**(11), 2910-2915. doi: https://doi.org/10.1002/ps.5486.

Gonthier DJ, Sciligo AR, Karp DS, Lu A, Garcia K, Juarez G, Chiba T, Gennet S, and Kremen C (2019) Bird services and disservices to strawberry farming in californian agricultural landscapes. *Journal of Applied Ecology* **56**(8), 1948-1959. doi: https://doi.org/10.1111/1365-2664.13422.

Klosterman ME, Linz GM, Slowik AA, and Homan HJ (2013) Comparisons between blackbird damage to corn and sunflower in north dakota. *Crop Protection* **53**, 1-5.

Koski WR, Gamage G, Davis AR, Mathews T, LeBlanc B, and Ferguson SH (2015) Evaluation of uas for photographic re-identification of bowhead whales, balaena mysticetus. *Journal of Unmanned Vehicle Systems* **3**(1), 22-29.

Kross SM, Ingram KP, Long RF, and Niles MT (2018) Farmer perceptions and behaviors related to wildlife and on-farm conservation actions. *Conservation Letters* **11**(1), e12364.

Linz GM, Avery ML, and Dolbeer RA (2017) *Ecology and management of blackbirds (icteridae) in north america* (Eds. GM Linz, ML Avery, and RA Dolbeer). CRC Press/Taylor & Francis, Boca Raton, FL, USA.

Linz GM, and Hanzel JJ (2015) Sunflower bird pests. In *Sunflower: Chemistry, Production, Processing, and Utilization*. AOCS Press in association with USDA APHIS Wildlife Services NWRC, Urbana, IL, USA, pp. 175-186.

Linz GM, Homan HJ, Werner SJ, Hagy HM, and Bleier WJ (2011) Assessment of bird-management strategies to protect sunflowers. *Bioscience* **61**(12), 960-970.

Linz GM, Peer BD, Homan HJ, Wimberly RL, Bergman DL, and Bleier WJ. Has an integrated pest managment approach reduced blackbird damage to sunflower? (Eds. Clark L, Hone J, Shivik JS, Watkins RW, VerCauteren KC, Yoder JK) Human Conflicts With Wildlife: Economic Considerations. Proceedings of the 3rd NWRC Special Symposium of the National Wildlife Research Center, Fort Collins, Colorado, USA, pp. 132–137.

McClelland GT, Bond AL, Sardana A, and Glass T (2016) Rapid population estimate of a surface-nesting seabird on a remote island using a low-cost unmanned aerial vehicle. *Marine Ornithology* **44**, 215-220.

McEvoy JF, Hall GP, and McDonald PG (2016) Evaluation of unmanned aerial vehicle shape, flight path and camera type for waterfowl surveys: disturbance effects and species recognition. *PeerJ* **4**, e1831.

Mulero-Pázmány M, Jenni-Eiermann S, Strebel N, Sattler T, Negro JJ, and Tablado Z (2017) Unmanned aircraft systems as a new source of disturbance for wildlife: a systematic review. *PloS One* **12**(6), e0178448.

Oh C-O, Herrnstadt Z, and Howard PH (2015) Consumer willingness to pay for bird management practices in fruit crops. *Agroecology and Sustainable Food Systems* **39**, 782-797.

Paranjape AA, Chung SJ, Kim K, and Shim DH (2018) Robotic herding of a flock of birds using an unmanned aerial vehicle. *IEEE Transactions on Robotics* **34**, 901-915.

Park MG, Joshi NK, Rajotte EG, Biddinger DJ, Losey JE, and Danforth BN (2018) Apple grower pollination practices and perceptions of alternative pollinators in new york and pennsylvania. *Renewable Agriculture and Food Systems* **35**, 1-14. doi: https://doi.org/10.1017/S1742170518000145.

Pejchar L, Clough Y, Ekroos J, Nicholas KA, Olsson O, Ram D, Tschumi M, and Smith HG (2018) Net effects of birds in agroecosystems. *Bioscience* **68**(11), 896-904.

Rosenberg KV, Dokter AM, Blancher PJ, Sauer JR, Smith AC, Smith PA, Stanton JC, Panjabi A, Helft L, Parr M, and Marra PP (2019) Decline of the north american avifauna. *Science* **366**(6461), 120-124. doi:https://doi.org/10.1126/science.aaw1313.

Saunders ME, Peisley RK, Rader R, and Luck GW (2016) Pollinators, pests, and predators: Recognizing ecological trade-offs in agroecosystems. *Ambio* **45**(1), 4-14. doi:https://doi.org/10.1007/s13280-015-0696-y.

Schofield G, Katselidis KA, Lilley MKS, Reina RD, and Hays GC (2017) Detecting elusive aspects of wildlife ecology using drones: New insights on the mating dynamics and operational sex ratios of sea turtles. *Functional Ecology* **31**(12), 2310-2319. doi:https://doi.org/10.1111/1365-2435.12930.

Vas E, Lescroël A, Duriez O, Boguszewski G, and Grémillet D (2015) Approaching birds with drones: first experiments and ethical guidelines. *Biology Letters* **11**(2), 20140754.

Wandrie LJ, Klug PE, and Clark ME (2019) Evaluation of two unmanned aircraft systems as tools for protecting crops from blackbird damage. *Crop Protection* **117**, 15-19.

Wang Z, Griffin AS, Lucas A, and Wong K (2019) Psychological warfare in vineyard: Using drones and bird psychology to control bird damage to wine grapes. *Crop Protection* **120**, 163-170.

Weissensteiner MH, Poelstra JW, and Wolf JB (2015) Low-budget ready-to-fly unmanned aerial vehicles: An effective tool for evaluating the nesting status of canopy-breeding bird species. *Journal of Avian Biology* **46**(4), 425-430.

CHAPTER 2: FARMER PERCEPTIONS OF CURRENT AND NOVEL MITIGATION TOOLS USED FOR BLACKBIRD-AGRICULTURE CONFLICT IN THE DAKOTAS

Abstract

Human-wildlife conflict in agricultural systems involves multiple stakeholders, occurs on multiple scales, and requires an array of damage management techniques. Blackbird (Icteridae) damage to sunflower (*Helianthus annuus L.*) crops in the northern Great Plains has elicited the development of new tools, methods, and technology over the last 50 years, but the farmers impacted have not been fully integrated into that development process. We conducted the first comprehensive evaluation of farmer perceptions to novel and current damage management methods and tools via mail and online surveys sent to farmers in North and South Dakota, USA in 2021. Farmers reported that few currently available methods were effective. The tool reported as the most effective (i.e., cattail management) was used less frequently than those perceived as relatively ineffective (e.g., propane cannons), largely due to scale of application or the ability for on farm application. A majority of respondents were willing to allow a novel tool, unmanned aircraft systems (UAS), on their property to conduct a variety of operations to mitigate blackbird damage, but willingness was dependent on sociodemographic factors, level of profit impacted, and farm characteristics. Farmers overall willingness to pay for bird damage management relied on previous tool use and the impact bird damage has to their profit. Identifying the factors that influence a farmer's decision-making process towards current and novel bird damage management revealed characteristics of early-adopters, and could be crucial for researchers or agencies when disseminating bird damage information.

Keywords: crop damage; deterrent tools; farmer attitudes; human-wildlife conflict; perception; sunflower; survey; technology adoption; UAV; unmanned aircraft system; vertebrate pests

Introduction

Mitigating conflicts between wildlife and agriculture is complex and multi-faceted, requiring a transdisciplinary approach that includes both wildlife ecology and the perceptions and actions of crucial stakeholders (König *et al.* 2020). A diversity of wildlife damage scenarios exists, across a variety of agriculture sectors, which range from nuisance disturbances to the total loss of economic livelihood (Conover 2002). The presence and severity of the conflict is influenced by ecological factors operating at multiple spatial and temporal scales, including the regional (e.g., population trends), landscape (e.g., habitat selection), and field scales (e.g., food sources; Sausse and Lévy 2021). In agriculture settings, it is important to extend research beyond reports of economic loss to understand the perceptions of the farmers who will be implementing damage management strategies (Kross *et al.* 2018). By doing this we can see how sociodemographic factors, like age and education, may play an important role in perceptions of damage and management methods used on a variety of scales (Tomass *et al.* 2020). Factors such as extent of prior damage or frequency of damage when combined with prior prevention efforts reveal a farmer's level of tolerance and views of the conflict; understanding this could provide insight towards potential solutions for conflict alleviation (Rollins *et al.* 2004). By engaging with relevant stakeholders (e.g., farmers), and including their perspectives in the development of mitigation tools, we can increase the likelihood of continued tool use and provide opportunities for success in the long term (Hill 2015). Thus, the tools to address human-wildlife conflict need to incorporate both animal and human behaviors at multiple scales unique to each damage scenario.

Tool options vary from lethal to nonlethal, high to low tech, and widely accepted to controversial; with most tools suffering from limited efficacy at a scale that matches modern, broad scale agriculture (Fall and Jackson 2002; Linz *et al.* 2017). The effective use of a tool depends not only on biological efficacy at the appropriate scale, but also requires acceptance and adoption by those implementing them. Along with the behavioral ecology of the pest (e.g., antipredator responses and foraging requirements), human perceptions and behaviors must be incorporated to consider aspects like the ease-of-use, cost-effectiveness, and labor-intensity of the tools (Conover 2002). In cases of human-wildlife conflict, a suite of integrated tools is often necessary for continued protection of resources threatened by vertebrate species capable of learning. Biological research must be combined with social research in an adaptive way, allowing for changes to be made dependent on prior outcomes, and to develop effective management solutions and increase the adoption of tools and methods (Madden 2004).

Unmanned aircraft systems (also known as unmanned aircraft vehicles [UAV]; remotely piloted aircraft systems [RPAS] or drones; hereafter, "UAS") have recently proven to be a useful tool for biological research. Most UAS platforms are relatively cheap, can be bought off-the-shelf, can cover a large areas, and are user friendly (Ivošević *et al.* 2015). There is an emerging use for UAS as a nonlethal deterrent tool in human-wildlife conflict, which focuses on exploiting the antipredator responses of target animals (Klug 2017). Studies on crop protection show UAS as promising tools against birds due to the UAS's mobility, range of use, and negative response elicited from flocks (Egan *et al.* 2020; Wandrie *et al.* 2019; Wang *et al.* 2019). Theoretical research has explored the integration of other tools with UAS platforms (e.g., spraying mechanisms to deploy a registered avian repellent) to potentially amplify the negative response and subsequent negative association for the flock (Ampatzidis *et al.* 2015). As research continues to refine the methods used to effectively deploy UAS for damage mitigation, particularly in avian-agriculture conflict, there is a distinct communication gap between the biological research and tool acceptance or implementation by farmers (Klug 2017). A vital component to evaluating the probability of UAS being incorporated into the suite of mitigation tools includes examining the social evaluations of those directly impacted by the conflict, especially since it is a potentially controversial tool (Sandbrook 2015).

The development of tools and methods to reduce wildlife conflict with agriculture is a worldwide economic issue (Linz and Hanzel 1997). Despite every damage scenario being unique, techniques developed and tested in a particular region can still have broad applicability and inform solutions for other scenarios involving other pests and crops. Extensive research has been conducted in the Prairie Pothole Region of the United States evaluating tools and methods for reducing blackbird damage to sunflower production (Linz *et al.* 2011). Currently, there has been no evaluation of farmers' perceptions towards blackbird damage and the factors influencing their tool selection. In 1997, a general survey revealed bird damage as the biggest problem for North Dakota sunflower farmers, but the questionnaire did not cover uses or perceptions of damage mitigation tools. To address farmers' needs and develop effective damage management tools, a comprehensive evaluation of farmer perceptions is necessary.

Study Location & Damage Scenario

Sunflower (*Helianthus annuus* L.) is an economically important crop in the United States, especially in the Northern Great Plains, where North Dakota and South Dakota routinely contribute over 75% of the crop acres planted in the United States (U.S. Department of Agriculture). When sunflower is nearing maturity and ready for harvest, blackbirds (Icteridae) are undergoing fall molt and preparing for migration by consuming the high-fat seeds and gathering in large roosts, sometimes exceeding one million birds (Clark *et al.* 2021; Linz and Hanzel 2015). Although damage across the sunflower industry is <5%, repeated and severe damage sustained by individual farmers can greatly exceed that threshold or reach complete economic losses (Klosterman *et al.* 2013) causing farmers to remove sunflower from their rotation (Hulke and Kleingartner 2014).

Adding increased complexity to this conflict is that the nuisance species are native birds of conservation concern that have faced a 44% reduction in continental populations since the 1970's (Rosenberg *et al.* 2019) and are federally protected under the Migratory Bird Treaty Act of 1918. Population trends across the United States have revealed decreased breeding populations in the eastern U.S., while the northern Great Plains are seeing stable or increasing populations (Sauer et al., 2017). Thus, finding nonlethal management tools that support the conservation of native species while minimizing their negative impact to food production is vital.

Current tools and methods to reduce bird damage to agriculture include habitat management, altered agricultural practices, chemical avian repellents, and frightening devices. Habitat management methods include the manual or chemical treatment of cattail (*Typha* spp.) to disperse birds across the landscape, or the planting of decoy crops as alternative food resources (Hagy *et al.* 2008; Linz and Homan 2011). Altered agriculture practices include shifting the seeding or harvest dates, using early-maturing crop varieties, and desiccating the crop to avoid peak timing for flock migrations (Clark *et al.* 2021; Wilson *et al.* 1989). Chemical avian repellents are applied to the crop to prevent seed consumption but have limited efficacy at the commercial field scale and are often too costly to cover large areas (Kaiser *et al.* 2021). Frightening devices are used to disperse flocks by capitalizing on their antipredator behavior and include auditory tools such as lethal shooting via a shotgun, non-lethal shooting via a pistol or rifle, propane cannons, pyrotechnics, bioacoustics (predator and species distress calls), and most recently UAS (Klug 2017). Lethal shooting is permitted under the depredation order for blackbirds (50 CFR § 21.43) when causing crop damage.

UAS have been evaluated for individual bird responses and flock responses (Egan *et al.* 2020) and has been suggested as a vehicle for deploying an avian repellent (Ampatzidis *et al.* 2015). With the development of precision agriculture and UAS integration, spot treatments of avian repellents could reduce costs by targeting problem areas, effectively treating the damaged portion of a field in real time. Albeit the process to apply a registered pesticide via a UAS is somewhat complex at this time. First, the applicator must hold the proper state pesticide applicator's license and the chemical avian repellent product label would need to have UAS allowances. The applicator is also required to be certificated as a Federal Aviation Administration (FAA) Commercial Agricultural Aircraft Operator under Title 14 of the Code of Federal Regulations (14 CFR) part 137, with Special Authority for Certain Unmanned Aircraft Systems (49 U.S.C. §44807) (Exemption No. 18690), which must include necessary exemptions for the specific UAS model used.

The purpose of our study is to evaluate the perceptions of sunflower farmers in the Dakotas towards bird damage management tools, with a special emphasis on UAS as a novel tool. This elicited three distinct objectives: 1) evaluation of perceived effectiveness of currently available damage management tools; 2) evaluation of a farmer's willingness to allow UAS operations for damage management purposes on their property and identify the factors that influence their opinions; and 3) identify the factors that influence the maximum cost a farmer is willing to spend on bird damage management.

Methods

Study Design and Implementation

We sent paper surveys with questions concerning farming experience and opinions on blackbird control techniques to recipients of the National Sunflower Association's mailing list in North Dakota (n = 7,350) and South Dakota (n = 2,568). A third party (Forum Publications, Fargo, ND USA) distributed the surveys to the mailing list, thus all recipients remained anonymous. The mailed envelopes contained a cover letter, 4-page booklet survey, and return envelope with business reply pre-paid postage (Supplementary Material). An identical online survey provided an opportunity for respondents to use an anonymous URL link or QR code (Qualtrics, Provo, UT). To encourage the highest level of participation, we provided five reminders to submit the mail survey, along with the URL link to the online survey, in the monthly e-newsletter and the National Sunflower Association magazine (The Sunflower) from January to March 2021. We sent additional press releases to a variety of agricultural information resources including local online magazines, county extension agents, and agriculture related email listservs. We mailed the paper survey to North Dakota recipients in January 2021 and South Dakota recipients in April 2021. We mailed the South Dakota survey after knowledge of the return rate from North Dakota respondents, due to limited funding.

Perceptions of Tools and Methods for Bird Damage Management

We listed ten damage management tools and methods available to farmers in the northern Great Plains capable of addressing blackbird damage at a variety of scales, including within the field and across the landscape (Figure 2.1; Linz *et al.* 2011). To evaluate farmers' perceptions of these damage management tools, we asked respondents to rank their effectiveness using a Likert-type scale of 1-5 (1 = Not Willing, 2 = Less Willing, 3 = Neutral, 4 = More Willing, 5 = Very

Willing; Supplementary Material). We requested respondents select whether they had ever used a tool or method to gauge their history of tool use and their opinions on tool efficacy (Figure 2.2). We used descriptive statistics to illustrate frequency of tool use and corresponding efficacy.

We evaluated farmers' willingness to allow UAS operations on their property through a series of questions with responses ranked 1-5 (1 = Not Willing, 2 = Less Willing, 3 = Neutral, 4 = More Willing, 5 = Very Willing; Supplementary Material). Due to the low number of responses between 'Not Willing' and 'Less Willing', we collapsed responses to three levels reflecting a combined negative willingness, a neutral, and a combined positive willingness. We used the Likert-scale responses as dependent variables for the following questions: (1) How willing would you be to allow UAS on your property to haze blackbirds? (2) How willing would you be to allow a UAS that applies a registered pesticide? (3) How willing would you be to operate a UAS that applies a registered pesticide (requires acquiring proper licensure)? (4) How willing would you be to hire a licensed aerial applicator to apply a registered pesticide via UAS? We used ordinal logistic regression (OLR) models to evaluate the factors influencing farmers' willingness-to-use UAS as a management tool for bird damage. The explanatory variables covered past bird damage, farming practices, previous UAS experience, and demographic information (Table 2.1). The four OLR models identified an increased intensity of use for UAS operations as a damage management tool, by starting at farmer willingness to allow a UAS to haze flocks and ending with farmer willingness to hire a pilot to operate and spray pesticide via UAS. All statistical analyses were conducted using RStudio software version 4.1.0 (R Studio Team 2020). We used the package MASS to run the OLR models, using the function *polr*.

We used a hurdle model to identify the factors that influenced a farmer's willingness to spend any money to combat bird damage and the maximum amount a farmer was willing to spend annually to control bird damage in sunflower. The responses to this fill-in-the-blank question resulted in many true zeros (Martin *et al.* 2005), because some farmers were not willing to pay anything, along with other farmers who were willing to pay and reported an actual ($) dollar amount. In the first part of the model, we evaluated the factors influencing a farmer's participation in bird damage management using a binomial distribution (a binary yes/no; logit model). In the second part of the model, a negative-binomial distribution (truncated count regression model), we examined the relationship between how much participants are willing to spend with selected covariates. This approach allows us to identify participants and their willingness-to-pay from the same set of covariates, which included bird damage, farming practices, and demographic information (Table 2.1). We used the package "pscl", using the function *hurdle*, with RStudio software version 4.1.0 to run the hurdle model and determined best fit when compared to zero-inflated models (Zeileis *et al.* 2008).

Table 2.1. Explanatory variables used in ordinal logistic regressions to explain willingness-to-adopt a novel damage management tool (i.e., unmanned aircraft systems; UAS) and in a hurdle model to explain participation in bird damage management and the maximum amount a farmer was willing to spend to mitigate crop damage in sunflower caused by mixed flocks of blackbirds (Icteridae). We used survey responses from North Dakota and South Dakota farmers who planted sunflower in 2020.

Explanatory Variable	**Definition**
Demographics	
Age [a,b]	Age of respondent (years)
Education [a,b]	Highest level of education completed (≤ High School, College, Graduate School)
Sunflower growing experience [a,b]	Number of years growing a sunflower crop
Generation [a,b]	Number of previous generations employed by farming in the Dakotas (1st, 2nd, 3rd, ≥4th)
Farming Practices	
Sunflower acreage [a,b]	Total sunflower acres planted in 2020
Bird Damage	
Yield lost to birds [a,b]	Average yield (%) lost to bird damage over the last 5 years (2016-2020)
Maximum cost [a]	Maximum cost ($) willing to spend to control bird damage to sunflower
Impact on profit [a,b]	Current impact of bird damage to sunflower production profit (Low, Medium, High)
Management action [a,b]	Action taken to prevent or reduce bird damage to crops (Yes/No)
Prior UAS [a]	Previous UAS flights on property (Yes/No)

[a] Variable used in all ordinal logistic regressions; [b] Variable used in the hurdle model.

Results

We received 1,065 surveys by July 2021, combining both the mail (n = 913) and online (n = 152) responses. There were four undeliverable surveys due to deceased recipients from the North Dakota mailing listserv, which reduced the effective sample size to 7,346. There were no undeliverable surveys from the South Dakota mailing listserv, keeping the sample size at 2,568. The combined response rate for the entire group of mailed surveys was 9.2% (ND = 10.5% and SD = 5.5%). However, a total of 3,125 farmers grew sunflower in the Dakotas in 2020 (United States Department of Agriculture, Farm Service Agency, North Dakota State Office, unpublished data), and we received 343 responses to give a 2020 farmer response rate of 11.0%. We could not calculate a non-response bias because we used a third-party listserv from the National Sunflower Association. We focused our results on farmers in North Dakota (n = 291) and South Dakota (n = 52) who planted a sunflower crop in 2020, allowing us to include acreage of sunflower planted (a question only asked of respondents who planted in 2020) and ensured that responses reflected farmers currently experiencing bird damage to sunflowers.

Overall demographic characteristics of respondents who planted sunflower in 2020 in the Dakotas revealed the respondent to be overwhelmingly male (99.7%), ≥3rd generation farmer (83.5%), college educated (68.7%), and middle-aged (mean = 55.4 years old) (Table 2.2). There was a wide range in farming experience (4-70 years), sunflower growing experience (1-48 years), sunflower acreage (10-6,000 acres), average yield lost to blackbirds over the last five years (0-99%), and the maximum annual cost a farmer was willing to spend to control bird damage (US $0-20,000) (Table 2.2).

Table 2.2. Farming practices and characteristics of survey respondents from the Dakotas who planted sunflower in 2020 (n = 343).

Categorical variables	***n***	**Percent in each category (%)**
Gender	328	Male = 99.7; Female = 0.30
Generation	322	1^{st} = 1.55; 2^{nd} = 14.91; 3^{rd} = 50.0; 4^{th} = 33.54
Education	326	≤High school = 24.85; College = 68.71; Graduate school = 6.44
Impact on profit	328	Low = 22.26, Medium = 51.22, High = 26.52

Continuous variables	***n***	**Range**	**Mean ± SD**
Age (yrs)	327	24-86	55.4 ± 10.7
Farming experience (yrs)	321	4-70	32.8 ± 12.8
Sunflower growing experience (yrs)	316	1-48	19 ± 10.7
Estimated annual cost to control bird damage ($)	300	0-30,000	1093 ± 3125
Maximum annual cost to control bird damage ($)	248	0-20,000	1628 ± 2789
Yield lost to birds over past 5 yrs (%) [a]	309	0-99	13.2 ± 14.3
Sunflower acreage in 2020 (ac) [b]	317	10-6,000	652 ± 690

[a] 2016-2020; [b] total acreage combines confection, oilseed, and conoil varieties of sunflower

For current damage management tools only two methods (i.e., cattail management and crop desiccation) had higher percentages of positive than negative perceptions of effectiveness. The percentage of respondents reporting “No Opinion” was over 50% for tools that had low frequency of reported use by sunflower producers in the northern Great Plains, including decoy crops, chemical repellents, acoustics, and UAS (Figures 2.1, 2.2). Lethal and non-lethal shooting, propane cannons, and pyrotechnics were among the most frequently used tools despite a higher percentage of respondents viewing these tools as ineffective (Figure 2.1, 2.2). In considering the efficacy of UAS to reduce bird damage, 58% had no opinion while 13% felt the tool was effective and 29% felt it was ineffective. The frequency of bird damage management method used by 2020 sunflower farmers in the Dakotas revealed lethal shooting as the most used method (36%) and decoy crops as the least used method (3%; Figure 2.2).

Survey questions about a farmer’s willingness to allow UAS operations on their property revealed 83% were willing to allow UAS on their property to haze blackbirds, 12% were neutral, and only 5% were unwilling (Figure 2.3). When asked about their willingness to allow UAS that sprayed a registered pesticide on their property, 71% were willing, 21% were neutral, and 8% were unwilling. The lowest percentage of willing responses was in response to acquiring proper licensure to operate an UAS that applied a registered pesticide, 48% were willing, 30% were neutral, and 22% were unwilling. Although 50% of respondents were willing to hire a licensed aerial applicator to operate a drone that applies a registered pesticide, 34% were neutral, and 16% were unwilling.

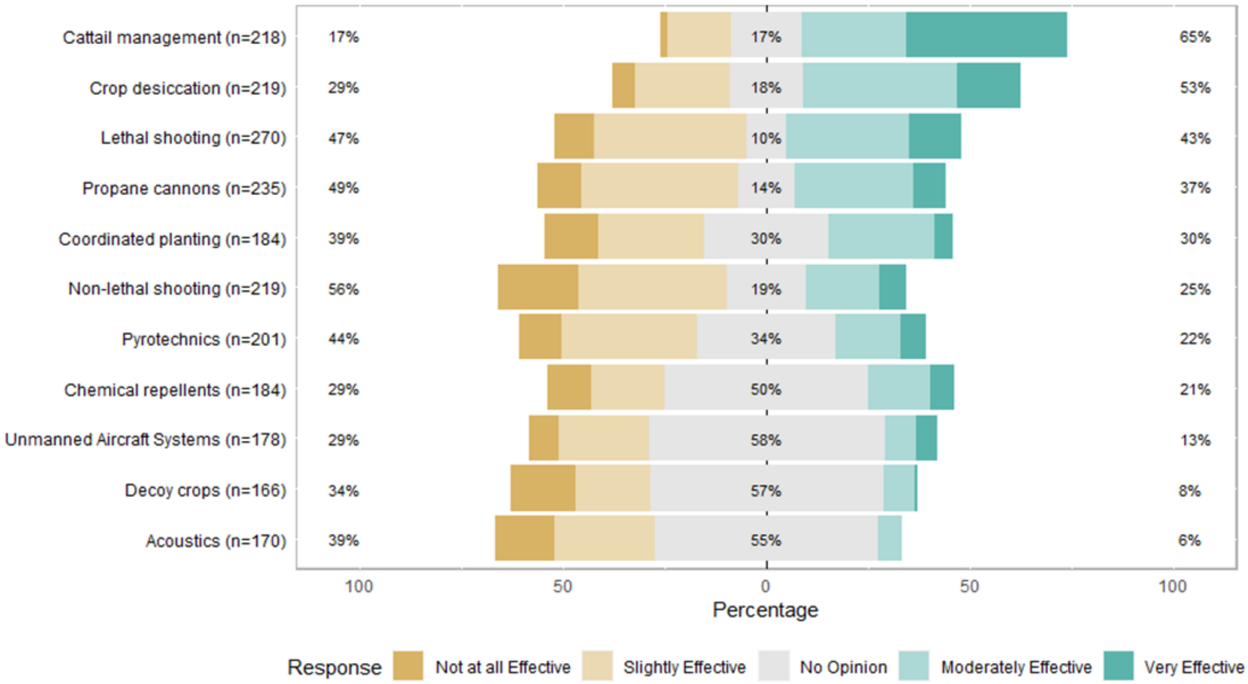


Figure 2.1. Sunflower farmers' perception of bird damage management methods and tools in North and South Dakota, USA. Responses range from very effective to not at all effective, with an option for neutral, and are displayed as percentages of total question responses (n = total responses for each tool). Percentages on the left are the combined negative responses, on the right are combined positive responses, and in the middle the neutral responses.

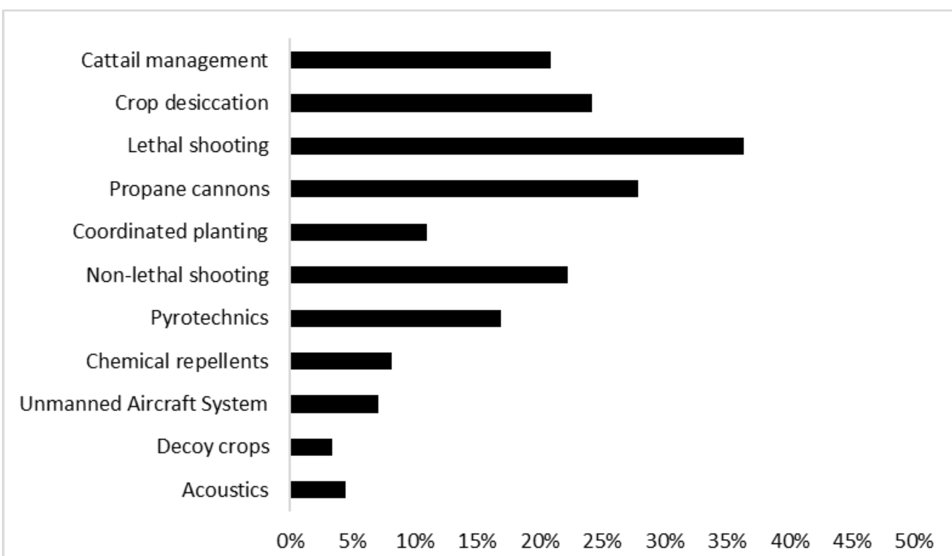


Figure 2.2. Frequency of use for bird damage management methods and tools by farmers growing sunflower in 2020 in North and South Dakota, USA. Unmanned aircraft systems are a novel tool for use in blackbird-sunflower conflicts. Responses are displayed as percentages, indicating use by total responses for each question (n = 343).

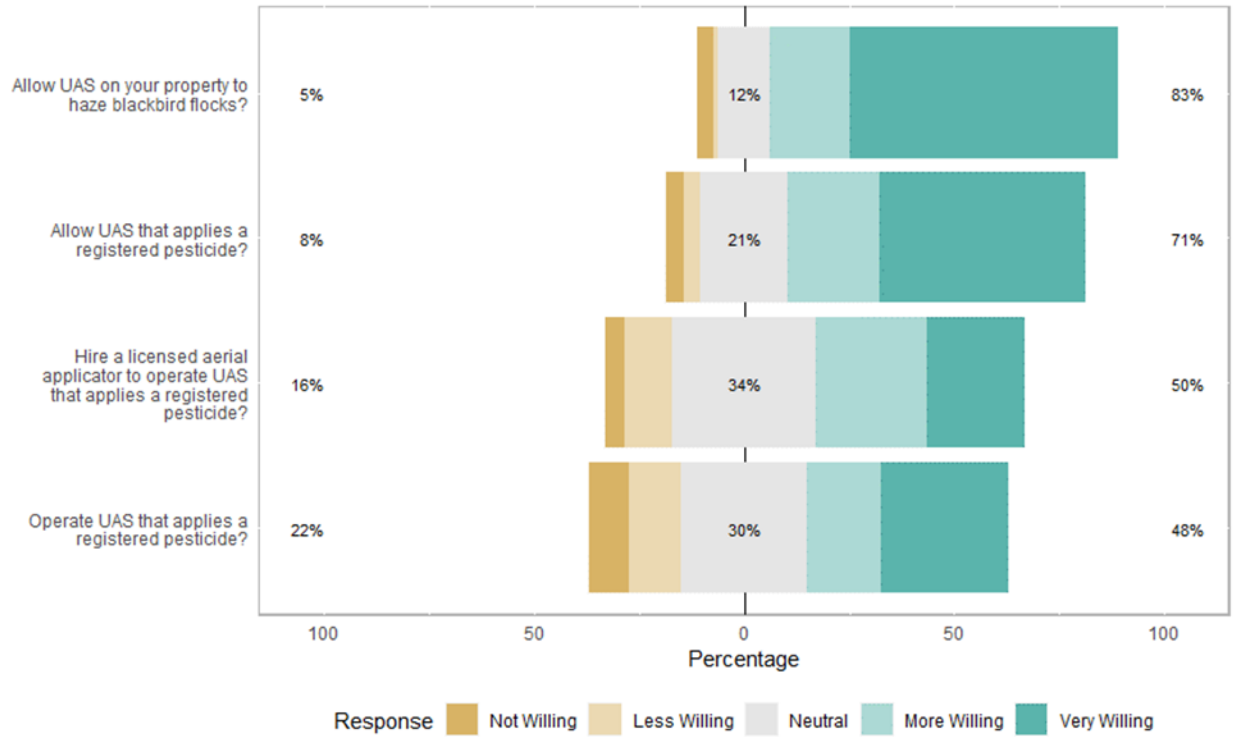


Figure 2.3. Sunflower farmers' willingness to allow UAS operations on their property in North and South Dakota, USA. Responses ranged from very willing to not willing, with an option for neutral, and are displayed as percentages of total question responses. Percentages on the left are the combined negative responses, on the right are combined positive responses, and in the middle are the neutral responses.

The first OLR model (Q1) was an overall good fit (LR $\chi^2 = 29.91$, $p \leq 0.01$) with four out of ten explanatory variables significantly influencing willingness to allow UAS to haze blackbirds on a farmer's property (McFadden pseudo $R^2 = 0.13$; Table 2.3). Prior UAS flights on farmers' properties were significantly associated with an increased willingness to allow UAS hazing ($p \leq 0.10$). Farmers with a medium and high level of profit impacted by bird damage were significantly associated with an increased willingness to allow UAS hazing, compared to those with a low level of profit impact ($p \leq 0.01$). Age ($p \leq 0.01$) and generation ($p \leq 0.01$) were both significantly associated with a decreased willingness to allow UAS hazing.

The second OLR model (Q2) was an overall good fit for the data with four out of ten explanatory variables significantly influencing willingness to allow a UAS to apply a registered pesticide on a farmer's property (LR $\chi^2 = 26.10$, $p \leq 0.01$, McFadden pseudo $R^2 = 0.08$; Table 2.3). Farmers with a college education (undergraduate or graduate) were significantly associated with an increased willingness to allow UAS pesticide application, compared to those with a high school education or less ($p \leq 0.10$). Farmers indicating a medium level of profit impacted by bird damage were significantly associated with an increased willingness to allow UAS pesticide application ($p \leq 0.05$). Farmers who take management action to reduce bird damage to sunflower were significantly associated with an increased willingness to allow UAS pesticide application ($p \leq 0.05$). Generation was significantly associated with a decreased willingness to allow UAS pesticide application, indicating individuals from farms held over multiple generations were less willing to allow UAS pesticide application ($p \leq 0.10$).

The third OLR model (Q3, a farmer operating the UAS to apply a pesticide) was an overall poor fit for the data (LR$\chi^2 = 18.1$, p = 0.08, McFadden pseudo $R^2 = 0.04$; Table 2.3) due to a violation of the proportional odds assumption, suggesting a different set of explanatory variables are needed for evaluation.

The fourth OLR model (Q4) was an overall good fit for the data with three out of ten explanatory variables significantly associated with a farmer's willingness to hire a UAS pilot to operate and apply a pesticide on their property (LR $\chi^2 = 33.02$, $p \leq 0.01$, McFadden pseudo $R^2 = 0.08$; Table 2.3). The maximum annual cost that a farmer was willing to spend to control bird damage was significantly positively associated with an increase in willingness to hire a UAS pilot ($p \leq 0.05$). Previous action taken to prevent or reduce bird damage to sunflower ($p \leq 0.05$), including prior UAS flights ($p \leq 0.10$), was significantly associated with an increased willingness to hire a UAS pilot.

Table 2.3. Results from four ordinal logistic regression models explaining the variables that influence a farmer who grew sunflower in 2020 willingness to allow UAS operations on their property to control blackbird flocks in sunflower. Coefficients for explanatory variables, along with standard error (SE), and odds ratios (OR) are given.

Dependent variable	Allow UAS to haze blackbirds (Q1)		Allow UAS to apply pesticide (Q2)		Operate UAS to apply pesticide (Q3)		Hire pilot to operate UAS and apply pesticide (Q4)	
Independent variable	Coefficient ± SE	OR	Coefficient ± SE	OR	Coefficient ± SE	OR	Coefficient ± SE	OR
Age	-0.056 ± 0.013***	0.945	0.004 ± 0.011	1.004	-0.025 ± 0.009***	0.975	0.008 ± 0.010	1.008
Education [a]								
≥ College	0.073 ± 0.453	1.076	0.656 ± 0.363*	1.928	0.412 ± 0.314	1.510	0.174 ± 0.319	1.190
Sunflower experience	0.035 ± 0.022	1.036	-0.002 ± 0.018	0.998	-0.006 ± 0.015	0.994	0.002 ± 0.016	1.002
Impact on profit [b]								
Medium	1.012 ± 0.329***	2.750	0.630 ± 0.261**	1.877	0.463 ± 0.206**	1.589	0.107 ± 0.374	1.113
High	0.624 ± 0.204***	1.867	0.235 ± 0.167	1.264	0.721 ± 0.146***	2.056	0.060 ± 0.523	1.062
Yield lost to birds (%)	0.016 ± 0.020	1.017	0.022 ± 0.016	1.022	-0.004 ± 0.012	0.996	0.013 ± 0.015	1.013
Generation	-0.843 ± 0.203***	0.430	-0.291 ± 0.163*	0.747	0.198 ± 0.134	1.218	0.224 ± 0.140	1.251
Sunflower acreage	<-0.001 ± <0.001	0.999	<-0.001 ± <0.001	0.999	<0.001 ± <0.001	1.000	<0.001 ± <0.001	1.000
Maximum cost	<0.001 ± <0.001	1.000	<0.001 ± <0.001	1.000	<0.001 ± <0.001	1.000	<0.001 ± <0.001**	1.000
Management action taken	0.423 ± 0.393	1.526	0.676 ± 0.318**	1.966	0.187 ± 0.283	1.206	0.788 ± 0.319**	2.198
Prior UAS experience	0.781 ± 0.459*	2.184	0.545 ± 0.357	1.724	0.371 ± 0.285	1.449	0.577 ± 0.297*	1.780
McFadden's Pseudo R^2	0.13		0.08		0.04		0.08	
L.R.χ^2	29.91***		26.10***		18.1*		33.02***	
N	208		208		207		207	

***p ≤0.01, **p ≤0.05, *p ≤0.10.

[a] reference category ≤high school, [b] reference category = low

A hurdle model, illustrating the factors that influence the maximum annual cost that a farmer is willing to spend to control bird damage to sunflower, was an overall good fit (Wald χ^2 = 68.6, df = 7, $p \leq 0.01$; Table 2.4). The two-part regression analysis indicated that the significant factors in the participation model were management actions taken in the past (p ≤0.01) and impacts of bird damage on profits (p ≤0.01). The significant factors in the willingness-to-pay model were acreage (p ≤0.01), age (p ≤0.05), and the impact of bird damage on profits (p ≤0.10).

Table 2.4. Hurdle model illustrating the factors that influence a farmer's participation in spending funds and the maximum cost a farmer is willing to spend annually to prevent bird damage to sunflower crops. For participation, the binomial distribution (logit model) models the probability that a farmer will indicate they are willing to spend money on bird damage management. For willingness-to-pay, a negative-binomial distribution (truncated count regression model) examines the relationship between the amount farmers are willing to pay and selected covariates (see Table 1).

	Participation	**Willingness-To-Pay**
Covariates	Coefficient ± S.E.	Coefficient ± S.E.
Age	-0.007 ± 0.018	-0.022 ± 0.010**
Education	0.280 ± 0.367	-0.152 ± 0.191
Sunflower growing experience	0.027 ± 0.019	0.004 ± 0.011
Yield lost to birds (%)	0.022 ± 0.017	0.002 ± 0.008
Impact on profit	0.549 ± 0.333*	0.336 ± 0.175*
Generation	-0.001 ± 0.261	-0.075 ± 0.126
Acreage in sunflower	<-0.001 ± 0.001	<0.001 ± <0.001***
Management action	2.017 ± 0.365***	0.295 ± 0.214
Log psuedolikelihood	-1,436 (df = 19)	
n	215	
Wald χ^2 (df = 7)	68.6***	

***p ≤0.01, **p ≤0.05, *p ≤0.10.

Discussion

The overwhelming majority of farmers were willing to allow UAS operations on their property, by way of hazing and applying pesticides, to protect sunflower crops from birds. Although 29% reported UAS as an ineffective tool, only 5% indicated an unwillingness to allow UAS hazing of blackbirds on their property. This potentially illustrates a desperation to try anything, and potential frustration at a lack of efficacy for currently available tools and methods.

In modeling the factors that influenced farmer's willingness to allow UAS operations, we found different significant variables influenced the four OLR models. Allowing a third-party to operate UAS on a property, by hazing or applying pesticide, may reflect responses from a more hesitant or lagging adopter, as that option requires no individual investment. While acquiring licensure to operate UAS and hiring UAS operations may reflect an innovative or early adopter, as those options require individual investment (Rogers 2010). The difference in these groups may be due to the differing levels of commitment required to adopt the tool, such as available time, money, or skills. Farmers' perceptions of UAS to mitigate human-wildlife conflict were unknown due to the novelty of the methodology, however examining farmers' perceptions of precision agriculture or other technology can give supportive insight to our results.

Sociodemographic factors that influenced a farmer's willingness to allow UAS operations on their property included age, generation, and education. Increased age is known to decrease willingness to adopt novel precision agriculture technologies, especially for those that may be more hesitant to adopt a novel technology (Daberkow and McBride 2003). A study by Michels *et al.* (2020), explored the intent to adopt UAS by German farmers for precision agriculture purposes and found that increased age negatively impacts tool adoption. In our study, age negatively influenced a willingness to allow UAS on their property to haze blackbirds. Generation negatively influenced both the willingness to allow UAS hazing operations and UAS spraying operations on a farmer's property. Most studies focus on intergenerational transfer as opposed to occupational generation of a current farmer, and those studies show support for precision agriculture adoption by farmers who have someone to take over the farm (Napier *et al.* 2000). Our results could show either a trend in multiple generations in the Dakotas not having the next generation to take over farming, or a first-generation farmer may be more willing to try new methods compared to a farming operation that has been run the same way for multiple generations. Lastly, the only model that had education significantly impacting the willingness to allow UAS operations was for pesticide application. A study by Hashemi and Damalas (2010) found that farmers with increased education have more positive opinions about pesticide efficacy. Increased education is often significantly associated with willingness to adopt precision agriculture technologies, given it is also associated with earlier adopters (Adrian *et al.* 2005).

Factors that were associated with economics, (e.g., impact on profits and a maximum amount willing to spend to prevent bird damage) influenced a farmer's willingness to allow UAS operations on their property. Farmers experiencing an impact to their profit due to wildlife damage are often less tolerant than those who do not face damage, and thus would be more willing to control or mitigate that loss (Conover 2002). Farmers who experience a medium or high level of impact to their profit are more willing to allow UAS operations (hazing, pesticide application, and acquiring licensure) compared to those who have low profit impacts from bird damage, but impact to profit was not a significant variable for hiring an UAS pilot.

Prior bird damage prevention actions and experience with UAS positively influenced some of the models. An indication of early adopters to a novel tool are those that already have prior experience on some level, like those farmers that already have UAS experience (Daberkow and McBride 2003). Prior UAS experience positively impacted willingness to allow UAS operations to haze blackbirds and willingness to hire an UAS pilot to apply pesticides, questions modeled on opposite ends of novel tool investment. Novel tool adopters may rely on proof of effectiveness before taking on a perceived risk, and once the effectiveness is known it is less risky to invest resources into the novel tool (Adrian *et al.* 2005). Those farmers who do take action to prevent bird damage from occurring show a commitment to taking action and could have an increased willingness to try novel management methods before efficacy is proven.

UAS was identified as the tool with the greatest amount of ‘No Opinion’ responses for perceived level of effectiveness, which we expected for a novel method, although 7% of the respondents have used UAS. Some respondents indicated a family member had attempted to haze blackbird flocks with a UAS, while others cited UAS flights from academic research or a federal agency. The overwhelming positive response towards UAS applications on commercial sunflower fields is promising for the development and continued research of this novel tool, and with appropriate education and outreach, perceptions could continue to improve across the Dakotas (Maas *et al.* 2021). This information can be used by organizations like the National Sunflower Association, seed companies, or USDA Wildlife Services Operations to develop workshops to support farmers that may be most willing to try novel blackbird damage prevention methods, such as new and young farmers, and those experiencing high impacts to their profits (Feder and Umali 1993).

Evaluating current damage management tools revealed a disconnect between those tools perceived as effective and those used frequently. Easy-to-access tools that require no long-term planning, such as lethal shooting with a shotgun, were found to be the most used tool (36%), but the perceived effectiveness and ineffectiveness was split among respondents (43% and 47%, respectively). Non-lethal shooting, propane cannons, and pyrotechnics were also among the most frequently used tools despite a higher percentage of respondents viewing these tools as ineffective. The disproportionate response of ineffective lethal removal techniques, like the use of shotguns, reflects the frustration farmers have towards the nature of bird damage and the lack of effective management options (Dickman 2010).

The percentage of respondents reporting “No Opinion” was >50% for tools that had low frequency of reported use by sunflower producers in the northern Great Plains, including decoy crops, chemical repellents, acoustics, and UAS (Figures 2.1, 2.2). Some of these methods or tools are more expensive, and others have logistical complications. For decoy crops, additional land is required along with knowledge of roosting locations or bird flight paths prior to migration. Acoustics require speakers and batteries and are more intensive to manage in that they cover small areas due to sound attenuation and wind conditions diminishing sound waves. Chemical repellents require hiring a pilot for aerial application, are expensive, and the vegetative and floral characteristics of the sunflower plant reduces effective application to the achenes where the chemical contacts the foraging bird (Kaiser *et al.* 2019).

Cattail management is the most difficult to implement method and arguably the most effective method to reduce bird damage, but it requires coordination between multiple landowners to treat large wetlands spanning property boundaries. Farmers who planted in 2020 valued cattail management as the most effective damage management method (65% of respondents), while only 21% have implemented cattail management. Cattails cover roughly one-third of the wetlands in the Prairie Pothole Region of North Dakota, and effective treatment of an entire slough requires coordination over multiple years that can be expensive due to equipment and time (Ralston *et al.* 2007; Svedarsky *et al.* 2019). Multiple stakeholders have joint interests in cattail management because the practice increases waterfowl production and hunting opportunities, reduces the size of blackbird roosts, and increases overall wetland quality and diversity (Bansal *et al.* 2019). As cattail management potentially includes multiple state and federal agencies, special interest groups or non-profits, and private landowners, a collaborative effort is necessary to address it on a landscape scale. A study by Shwiff *et al.* (2012) found a gap in stakeholder communication and identified an opportunity where state and federal agencies could assist with invasive bird species control at dairy facilities to simultaneously reduce related environmental damage. Other methods or tools highlighted in our study that require coordination at the landscape scale include coordinated planting and harvesting with neighbors, and the planting of decoy crops, which have low frequency of use rates (Figure 2.2). Identifying ways to implement these methods at the landscape scale is complex but developing a network to coordinate these methods could benefit more than just avian-agriculture conflict (Pretty *et al.* 2010).

Most willingness-to-pay studies focus on the conservation of species or the increase of taxes to pay for habitat or conservation efforts (Chandr Jaunky *et al.* 2021; Martínez-Espiñeira 2006). Far fewer studies have been conducted on the willingness of farmers to pay for wildlife damage, outside of insurance research (Nyhus *et al.* 2005). However, it is critical to understand the factors that influence a farmer's willingness-to-pay for wildlife damage management, especially in the process of developing tools and methods for farmer use. Despite blackbird damage being cited as the main reason farmers remove sunflower from their rotation, a portion of respondents cited an unwillingness to pay anything to control bird damage (26.6%). An unwillingness to invest any funds may be because current methods and tools are not enough of an incentive, whereas the discovery of a new tool or combination of tools that are cost-effective could result in an increased willingness-to-pay (Neupane *et al.* 2017). Farmers reporting higher levels of profit impacted by bird damage and farmers who already take management action to prevent bird damage jump the first hurdle and are willing to spend money annually to control bird damage. Our results are supported based on a study by van Velden *et al.* (2016), who found that farmers with higher damage from blue cranes (*Anthropoides paradiseus*) were more willing to use new management strategies, although some farmers felt so hopeless about management tools that they were not willing to try anything.

Younger farmers with higher amounts of sunflower acreage and experiencing higher impact to profit from birds were willing to spend more annually to prevent bird damage. A potential avenue to decrease the cost of bird damage prevention efforts on the individual farmer would be to adjust product prices. Research on consumers' willingness-to-pay for fruit impacted by avian damage revealed increased cost of a product is acceptable if nonlethal bird management practices are used (Oh *et al.* 2015). A sunflower product could be advertised as "bird friendly" and the product price adjusted to account for nonlethal bird damage management techniques used (Herrnstadt *et al.* 2015).

Assisting farmers in the Dakotas with bird damage in sunflower will require innovation of ideas and tools. This study highlights sunflower farmers' willingness to use UAS applications as a novel tool by either allowing it on their property or hiring an applicator to address bird damage. Workshops highlighting current and novel damage management tools or methods might be helpful to reach farmers that may be more hesitant. Land managers, extension agents, or academic researchers should target outreach efforts to reach potential early adopters of these novel methods by taking into consideration farmer demographics and prior bird damage management actions. Tool adoption in agricultural communities often follows a diffusion model where effective strategies start with early adopters and spread by word of mouth (Feder and Umali 1993). Collaborative management efforts are imperative to an avian-agriculture conflict as multifaceted as blackbirds and sunflower production.

Acknowledgements

The United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center (USDA-APHIS-WS-NWRC; #20-7438-0020-CA; QA-3231) funded this research. The North Dakota State University, Institutional Review Board determined that the project did not require approval or certification of exempt status. Any use of trade, firm, or product names is for descriptive purpose only and does not imply endorsement by the U.S. Government. We thank K. Williams and D. Mataic for helpful assistance with statistical analyses. We thank E. Kotten for data entry. We are grateful to M. Donaldson, J. Elser, S. Kross, J. Boulanger, J. Momsen, and the National Sunflower Association Board of Directors for valuable feedback on the survey instrument. We thank The National Sunflower Association for assistance with the collection of survey data and the farmers that responded to our survey. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the US Government.

References

Adrian AM, Norwood SH, and Mask PL (2005) Producers' perceptions and attitudes toward precision agriculture technologies. *Computers and Electronics in Agriculture* **48**, 256-271. doi: https://doi.org/10.1016/j.compag.2005.04.004.

Ampatzidis Y, Ward J, and Samara O Autonomous system for pest bird control in specialty crops using unmanned aerial vehicles. 2015 ASABE Annual International Meeting, New Orleans, LA, USA.

Bansal S, Lishawa SC, Newman S, Tangen BA, Wilcox D, Albert D, Anteau MJ, Chimney MJ, Cressey RL, DeKeyser E, Elgersma KJ, Finkelstein SA, Freeland J, Grosshans R, Klug PE, Larkin DJ, Lawrence BA, Linz G, Marburger J, Noe G, Otto C, Reo N, Richards J, Richardson C, Rodgers L, Schrank AJ, Svedarsky D, Travis S, Tuchman N, and Windham-Myers L (2019) *Typha* (cattail) invasion in North American wetlands: Biology, regional problems, impacts, ecosystem services, and management. *Wetlands* **39**, 645-684. doi: 10.1007/s13157-019-01174-7.

Chandr Jaunky V, Jeetoo J, and Michael Thomas J (2021) Willingness to pay for the conservation of the mauritian flying fox. *Global Ecology and Conservation* **26**, e01504. doi: https://doi.org/10.1016/j.gecco.2021.e01504.

Clark BA, Klug PE, Stepanian PM, and Kelly JF (2021) Using bioenergetics and radar-derived bird abundance to assess the impact of a blackbird roost on seasonal sunflower damage. *Human-Wildlife Interactions* **14**, 427-441. doi: https://doi.org/10.26077/9c95-48eb.

Conover MR (2002) 'Resolving human-wildlife conflicts: The science of wildlife damage management.' (CRC Press: Boca Raton, FL, USA)

Daberkow SG and McBride WD (2003) Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the us. *Precision Agriculture* **4**, 163-177. doi: 10.1023/A:1024557205871.

Dickman AJ (2010) Complexities of conflict: The importance of considering social factors for effectively resolving human–wildlife conflict. *Animal Conservation* **13**, 458-466. doi: https://doi.org/10.1111/j.1469-1795.2010.00368.x.

Egan CC, Blackwell BF, Fernández-Juricic E, and Klug PE (2020) Testing a key assumption of using drones as frightening devices: Do birds perceive drones as risky? *Condor* **122**, 1-15. doi: 10.1093/condor/duaa014.

Fall MW and Jackson WB (2002) The tools and techniques of wildlife damage management—changing needs: An introduction. *International Biodeterioration & Biodegradation* **49**, 87-91. doi: https://doi.org/10.1016/S0964-8305(01)00107-X.

Feder G and Umali DL (1993) The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change* **43**, 215-239. doi: https://doi.org/10.1016/0040-1625(93)90053-A.

Hagy HM, Linz GM, and Bleier WJ (2008) Optimizing the use of decoy plots for blackbird control in commercial sunflower. *Crop Protection* **27**, 1442-1447.

Hashemi SM and Damalas CA (2010) Farmers' perceptions of pesticide efficacy: Reflections on the importance of pest management practices adoption. *Journal of Sustainable Agriculture* **35**, 69-85. doi: 10.1080/10440046.2011.530511.

Herrnstadt Z, Howard PH, Oh C-O, and Lindell CA (2015) Consumer preferences for ‘natural’agricultural practices: Assessing methods to manage bird pests. *Renewable Agriculture and Food Systems* **31**, 516-523.

Hill CM (2015) Perspectives of “conflict” at the wildlife–agriculture boundary: 10 years on. *Human Dimensions of Wildlife* **20**, 296-301. doi: 10.1080/10871209.2015.1004143.

Hulke BS and Kleingartner LW (2014) Sunflower. In 'Yield gains in major us field crops'. (Eds. S Smith, B Diers, J Specht, and B Carver) pp. 433-458. Soil Science Society of America Special Publication 33. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America: Madison, WI, USA.

Ivošević B, Yong-Gu H, Youngho C, and Ohseok K (2015) The use of conservation drones in ecology and wildlife research. *Journal of Ecology and Environment* **38**, 113-118.

Kaiser BA, Johnson BL, Ostlie MH, Werner SJ, and Klug PE (2021) Inefficiency of anthraquinone-based avian repellents when applied to sunflower: The importance of crop vegetative and floral characteristics in field applications. *Pest Management Science* **77**, 1502-1511.

Klosterman ME, Linz GM, Slowik AA, and Homan HJ (2013) Comparisons between blackbird damage to corn and sunflower in North Dakota. *Crop Protection* **53**, 1-5.

Klug PE (2017) The future of blackbird management research. In 'Ecology and management of blackbirds (Icteridae) in North America'. (Eds. GM Linz, ML Avery, and RA Dolbeer) pp. 217-234. CRC Press/Taylor & Francis: Boca Raton, FL, USA.

König HJ, Kiffner C, Kramer-Schadt S, Fürst C, Keuling O, and Ford AT (2020) Human–wildlife coexistence in a changing world. *Conservation Biology* **34**, 786-794. doi: https://doi.org/10.1111/cobi.13513.

Kross SM, Ingram KP, Long RF, and Niles MT (2018) Farmer perceptions and behaviors related to wildlife and on-farm conservation actions. *Conservation Letters* **11**, e12364.

Linz GM, Avery ML, and Dolbeer RA (2017) History of regulations, policy, and research related to conflicts between blackbirds and people. In 'Ecology and management of blackbirds (Icteridae) in North America'. (Eds. GM Linz, ML Avery, and RA Dolbeer) pp. 1-15. CRC Press/Taylor & Francis: Boca Raton, FL, USA.

Linz GM and Hanzel J (1997) Birds and sunflower. *Sunflower Technology and Production*. Monograph, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI, USA, pp. 381-394.

Linz GM and Hanzel JJ (2015) Sunflower bird pests. In Sunflower: Chemistry, Production, Processing, and Utilization. (Eds. Martinez-Force, E., Dunford, N.T., Salas, J.J.), AOCS

Press in association with USDA APHIS Wildlife Services NWRC, Urbana, IL, USA, pp. 175-186.

Linz GM and Homan HJ (2011) Use of glyphosate for managing invasive cattail (*Typha* spp.) to disperse blackbird (Icteridae) roosts. *Crop Protection* **30**, 98-104.

Linz GM, Homan HJ, Werner SJ, Hagy HM, and Bleier WJ (2011) Assessment of bird-management strategies to protect sunflowers. *Bioscience* **61**, 960-970.

Maas B, Fabian Y, Kross SM, and Richter A (2021) Divergent farmer and scientist perceptions of agricultural biodiversity, ecosystem services and decision-making. *Biological Conservation* **256**, 109065. doi: https://doi.org/10.1016/j.biocon.2021.109065.

Madden F (2004) Creating coexistence between humans and wildlife: Global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife* **9**, 247-257. doi: 10.1080/10871200490505675.

Martin T, Wintle B, Rhodes J, Kuhnert P, Field S, Lowchoy S, Tyre A, and Possingham H (2005) Zero tolerance ecology: Improving ecological inference by modelling the source of zero observations. *Ecology Letters* **8**, 1235-1246. doi: 10.1111/j.1461-0248.2005.00826.x.

Martínez-Espiñeira R (2006) A box-cox double-hurdle model of wildlife valuation: The citizen's perspective. *Ecological Economics* **58**, 192-208. doi: https://doi.org/10.1016/j.ecolecon.2005.07.006.

Michels M, von Hobe C-F, and Musshoff O (2020) A trans-theoretical model for the adoption of drones by large-scale german farmers. *Journal of Rural Studies* **75**, 80-88. doi: https://doi.org/10.1016/j.jrurstud.2020.01.005.

Napier TL, Robinson J, and Tucker M (2000) Adoption of precision farming within three Midwest watersheds. *Journal of Soil and Water Conservation* **55**, 135-141.

Neupane D, Kunwar S, Bohara AK, Risch TS, and Johnson RL (2017) Willingness to pay for mitigating human-elephant conflict by residents of Nepal. *Journal for Nature Conservation* **36**, 65-76. doi: https://doi.org/10.1016/j.jnc.2017.02.004.

Nyhus PJ, Osofsky SA, Ferraro P, Madden F, and Fischer H (2005) Bearing the costs of human-wildlife conflict: The challenges of compensation schemes. In R. Woodroffe, S. Thirgood and A. Rabinowitz (Eds.). People and wildlife: Conflict or coexistence?, pp. 107–121. Cambridge University Press, Cambridge, United Kingdom.

Oh C-O, Herrnstadt Z, and Howard PH (2015) Consumer willingness to pay for bird management practices in fruit crops. *Agroecology and Sustainable Food Systems* **39**, 782-797.

Pretty J, Sutherland WJ, Ashby J, Auburn J, Baulcombe D, Bell M, Bentley J, Bickersteth S, Brown K, and Burke J (2010) The top 100 questions of importance to the future of global agriculture. *International Journal of Agricultural Sustainability* **8**, 219-236.

Ralston ST, Linz G, Bleier W, and Homan H (2007) Cattail distribution and abundance in north dakota. *Journal of Aquatic Plant Management* **45**, 21-24.

Rogers EM (1962) 'Diffusion of innovations.' New York: The Free Press.

Rollins K, Heigh L, and Kanetkar V (2004) Net costs of wildlife damage on private lands. *Journal of Agricultural and Resource Economics* **29**, 517-536.

Rosenberg KV, Dokter AM, Blancher PJ, Sauer JR, Smith AC, Smith PA, Stanton JC, Panjabi A, Helft L, Parr M, and Marra PP (2019) Decline of the North American avifauna. *Science* **366**, 120-124. doi: 10.1126/science.aaw1313.

Sandbrook C (2015) The social implications of using drones for biodiversity conservation. *Ambio* **44**, 636-647. doi: 10.1007/s13280-015-0714-0.

Sausse C and Lévy M (2021) Bird damage to sunflower: International situation and prospects. *Oilseeds and fats, Crop and Lipids* **28**, 34.

Shwiff SA, Carlson JC, Glass J, Suckow J, Lowney MS, Moxcey K, Larson B, and Linz GM (2012) Producer survey of bird-livestock interactions in commercial dairies. *Journal of Dairy Science* **95**, 6820-6829.

Svedarsky D, Grosshans R, Venema H, Ellis-Felege S, Bruggman J, Ostlund A, and Lewis J (2019) Integrated management of invasive cattails (*Typha* spp.) for wetland habitat and biofuel in the northern great plains of the United States and Canada: A review. *Mires and Peat* **25**, 1-14.

Tomass Z, Shibru S, Yonas M, and Leirs H (2020) Farmers' perspectives of rodent damage and rodent management in smallholder maize cropping systems of southern Ethiopia. *Crop Protection* **136**, 105232. doi: https://doi.org/10.1016/j.cropro.2020.105232.

U.S. Department of Agriculture, Economics, Statistics and Market Information System (USDA-ESMIS) (2021) Crop acreage (National Agricultural Statistics Service).

van Velden JL, Smith T, and Ryan PG (2016) Cranes and crops: Investigating farmer tolerances toward crop damage by threatened blue cranes (*Anthropoides paradiseus*) in the western cape, South Africa. *Environmental Management* **58**, 972-983. doi: 10.1007/s00267-016-0768-1.

Wandrie LJ, Klug PE, and Clark ME (2019) Evaluation of two unmanned aircraft systems as tools for protecting crops from blackbird damage. *Crop Protection* **117**, 15-19.

Wang Z, Griffin AS, Lucas A, and Wong K (2019) Psychological warfare in vineyard: Using drones and bird psychology to control bird damage to wine grapes. *Crop Protection* **120**, 163-170.

Wilson EA, Leboeuf EA, Weaver KM, and Leblanc DJ (1989) Delayed seeding for reducing blackbird damage to sprouting rice in southwestern Louisiana. *Wildlife Society Bulletin*, **17**, 165-171.

Zeileis A, Kleiber C, and Jackman S (2008) Regression models for count data in R. *Journal of Statistical Software* **27**, 1-25. doi: 10.18637/jss.v027.i08.

CHAPTER 3: FLOCK CHARACTERISTICS AND ENVIRONMENTAL VARIABLES INFLUENCE THE BEHAVIORAL RESPONSE OF BLACKBIRD FLOCKS TO UAS APPROACH AND HAZING IN AN AGROECOSYSTEM

Abstract

Unmanned aircraft systems (hereafter, UAS) are a dynamic and adaptive tool that have shown success as a hazing tool in situations of avian-agriculture conflict. The antipredator behavior elicited by birds in response to a direct UAS approach makes it a suitable option for use on nuisance blackbirds (*Icteridae*) in large sunflower (*Helianthus annuus*) fields. During peak blackbird damage to sunflowers (September to October) in 2019 and 2020, we evaluated the behavioral responses of free-ranging blackbird flocks to UAS upon first approach and with 10 min of hazing via a large octocopter UAS (DJI Agras MG-1P). We used a small eye-in-the-sky UAS (DJI Phantom 4 or Mavic Air 2) to record video of the approaching UAS to capture and measure flight initiation distance (FID = 39.9 ± 14.3 m). We used on-the ground behavioral observations to record the antipredator responses of the mixed blackbird flocks to UAS hazing. FID was shorter (i.e., drone viewed as less risky) when the UAS was launched further away from small flocks, later in the day, and in fields with greater area of cattail marsh. The probability of flock abandonment increased as the day progressed but decreased with larger flock sizes and warmer daytime temperatures. The UAS appears riskier earlier in the day based on FID, however the increased probability of abandonment later in the day was likely due to completion of foraging and movement to nighttime roosting sites. Our hazing trials resulted in flock reductions of 35.6%, along with reduced activity after UAS exposure with an average of 19.4% less flight time and 49.7% fewer flock lift offs after UAS hazing. Thus, birds in open agricultural environments used the crop or other local habitat as refugia until the threat passed, which is further supported in that 80.6% of the flocks that abandoned returned within 15 min. This study provides crucial information for UAS applications on both large flocks and in broad-scale agriculture environments and highlights the environmental variables that influence successful hazing protocols.

Keywords: antipredator behavior, blackbirds; drone; FID; flock; frightening devices; hazing; human-wildlife conflict; *Icteridae*; remotely piloted aircraft systems; UAV; vertebrate pests; visual deterrent

Introduction

The annual damage and profit loss to global crop production due to birds is in the millions (US $), impacting specialty crops like wine grapes (*Vitus* spp.) to commercial row crop agriculture like sunflowers (*Helianthus annuus* L.; Conover 2002). The species of nuisance bird may differ depending on the region or location and the crop, but blackbirds (*Icteridae*) are known for their impact on crop production throughout North America (Shwiff *et al.* 2017). Direct production losses reach roughly $3.5 million annually in North Dakota, while the additive impacts of indirect loss affecting local economies (e.g., transportation, processing facilities), labor requirements, and time spent managing the issue extend to roughly $18 million (Ernst *et al.* 2019; Klosterman *et al.* 2013).

The blackbird family is facing overall population declines of roughly 1% annually, while red-winged blackbird (*Agelaius phoeniceus*) populations vary geographically with regions like the northern Great Plains experiencing a 1.5% annual breeding population increase (Rosenberg *et al.* 2019; Sauer *et al.* 2017). Landscapes dominated by cattails are preferred habitats during the breeding season and important roosting habitat for fall molt and migration in blackbirds (Forcey *et al.* 2015; Linz *et al.* 2003). Blackbirds will travel 8-10 km from their nighttime cattail roost to forage; thus, sunflower fields near cattail marshes or with cattail marshes imbedded within the field will suffer higher crop damage (Dolbeer 1990; Dolbeer and Linz 2016; Homan *et al.* 2005; Linz and Hanzel 1997). In North Dakota, cattail roosts can host upwards of 1 million migrating blackbirds in the fall, causing significant damage to nearby crops (Clark *et al.* 2021).

Tools and methods to mitigate damage caused by blackbirds can be implemented at multiple spatial scales (field, landscape, and region). Mitigation tools at the field scale are most accessible to farmers, and thus most frequently used. However, of the options currently available (e.g., exclusionary methods, frightening devices, habitat manipulation, and chemical repellents) considerable limitations exist in terms of efficacy, range, feasibility, or cost (Sausse *et al.* 2021). In situations of broad-scale agriculture, stationary field-based tools are not sufficient to move large flocks out of large fields and flocks often become habituated to the tools. Thus, dynamic, mobile tools are necessary to produce effective results and may require the incorporation of multiple tools or methods to increase the negative stimulus (Klug 2017).

Unmanned aircraft systems are dynamic, highly mobile, and show promise for use in avian-agriculture conflicts. Managers of small-scale agriculture systems such as vineyards, rice paddies (*Oryza* spp.), and commercial aquaculture ponds have deployed UAS to harass nuisance birds (Mohamed *et al.* 2020; Rhoades *et al.* 2019; Wang *et al.* 2020). Antipredator alert and escape responses were elicited by individual male, red-winged blackbirds approached by an UAS in controlled aviary settings (Egan *et al.* 2020a; Wandrie *et al.* 2019). However, on a broader agriculture scale with an increased number of birds in a flock, there is proven difficulty in UAS producing a consistent abandonment response (i.e., success is an entire flock leaving a field; Egan 2018a). Increasing the negative stimulus associated with UAS platforms, to affect a greater proportion of the flock, may increase abandonment rates. Suggestions have included emitting frightening acoustics (Wang *et al.* 2019), coordinating a fleet of swarming UAS (Paranjape *et al.* 2018), designing UAS to resemble an avian predator (Egan *et al.* 2020), and targeting nuisance birds in real-time with a UAS deploying an avian repellent (Ampatzidis *et al.* 2015). That said, we need to first understand how basic behavioral responses of birds vary under different environmental conditions, flock characteristics, and UAS flight patterns when approach in complex field settings.

The blackbird-sunflower conflict in North Dakota works as a case study for evaluating flock responses to an approaching UAS and extended UAS hazing, because of the severity of bird damage along with large flock sizes and complex agroecosystem landscapes (Klug 2017). Evaluation of behavioral responses on this scale must begin with exploration of a flock's perception of risk towards UAS, prior to more complex studies that modify UAS with additional negative stimuli. Our goal was to test whether blackbird flocks alter their antipredator responses to drones in relation to flock characteristics, environmental conditions, and basic UAS movement characteristics.

Our study evaluated the flight initiation distance (FID) of free-ranging, mixed blackbird flocks to a large octocopter spraying UAS, so future research can build off a baseline understanding of behavioral responses. FID is the measurable distance between the bird and the approaching object at the moment the bird decides to take flight (Cooper and Blumstein 2015) and is a behavioral metric to determine how threatened birds are by an approaching object. Many factors influence the FID of birds, including habitat, group size, hunting pressure, approach angle and speed (Cooper and Blumstein 2015; Egan *et al.* 2020; Fernández-Juricic *et al.* 2002). We also evaluated free-ranging blackbird flock behavioral responses to UAS hazing as a function of flock characteristics, environmental conditions, and basic UAS movement characteristics. The variables that influence FID may differ from the variables that influence flock behavior due to extended hazing. FID is a snapshot of the perceived risk of an approaching threat, whereas extended hazing impacts risk perception over time and the decision to flee the area could vary.

We evaluated the variables influencing FID, probability of field abandonment, flock reduction, and changes in behavioral metrics in response to hazing of free-ranging blackbird flocks in sunflower-cattail complexes approached directly by UAS. We predicted that larger flocks would react to the approaching UAS at greater distances, given this trend was seen in multiple species of waterbirds when approached on foot (Laursen *et al.* 2005). We also predicted that the distance from UAS launch site would influence FID given the cost of continual monitoring of an approaching threat that has been reported in numerous bird species (Blumstein 2003; Vas *et al.* 2015). We predicted that flocks located closer to the edge of the habitat would have a lower FID and higher probability of abandonment, due to their ability to flee to refugia bordering the field (e.g., trees or other crop fields such as corn) and the vast area of cattail marshes on the landscape (Bansal *et al.* 2019; Fernández-Juricic *et al.* 2002). We predicted that field size and flock size would influence the probability of flock abandonment given their importance in previous research on blackbirds in the same environment (Egan 2018a). We predicted that returning or remaining flocks would reduce their activity during a post-hazing observation period, by hunkering down after disturbance (Wang *et al.* 2019). We expected there to be an overall reduction in flock size, regardless if total flock abandonment occurred, due to UAS hazing as seen in vineyards (Bhusal *et al.* 2018).

We expected to see blackbird responses to UAS differ based on environmental conditions. Temperature can have a varying effect on avian response by either the cold causing increased metabolic needs and thus a stronger commitment to food, or the heat inducing a stress response (Fernández-Juricic *et al.* 2002). Wind speed can have an impact on UAS performance (e.g., speed), but birds may also choose to conserve energy by not flushing or flying in response to increased wind (Egan *et al.* 2020). High ambient light has been shown to reduce detection rates of birds towards an approaching threat (Fernández-Juricic *et al.* 2012). Both habitat types (cattail and sunflower) provide potential structural safety, but activities (e.g., foraging in sunflower and loafing in cattail) could impact detection and commitment to location as seen in the antipredator responses of European starlings (*Sturnus vulgaris*) changing with grass height (Devereux *et al.* 2008). Feeding rates are typically highest in the morning and decline in the afternoon for blackbirds, as foraging needs have been met for the day (Hintz and Dyer 1970), thus we expected a higher commitment to location in the morning compared to the afternoon or evening. Lastly, we included Julian day as it could indicate food availability on the landscape (increased sunflower harvest as the season progresses) or a progression toward migration and subsequent caloric need by birds (Cooper Jr and Blumstein 2015).

Methods

We conducted UAS trials in commercial sunflower fields in North Dakota counties (Bottineau, Burleigh, Emmons, Kidder, Logan, and McHenry) experiencing blackbird damage (Figure 3.1). We targeted locations where mixed-species blackbird flocks were either actively foraging on sunflower or loafing in cattails within or adjacent to commercial sunflower fields, from 4 September to 25 October in 2019 and 2020 between the hours of 07:30 and 19:00.

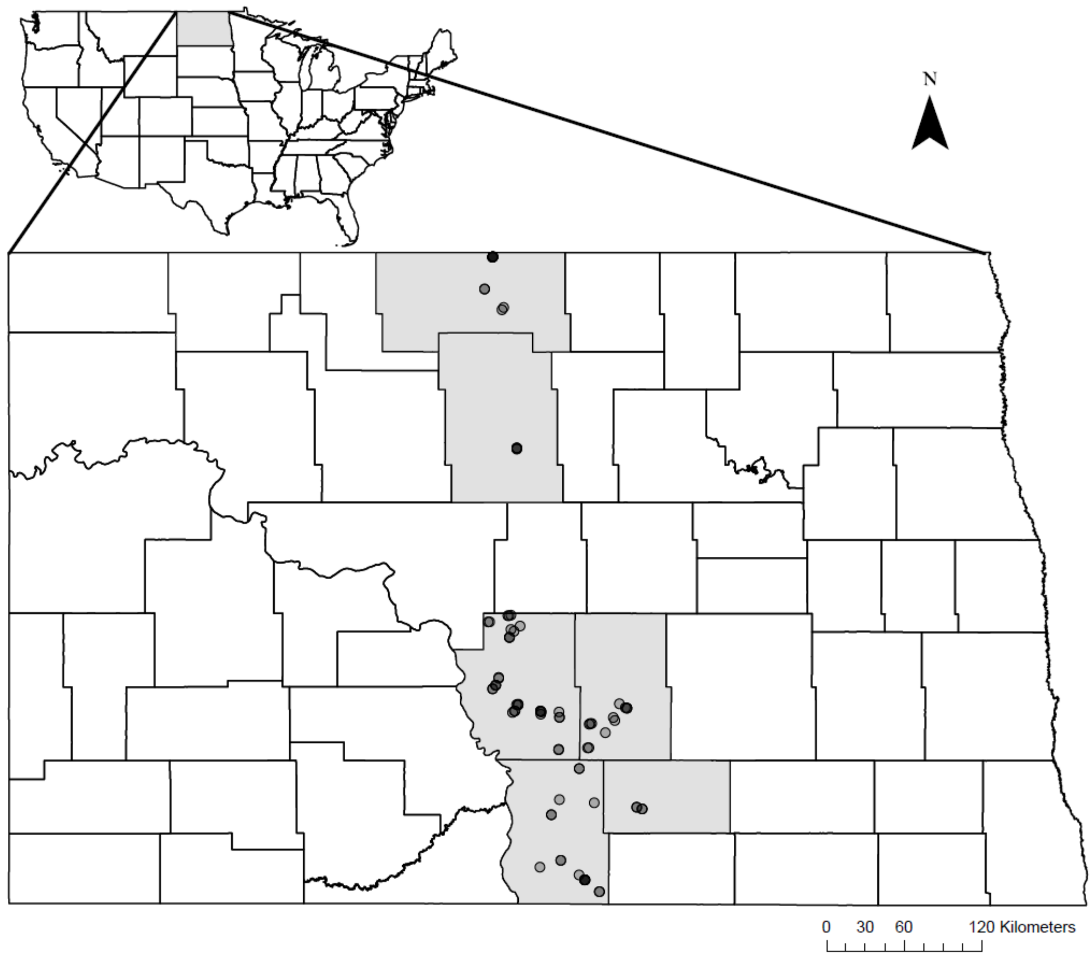


Figure 3.1. Locations of unmanned aircraft system (UAS) trials where mixed blackbird flocks were actively damaging commercial sunflower fields. We approached and subsequently hazed flocks with a spraying UAS (DJI Agras MG-1P). We conducted 95 trials (2019: FID = 35 and 2020: combined FID and hazing = 60) in central North Dakota, USA from 4 September to 25 October 2019 and 2020 (overlap occurs due to scale).

These large mixed-species flocks of blackbirds are mainly composed of red-winged blackbirds but can also include yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), common grackles (*Quiscalus quiscula*), brown-headed cowbirds (*Molothrus ater*), Brewer's blackbirds (*Euphagus cyanocephalus*), and European starlings. Cattail marshes are often within or adjacent to a sunflower field in the Prairie Pothole Region of North Dakota, and are used as daytime loafing, refugia and nighttime roosting sites. Our study period coincided with the 8-week damage window (ray-petal drop of the sunflower plants up until harvest) when blackbirds are undergoing fall molt and migration (Linz *et al.* 2017). If we operated multiple trials within a single field, we allowed an average interval of 13.9 (± 9.1) days between trials in the same year. Sunflower producers practice rotational agriculture; thus, no sunflower fields were repeated in both 2019 and 2020. We considered each blackbird flock as an independent experimental unit given population turnover with incoming migrant birds and flock mixing at roosting sites indicates that no two flocks are ever the same over time (Linz et al., 1991). We did not tag or mark flocks in any way, so there was a possibility that individual blackbirds were approached multiple times at different locations.

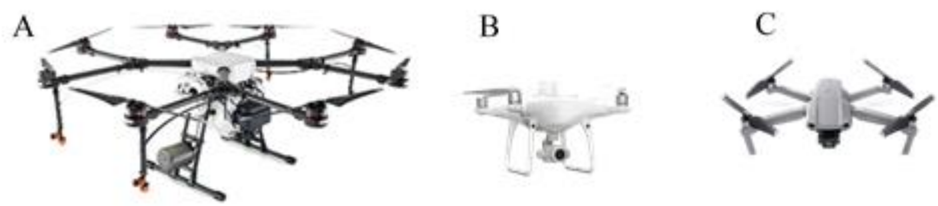


Figure 3.2. A) The DJI Agras MG-1P has a diagonal length of 1,500 mm, a maximum speed of 15 m/s, a tank that can hold 10 kg (approximately 2.5 gallons [9.5L]) of liquid, and a maximum hovering time of 20 min with an empty tank (9 min with a full tank). B) The DJI Phantom 4 has a diagonal length of 350 mm, a maximum speed of 20 m/s, a maximum flight time of approximately 28 min, and a vertical and horizontal positioning accuracy of 0.5 m and 1.5 m, respectively. C) The DJI Mavic Air 2 has a diagonal length of 302 mm, a maximum speed of 19 m/s, a maximum flight time of approximately 34 min, and a vertical and horizontal positioning accuracy of 0.5 m and 1.5 m, respectively.

We used a precision agriculture spraying octocopter (DJI AGRAS MG-1P; DJI Shenzhen, China; hereafter, Agras; Figure 3.2A) to approach and haze blackbird flocks. We used smaller quadcopters (DJI Phantom 4; DJI Shenzhen, China; Figure 3.2B and DJI Mavic Air 2; DJI Shenzhen, China; Figure 3.2C), which acted as eye-in-the-sky drones, to video record avian behavioral metrics in response to the Agras. We flew the Phantom 4 in 2019 at 60 m above ground level (AGL) and the Mavic Air 2 in 2020 at 80 m AGL; we upgraded the eye-in-the-sky drone for better video resolution to capture flock behavior and provide higher quality video for analysis. While both platforms capture 4K video resolution, the Mavic Air 2 was able to do so at 60 frames per second compared to 30 frames per second for the Phantom 4.

At the start of each trial, we recorded habitat location of flock (cattail or sunflower), time of day, Julian day, ambient light (µmol) with a Li-Cor LI-250 Light Meter and LI-190SA Quantum Sensor (Lincoln Nebraska, USA), ambient temperature (°C) and wind speed (m/s) with a Skymaster SM-28 weather meter (Speedtech Instruments, Great Falls Virginia USA). We used Google Earth Pro (version 7.3.4.8248, image dates 2016-2020) to measure the size of the sunflower field including embedded cattail marshes (acres), flock distance to edge (m), and flock distance to UAS launch site (m). We calculated flock distance to UAS launch site by adding the distance between launch site and where the UAS stopped after the flock took flight and the distance between the stopped UAS and the flock using the eye-in-the-sky drone footage (see FID methods below). We calculated flock distance to edge by measuring the distance between the leading edge of the flock and the edge of the habitat in Google Earth Pro (i.e., edge of cattail for flocks in cattail habitat and edge of sunflower for flocks in sunflower fields). The general progression of events for UAS trials was as follows: pre-trial observation period (15 min), UAS launch, FID trial, hazing trial (10 min), UAS landing, post-trial observation period (15 min). We did not include the hazing trial portion in 2019.

FID Trials

FID trials began after the eye-in-the-sky platform reached its designated height AGL (60-80 m), and the Agras reached 5 m AGL. The remote pilot-in-command (MGW) and an additional pilot flew both platforms manually, in a synchronous manner, so that the Agras was always at the trailing edge of the eye-in-the-sky video feed. The Agras was flown at a consistent speed (4 m/s) and height (5 m AGL), and both proceed in a straightline direction toward the flock location. Both platforms ceased forward movement when the remote pilot-in-command visually established that the flock initiated flight, all while the eye-in-the-sky drone recorded video footage to capture FID. We measured the straight-line distance between the Agras and the first bird in the flock to take flight (FID) using a still frame captured from each video in ImageJ (Schneider *et al.* 2012) (Figure 3.3). We used the known width of the Agras body as the frame of reference for pixel size to estimate the distance between the Agras and the leading edge of the blackbird flock at the moment flight occurred.

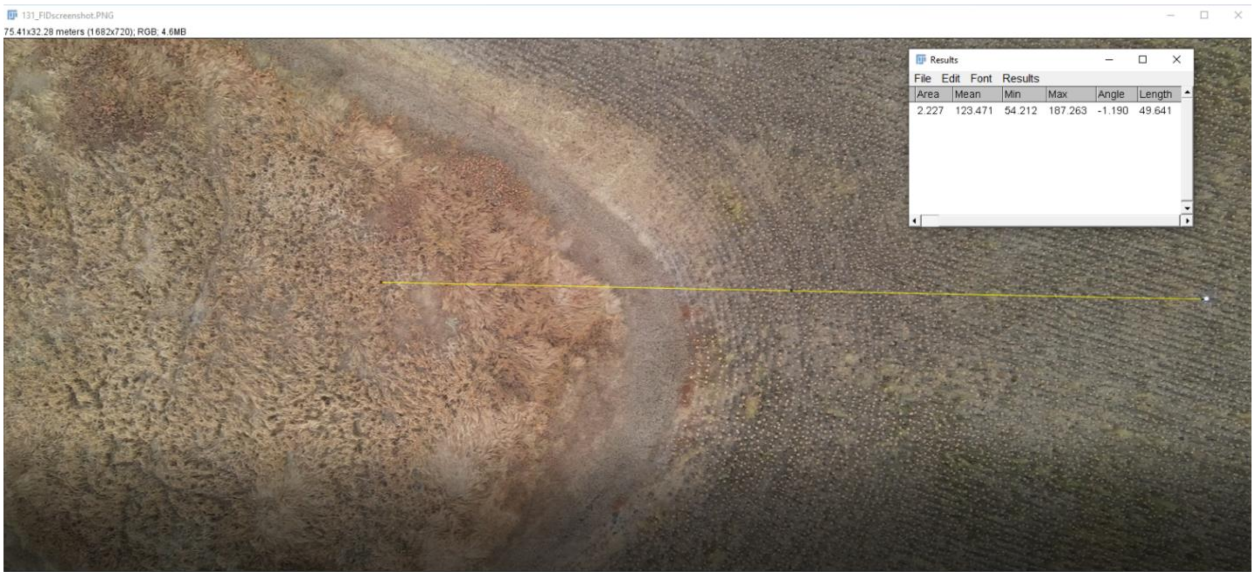


Figure 3.3. A screenshot from ImageJ showing the measured distance (yellow line = 49.6 m) between the DJI Agras MG-1P and a single bird at the leading edge of the blackbird flock located in a cattail marsh at the moment an escape response was elicited, also known as flight initiation distance (FID). The view of the sunflower field was captured from 80 m above ground level (AGL) by the DJI Mavic Air 2 (field of view = 75.4 x 32.3 m) in North Dakota, USA in 2020.

Hazing Trials

Hazing trials were bracketed by pre- and post-trial observation periods (15 min each) to assess flock size (number of birds), number of times the flock took flight (tally of lift-offs), and total time flock spent in flight (s) and to evaluate the change post trial. Hazing trials began immediately after the initial approach recorded the FID. As both platforms hovered in place following data collection on FID, we set a stopwatch for 10 min to assure every flock received the same amount of UAS hazing time. We hazed flocks using one of two flight paths including 1) chaotic (fast flight paths cutting through the flock) or 2) herding (flight paths along the outer edge of a flock pushing the flock towards the nearest habitat edge). We considered the hazing attempt successful if an entire flock abandoned the habitat they were occupying for another habitat (i.e., sunflower to any other habitat or cattail to any other habitat). If flocks abandoned the targeted habitat prior to 10 mins, we flew the UAS platforms along the habitat edge where the flock exited until the end of the allotted time.

Statistical Analyses

We used a linear model to evaluate the relationship between FID and a suite of relevant covariates. We considered flock characteristics (i.e., flock size, distance to habitat edge, and location habitat of either cattails or sunflower), environmental conditions (i.e., wind speed, temperature, ambient light intensity, Julian day, time of day, cattail acreage, and sunflower acreage), and UAS characteristics (i.e., flock distance to launch site) per trial as covariates to model FID. FID is known to vary depending on the starting distance (i.e., UAS launch distance from flock) (Blumstein 2003). However, the launching distance was not standardized but treated as a covariate, because the UAS launch sites in relation to the free-ranging flocks varied depended on field logistics (e.g., access to land, location of roads within and around the sunflower fields, topography, and other obstacles).

We used a generalized linear model (GLM) to model the probability of a flock abandoning the hazing location (logit link, binomial distribution, 0 = remained, 1 = abandoned). We did not consider partial abandonment as a success. We considered flock characteristics (i.e., size, pre-trial flight duration, and location habitat of either cattails or sunflower), environmental conditions (i.e., wind speed, temperature, ambient light intensity, Julian day, time of day, cattail acreage, sunflower acreage), and UAS characteristics (i.e., hazing flight path style) per trial as covariates to model the probability of a flock abandoning the initial location habitat.

We used the protocol outlined by Zuur et al. (2010) to apply systematic data exploration and assess model assumptions for the linear and generalized linear models. This process began by assessing collinearity of continuous variables using Pearson correlation coefficients, removing variables with a $|r| \geq 0.6$, and variance inflation factors ≥ 3 (*vif* function; Fox *et al.* 2021). Due to the exploratory nature of this analysis, we selected optimal models by dropping individual explanatory variables one-by-one using a stepwise backwards selection based on Akaike's information criterion (AIC) (Table 3.1) (Zuur *et al.* 2009). We evaluated the optimal model by ΔAIC comparison, and selected the model with a score of 0.00. Then we applied model validation as outlined by Zuur et al. (2010) and evaluated each optimal model to determine the effect of each variable (Table 3.2). We used Cook's distance to identify overly influential observations but did not find any instances where Cook's D score >1 or altered the outcome of our optimal models. Measurements of distance and flock size were log transformed but the results did not differ from non-transformed data, so we only reported untransformed results. Finally, we assessed normality and homogeneity by plotting the residuals vs. fitted models. We conducted all statistical analyses using RStudio software, version 4.1.0, (RStudio Team 2020).

To evaluate any changes to flock size, proportion of time flock spent in flight (s), and number of flock lift-offs (tally count) we used a nonparametric Wilcoxon signed-rank test to compare flock behavior from the 15-min pre- and post-hazing trial observation period.

Results

We conducted 35 FID trials in 2019 and 60 trials in 2020. Only 62 trials (2019 = 21, 2020 = 41) had FID captured on video from the eye-in-the-sky drone due to misses stemming from pilot coordination. The average FID for all viable trials was 39.9 m (± 14.3 m). There was no statistical difference ($t_{60} = 0.10$, $p = 0.92$) between FID measurements in 2019 (39.16 = ± 2.23) and 2020 (38.77 = ± 2.52), and thus we combined trials from both years for analysis. We approached 36 flocks located in sunflower and 26 flocks located in cattail adjacent or within the sunflower field. We dropped Julian day from the linear model due to collinearity with temperature resulting in $| r | = 0.6$. No covariates warranted criteria for removal with a VIF ≥ 3. The optimal model for FID included the following explanatory variables: time of day, cattail acreage, estimated flock size, and distance to UAS launch site (Table 3.2, Figure 3.4) after removing covariates where our AIC analysis indicated support for removal (Table 3.1). Parameter estimates indicated that FID was shorter (i.e., drone viewed as less risky) when the UAS was launched further way from large flocks, later in the day, in fields with greater amounts of cattail marsh (Table 3.2, Figure 3.4).

Table 3.1. We applied a backwards selection based on Akaike's information criterion (AIC) to arrive at the optimal linear model and generalized linear model. The parameters are coded as follows: TD (time of day), FS (flock size), W (wind), T (temperature), AL (ambient light), CA (cattail acreage), SA (sunflower acreage), DTL (distance to launch), DTE (distance to edge), H (habitat), JD (Julian day), TFD (total flight duration), and FP (flight path).

Linear Model - FID	**ΔAIC**	***K***
TD + FS + W + T + AL + CA + SA + DTL + DTE + H	8.31	12
TD + FS + W + AL + CA + SA + DTL + DTE + H	6.31	11
TD + FS + AL + CA + SA + DTL + DTE + H	4.48	10
TD + FS + AL + CA + DTL + DTE + H	2.81	9
TD + FS + AL + CA + DTL + DTE	1.83	8
TD + FS + CA + DTL + DTE	0.86	7
TD + FS + CA + DTL	0.00	6
Generalized Linear Model - Hazing	**ΔAIC**	***K***
JD + CA + SA + W + TD + T + FS + TFD + FP + H	7.65	11
CA + SA + W + TD + T + FS + TFD + FP + H	5.71	10
CA + SA + W + TD + T + FS + TFD + H	3.83	9
CA + SA + W + TD + T + FS + H	1.95	8
CA + SA + TD + T + FS + H	1.03	7
SA + TD + T + FS + H	0.90	6
TD + T + FS + H	0.50	5
TD + T + FS	0.00	4

Table 3.2. Parameter estimates with standard errors from A) the optimal linear model for the flight initiation distance (FID) of mixed blackbird flocks approached by a DJI Agras MG-1P in 2019 and 2020 and B) the optimal generalized linear model for probability of field abandonment by mixed blackbird flocks due to hazing by the DJI Agras MG-1P (10 min) in 2020. The study took place in commercial sunflower fields interspersed with cattail marshes in central North Dakota, USA.

Parameter	**Estimate**	**SE**
A) Linear Model		
Time of day	-2.267	0.684
Cattail area (ac)	-0.147	0.099
Flock size	0.004	0.001
Distance to UAS launch (m)	-0.025	0.016
B) Generalized Linear Model		
Time of day	0.558	0.179
Flock size	-0.001	<0.001
Temperature (°C)	-0.098	0.053

We conducted 60 hazing trials in 2020 (chaos = 30 flocks, herding = 30 flocks). We hazed 36 flocks initially located in sunflower and 24 flocks initially located in cattail adjacent or within the sunflower field. Hazing trials resulted in 52% of the flocks abandoning the targeted area at the conclusion of the 10-min hazing trial (n = 31), while 37% of the flocks partially abandoned (n = 22) and 12% remained (n = 7). We dropped ambient light from the GLM due to collinearity with time of day, resulting in $|r| = 0.6$. No covariates warranted criteria for removal with a VIF ≥ 3. The optimal model for field abandonment included the following explanatory variables: time of day, estimated flock size, and ambient temperature (Table 3.2, Figure 3.5) after removing covariates where our AIC analysis indicated support for removal (Table 3.1). The probability of flock abandonment early in the morning was around 15% and increased as the day progressed, while the probability for small flock abandonment started at roughly 70% and decreased as flock size increased. The probability of abandonment started around 76% for very cold temperatures and decrease as the temperature increased (Table 3.2, Figure 3.5).

During the 15-min post-trial observation, 48.3% of the hazed flocks never left the hazed location habitat (n = 29) and 80.6% of the flocks that abandoned during the 10-min hazing trial returned to the hazing location habitat (n = 25). We did see shifts in flock size and behavior after the UAS hazing trials (Figure 3.6). We found an average percent reduction in flock size of 35.6% (341.2 fewer birds ± 101.1) when examining flock size between the pre-trial and post-trial observations ($V = 1{,}081$; $p < 0.001$). We also observed an average 19.4% reduction (18.58 seconds ± 9.7) for the amount of time the flock spent in flight ($V = 1{,}245$; $p = 0.003$) and a 49.7% reduction in the number of flock lift offs (2.1 fewer lift-offs ± 0.40) in the post-trial observation period ($V = 1{,}319$; $p < 0.001$).

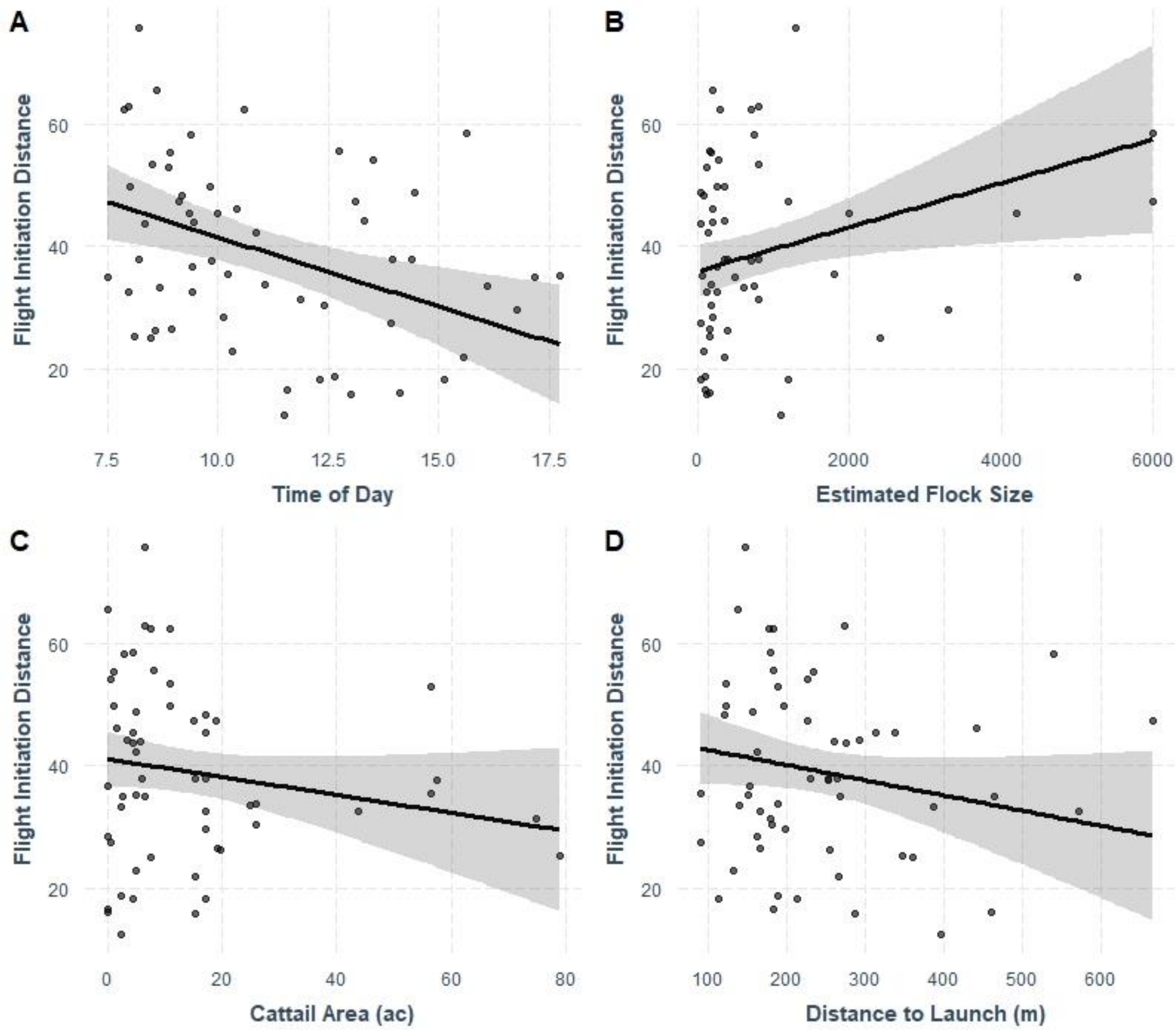


Figure 3.4. Model-based estimates of flight initiation distance of mixed blackbird flocks in response to the approach of the DJI Agras MG-1P spraying drone as a function of: A) time of day, B) flock size, C) cattail acres, and D) distance to UAS launch site. The models are based on FID trials conducted from 4 September to 25 October in 2019 and 2020 in sunflower fields being actively damaged by mixed flocks of blackbirds in North Dakota, USA. We held the other model covariates at mean values. The shaded area on both graphs shows 95% confidence interval.

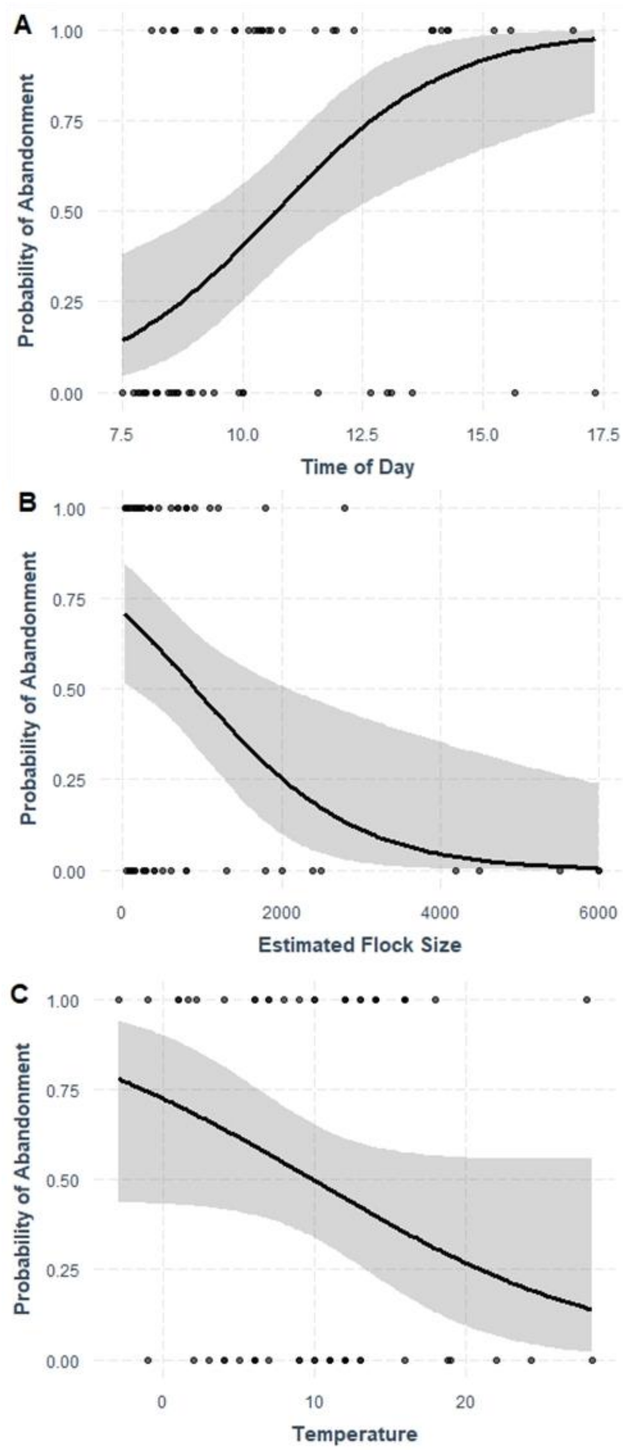


Figure 3.5. The probability of blackbird flocks abandoning the target location (i.e., sunflower or cattails) within commercial sunflower fields after 10 min of continuous hazing by the DJI Agras MG-1P spraying drone as a function of A) time of day, B) flock size, and C) temperature (°C). The models are based on UAS trials conducted from 4 September to 25 October in 2020 in sunflower fields being actively damaged by mixed flocks of blackbirds in North Dakota, USA. We held the other model covariates at mean values. The gray shaded area indicates a 95% confidence interval.

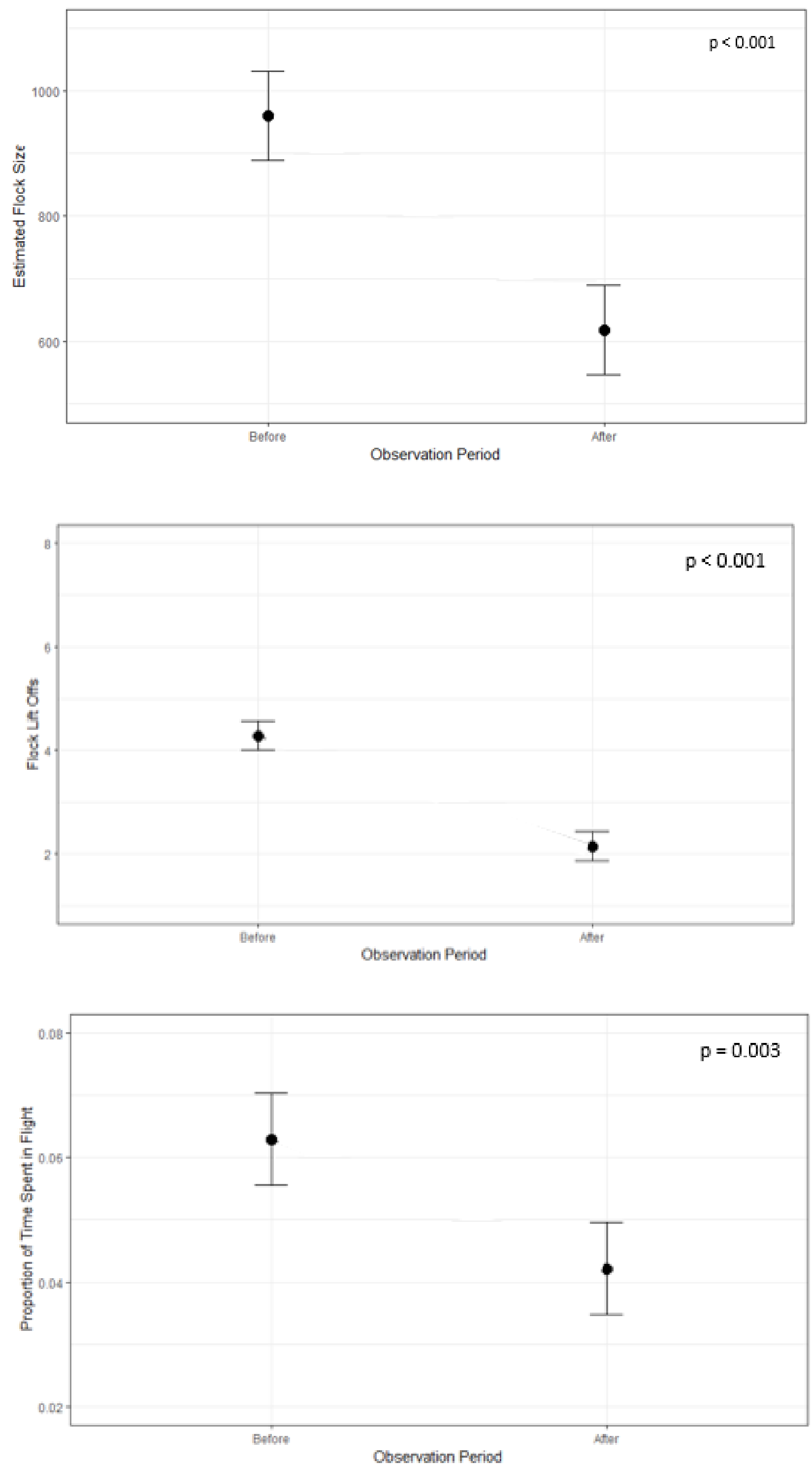


Figure 3.6. A) Estimated flock size, B) proportion of time flock spent in flight, and C) number of flock lift offs before and after 10 min of hazing of blackbird flocks in sunflower-cattail complexes in North Dakota from 4 September to 25 October 2020. Averages and standard error bars shown.

Discussion

We found that both time of day and flock size were important components to blackbird flock perceptions of risk toward UAS approach (FID), as well as their response to 10-min of hazing. Based on FID, the flock perception of risk appeared highest in the morning, but higher probability of abandonment did not occur until later in the day, most likely due to energetic needs being met and birds ready to move to roosting locations. We also saw that larger flocks responded to the approaching UAS sooner (larger FID), but the probability of abandonment was reduced with larger flocks, most likely due to increased vigilance combined with safety in numbers and how birds in large flocks evolved to avoid predation. Overall, 10-min of hazing by a large octocopter resulted in 52% of the flocks abandoning the hazed area; however, within 15 min of the trial concluding 90% of the flocks had returned.

Flight initiation distance in flocks is the direct response of the birds located on the nearest edge of the flock seeking safety and moving towards the center of the flock (Ballerini *et al.* 2008). The collective movement of birds on the outer edge towards the center is an antipredator behavioral strategy that results in murmurations (Sumpter 2010). Estimated flock size influenced flock FID, and larger flocks flushed earlier to the approaching UAS. Our study supports other research indicating that increased flock sizes have an earlier response time, as more eyes are watching for threats, when approached by UAS (Lima and Dill 1990). Flock size is known to have an impact on flock perceptions of safety (Cooper Jr and Blumstein 2015). Although larger flocks may attract more raptors, the likelihood of an individual facing an attack is greatly reduced in a large flock (Cresswell 1994). Our study contained a small sample of large flocks, which caused more spread in our confidence intervals.

Our trials showed that flocks took flight earlier in response to the approaching UAS earlier in the day and FID decreased later in the day. Although the risk of individual predation is reduced in larger flocks, that risk could still be highest at certain times of day when predators are also in search of food (Lima and Dill 1990). We observed blackbird flocks refusing to abandon locations early in the morning, and the probability of abandonment increasing throughout the day. As flocks are feeding for the first time in the early morning and a threat approaches, it creates a critical forging decision: either remain at the valuable food source or leave and travel a good distance to another location with an unknown outcome (Abdulwahab *et al.* 2019). The agricultural landscape of the trials, large monoculture fields, does not provide an abundance of diversity in refugia or alternative food resources, which may have led to decision making that determined the UAS threat was not high enough to entirely abandon (Whittingham and Evans 2004). The probability of abandonment increased later in the afternoon, which is after maximum damage has likely occurred due to seed consumption in the morning feeding window, and birds were most likely already on their way to cattail roosts (Hintz and Dyer 1970). Future UAS research should target flocks in the morning, to determine what methods work to reduce damage during an important feeding window when flocks seem to be committed to the location.

Reduced flock sizes and activity levels of flocks, when comparing pre- and post-trial observations, support that UAS hazing has an immediate short-term impact on behavior. We observed a reduction in flock size and in activity levels of flocks that remained or returned in the 15-min post-trial observation period. Wang *et al.* (2019) also found that flock activity was reduced immediately following UAS hazing of silvereyes (*Zosterops lateralis*) in an Australian vineyard; however, the birds were hunkered down into the vines and not necessarily abandoning the area. Bhusal *et al.* (2018) reported reduced flock sizes due to UAS hazing and increased flock sizes on days where no UAS hazing took place. Reduced activity does not necessarily mean that the birds are not present in the hazing area during the observation period, but instead they are likely less mobile immediately after UAS hazing. Thus, a reduction in activity does not necessarily correlate to a reduction in crop damage. Depending on the crop, the disturbance of a flock could cause them to target different plants within a field, creating more damage in return. For example, damage to individual sweet corn kernels impacts the sale of the whole cob and a hazing strategy that not only limits damage but limits the number of plants impacted would be necessary to have any real impact on overall damage mitigation (Carlson *et al.* 2013). Comparing flock activity level (time spent in flight and flock lift-offs) to a natural study, evaluating flock behavior after a predator attack, would be beneficial for a foundational understanding of UAS impact on behavior; however, that research has not been done yet.

We did not find that the environmental variables of wind speed, ambient light, or Julian day had any impact on flock behavioral responses. While ambient light may be important for first detecting a threat, it may become less important when that threat is sustained. The UAS was not flown in wind speeds higher than 7 m/s, which is why we may not have observed an effect on UAS speed or experienced wind speed that would have impeded flock movements. Julian day is likely not as impactful because of extreme climatological variation in the northern Great Plains during the damage window when trials took place and direct measurements of climatological variables would be more informative.

Habitat can also have an impact on birds alerting to predators (Devereux *et al.* 2008), and the structure of sunflowers, with dense leaf vegetation, could both provide refuge and delay individual blackbird reactions. We were unsure about the impact of hazing location habitat and distance to edge on FID and abandonment, but we found that it had no discernable impact on the responses of blackbird flocks. FID studies have often looked at responses in open areas and distance to refugia habitat, like nearby trees (Cooper Jr and Blumstein 2015). The complex structure of both cattails and sunflower, providing ample opportunity to hide within both foraging or loafing areas, could be why we saw no influence of distance to edge or habitat on perceptions of risk (Rodriguez-Prieto *et al.* 2008). However, the heterogeneity of a sunflower field with greater amounts of cattail within and around it could be perceived as less risky, as shown in our optimal model for FID, compared to a field with less alternative habitat (Whittingham and Evans 2004).

Overall, 10-min of UAS hazing in large sunflower fields was likely not sufficient to reduce crop damage and future research should evaluate the degree of continual hazing that is needed within a field to reduce bird damage. Smaller flocks are easier to move from a sunflower field, which is important for hazing early in the season prior to large flocks forming. Thus, early season hazing prior to sunflower maturity may be beneficial to prevent the establishment of foraging locations (Besser *et al.* 1979). Future research should evaluate a consistent hazing approach: increasing frequency of hazing to targeted fields over an entire season or the addition of a negative stimulus, such as an avian repellent. Simultaneous damage estimates would benefit UAS hazing trials, as direct comparisons of efficacy would be possible. There is promise for the use of UAS hazing in large-scale agriculture, and additional research can use this study for a foundational understanding of blackbird flock behavioral responses.

Acknowledgements

The United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center (USDA-APHIS-WS-NWRC; 7438-0020-CA; QA-3108) and The National Sunflower Association (Project #20-P03) funded this research. The North Dakota State University, Institutional Animal Care and Use Committee (IACUC) approved data collection protocols for this project (Protocol #A20011). We thank A. Schumacher, I. Carbajal, J. Duttenhefner, B. Clark, and M. Donaldson for fieldwork and assistance in data collection. We sincerely thank all the farmers that gave us access to their commercial sunflower fields. Any use of trade, firm, or product names is for descriptive purpose only and does not imply endorsement by the U.S. Government. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the US Government.

References

Abdulwahab UA, Osinubi ST, and Abalaka J (2019) Risk of predation: A critical force driving habitat quality perception and foraging behavior of granivorous birds in a nigerian forest reserve. *Avian Research* **10**, 33. doi: 10.1186/s40657-019-0173-6.

Ampatzidis Y, Ward J, and Samara O (2015) Autonomous system for pest bird control in specialty crops using unmanned aerial vehicles. 2015 ASABE Annual International Meeting, New Orleans, LA, USA.

Ballerini M, Cabibbo N, Candelier R, Cavagna A, Cisbani E, Giardina I, Orlandi A, Parisi G, Procaccini A, Viale M, and Zdravkovic V (2008) Empirical investigation of starling flocks: A benchmark study in collective animal behaviour. *Animal Behaviour* **76**, 201-215. doi: https://doi.org/10.1016/j.anbehav.2008.02.004.

Bansal S, Lishawa SC, Newman S, Tangen BA, Wilcox D, Albert D, Anteau MJ, Chimney MJ, Cressey RL, DeKeyser E, Elgersma KJ, Finkelstein SA, Freeland J, Grosshans R, Klug PE, Larkin DJ, Lawrence BA, Linz G, Marburger J, Noe G, Otto C, Reo N, Richards J, Richardson C, Rodgers L, Schrank AJ, Svedarsky D, Travis S, Tuchman N, and

Windham-Myers L (2019) *Typha* (cattail) invasion in North American wetlands: Biology, regional problems, impacts, ecosystem services, and management. *Wetlands* **39**, 645-684. doi: 10.1007/s13157-019-01174-7.

Besser JF, Berg WJ, and Knittle CE (1979) Late-summer feeding patterns of red-winged blackbirds in a sunflower-growing area of North Dakota. Bird Control Seminars Proceedings, pp. 27.

Bhusal S, Khanal K, Karkee M, Steensma KM, and Taylor ME (2018) Unmanned aerial systems (UAS) for mitigating bird damage in wine grapes. Proceedings of the 14th International Conference on Precision Agriculture Monticello, IL: International Society of Precision Agriculture, Montreal, Quebec, Canada.

Blumstein DT (2003) Flight-initiation distance in birds is dependent on intruder starting distance. *Journal of Wildlife Management* **67**, 852-857.

Carlson JC, Tupper SK, Werner SJ, Pettit SE, Santer MM, and Linz GM (2013) Laboratory efficacy of an anthraquinone-based repellent for reducing bird damage to ripening corn. *Applied Animal Behaviour Science* **145**, 26-31. doi: 10.1016/j.applanim.2013.01.011.

Clark BA, Klug PE, Stepanian PM, and Kelly JF (2021) Using bioenergetics and radar-derived bird abundance to assess the impact of a blackbird roost on seasonal sunflower damage. *Human-Wildlife Interactions* **14**, 427-441. doi: https://doi.org/10.26077/9c95-48eb.

Conover MR (2002) 'Resolving human-wildlife conflicts: The science of wildlife damage management.' (CRC press: Boca Raton, FL, USA)

Cooper WE, Jr and Blumstein DT (2015) 'Escaping from predators: An integrative view of escape decisions.' (Cambridge University Press: Cambridge, United Kingdom)

Cresswell W (1994) Flocking is an effective anti-predation strategy in redshanks, tringa totanus. *Animal Behaviour* **47**, 433-442. doi: https://doi.org/10.1006/anbe.1994.1057.

Devereux CL, Fernández-Juricic E, Krebs JR, and Whittingham MJ (2008) Habitat affects escape behaviour and alarm calling in common starlings (*Sturnus vulgaris*). *Ibis* **150**, 191-198.

Dolbeer R (1990) Ornithology and integrated pest management: Red-winged blackbirds *Agelaius phoeniceus* and corn. *Ibis* **132**, 309-322.

Dolbeer RA and Linz GM (2016) Blackbirds. In 'Wildlife damage management technical series': U.S. Department of Agriculture, Animal & Plant Health Inspection Service, Wildlife Services, Fort Collin, Colorado, USA).

Egan C (2018) Testing a key assumption of wildlife-drone interactions: Do animals perceive drones as low-disturbance flying objects? MS Thesis, Environmental and Conservation Sciences (Biological Sciences), North Dakota State University, Fargo, ND, USA.

Egan CC, Blackwell BF, Fernández-Juricic E, and Klug PE (2020) Testing a key assumption of using drones as frightening devices: Do birds perceive wildlife-monitoring drones as risky? *Condor* **122**, 1-15.

Ernst K, Elser J, Linz G, Kandel H, Holderieath J, DeGroot S, Shwiff S, and Shwiff S (2019) The economic impacts of blackbird (Icteridae) damage to sunflower in the USA. *Pest Management Science* **75**, 2910-2915. doi: 10.1002/ps.5486.

Fernández-Juricic E, Jimenez M, and Lucas E (2002) Factors affecting intra-and inter-specific variations in the difference between alert distances and flight distances for birds in forested habitats. *Canadian Journal of Zoology* **80**, 1212-1220.

Fernández-Juricic E, Deisher M, Stark AC, and Randolet J (2012) Predator detection is limited in microhabitats with high light intensity: An experiment with brown-headed cowbirds. *Ethology* **118**, 341-350.

Forcey GM, Thogmartin WE, Linz GM, Mckann PC, and Crimmins SM (2015) Spatially explicit modeling of blackbird abundance in the Prairie Pothole Region. *Journal of Wildlife Management* **79**, 1022-1033.

Fox J, Weisberg S, Adler D, Bates D, Baud-Bovy G, and Ellison S, et al. (2021) Package 'car'. https://cran.r-project.org/web/ packages/car/index.html.

Hintz JV and Dyer M (1970) Daily rhythm and seasonal change in the summer diet of adult red-winged blackbirds. *Journal of Wildlife Management* **34**, 789-799.

Homan H, Slowik A, and Linz G (2005) Fall dispersal patterns of red-winged blackbirds (*Agelaius phoeniceus*) migrating from the Prairie Pothole Region of North Dakota. *Final Report: North Dakota Crop Protection Product Harmonization and Registration Board (Agreement No. 04-73-38-5502-TF)*.

Klosterman ME, Linz GM, Slowik AA, and Homan HJ (2013) Comparisons between blackbird damage to corn and sunflower in North Dakota. *Crop Protection* **53**, 1-5.

Klug PE (2017) The future of blackbird management research. In 'Ecology and management of blackbirds (Icteridae) in North America'. (Eds. GM Linz, ML Avery, and RA Dolbeer) pp. 217-234. (CRC Press/Taylor & Francis: Boca Raton, FL, USA)

Laursen K, Kahlert J, and Frikke J (2005) Factors affecting escape distances of staging waterbirds. *Wildlife Biology* **11**, 13-19.

Lima S and Dill L (1990) Behavioral decisions made under the risk of predation: A review and prospectus. *Canadian Journal of Zoology* **68**, 619-640. doi: 10.1139/z90-092.

Linz GM, Avery ML, and Dolbeer RA (2017) 'Ecology and management of blackbirds (Icteridae) in North America.' (CRC Press/Taylor & Francis: Boca Raton, FL, USA)

Linz GM and Hanzel J (1997) Birds and sunflower. *Sunflower Technology and Production*, Monograph, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI, USA, pp. 381-394.

Linz GM, Sawin RS, Lutman MW, Homan HJ, Penry LB, and Bleier WJ (2003) Characteristics of spring and fall blackbird roosts in the northern Great Plains. (Ed. KA Fagerstone and GW Witmer). Proceedings of the 10th Wildlife Damage Management Conference, pp. 242.

Mohamed WMW, Naim MNM, and Abdullah A (2020) The efficacy of visual and auditory bird scaring techniques using drone at paddy fields. IOP Conference Series: Materials Science and Engineering. IOP Publishing, p. 012072.

Paranjape AA, Chung S-J, Kim K, and Shim DH (2018) Robotic herding of a flock of birds using an unmanned aerial vehicle. *IEEE Transactions on Robotics*, **34**, 1-15.

Rhoades CA, Allen PJ, and King DT (2019) Using unmanned aerial vehicles for bird harassment on fish ponds. In: Armstrong, J.B., Gallagher, G.R. (Eds.), Proceedings of the 18th Wildlife Damage Management Conference, pp. 13-23.

Rodriguez-Prieto I, Fernández-Juricic E, and Martín J (2008) To run or to fly: Low cost versus low risk escape strategies in blackbirds. *Behaviour*, **145**, 1125-1138.

Rosenberg KV, Dokter AM, Blancher PJ, Sauer JR, Smith AC, Smith PA, Stanton JC, Panjabi A, Helft L, Parr M, and Marra PP (2019) Decline of the North American avifauna. *Science* **366**, 120-124. doi: 10.1126/science.aaw1313.

Sauer JR, Niven DK, Hines JE, Ziolkowski DJJ, Pardieck KL, Fallon JE, and Link WA (2017) The North American breeding bird survey, results and analysis 1966-2015. (Ed. PWRC USGS): Laurel, MD, USA)

Sausse C, Baux A, Bertrand M, Bonnaud E, Canavelli S, Destrez A, Klug PE, Olivera L, Rodriguez E, Tellechea G, and Zuil S (2021) Contemporary challenges and opportunities for the management of bird damage at field crop establishment. *Crop Protection* **148**, 105736. doi: https://doi.org/10.1016/j.cropro.2021.105736.

Schneider CA, Rasband WS, and Eliceiri KW (2012) NIH image to ImageJ: 25 years of image analysis. *Nature Methods* **9**, 671-675.

Shwiff SA, Ernest KL, Degroot SL, Anderson AM, and Shwiff SS (2017) The economic impact of blackbird damage to crops. In 'Ecology and management of blackbirds (Icteridae) in North America'. (Eds. GM Linz, ML Avery, and RA Dolbeer) pp. 207-216. (CRC Press/Taylor & Francis: Boca Raton, FL, USA)

Sumpter DJ (2010) 'Collective animal behavior.' (Princeton University Press, Princeton, NJ, USA)

Vas E, Lescroël A, Duriez O, Boguszewski G, and Grémillet D (2015) Approaching birds with drones: First experiments and ethical guidelines. *Biology Letters* **11**, 20140754.

Wandrie LJ, Klug PE, and Clark ME (2019) Evaluation of two unmanned aircraft systems as tools for protecting crops from blackbird damage. *Crop Protection* **117**, 15-19.

Wang Z, Fahey D, Lucas A, Griffin AS, Chamitoff G, and Wong KC (2020) Bird damage management in vineyards: Comparing efficacy of a bird psychology-incorporated unmanned aerial vehicle system with netting and visual scaring. *Crop Protection* **137**, 105260. doi: https://doi.org/10.1016/j.cropro.2020.105260.

Wang Z, Griffin AS, Lucas A, and Wong K (2019) Psychological warfare in vineyard: Using drones and bird psychology to control bird damage to wine grapes. *Crop Protection* **120**, 163-170.

Whittingham MJ and Evans KL (2004) The effects of habitat structure on predation risk of birds in agricultural landscapes. *Ibis* **146**, 210-220.

Zuur A, Ieno EN, Walker N, Saveliev AA, and Smith GM (2009) 'Mixed effects models and extensions in ecology with R.' (Springer Science+Business Media, New York, NY, USA).

CHAPTER 4: FUTURE DIRECTIONS

The research done in these two studies supports the need for human-wildlife conflict tool evaluation to include social and biological components. By doing this we found that sunflower farmers are very willing to try a novel mitigation tool, like UAS, however many comments were written in saying "if effective" or "I'll try anything as long as it works!" The field study gave foundational information for the future research and development of UAS as a hazing tool for avian-agriculture conflict; however, an increased negative association with UAS is necessary to elicit long-term behavioral changes.

A few options for increasing the efficacy of UAS hazing in large-scale, large flock avian-agriculture scenarios could be increasing the frequency of hazing, applying an avian repellent from the UAS, or identifying and hazing large roosting sites. While this field study (Chapter 3) focused on independent flock responses to 10 min of hazing, future research should focus on daily hazing from the start of the damage window until harvest. Repeated hazing efforts may yield increased flock abandonment responses or reductions in flock sizes over time (Bhusal *et al.* 2018). To evaluate the impact UAS hazing has on actual bird damage rates, we suggest completing in-field damage estimates throughout that same time period (Klosterman *et al.* 2013). The DJI Agras MG-1P is already outfitted with a 2L tank and 4 drop nozzles for liquid applications and should be evaluated for flock responses to avian repellent, flown manually from what has been researched in theory for automation (Ampatzidis *et al.* 2015). Lastly, future work could evaluate UAS hazing at different times and locations. Hazing male red-winged blackbirds when they are establishing breeding sites in cattails within or adjacent to sunflower fields, in an attempt to discourage territory establishment in those areas. Hazing post-breeding when young of the year and adults are selecting cattail marshes for roosting, to limit flocks accumulation near sunflower fields. Hazing fall roosting locations morning and night when large migrating mixed-species flocks are coming together.

Finding an effective tool at the field scale and addressing the need for real-time solutions for farmers will most likely require the incorporation of multiple tools or methods. There is no proverbial "silver bullet" in the field of human-wildlife conflict. However, we can be working towards effective communication and bridging the gap between research and field application. One of my favorite quotes to encompass this need for multi-faceted approaches to avian-agriculture conflicts is, "Biological science alone does not provide a complete understanding of, or solutions to the conflict" (Madden 2004).

Farmers obtain information in a different way than researchers, often relying on extension agents or agriculture related media sources (Maas *et al.* 2021). In order to reach sunflower farmers and disseminate novel UAS research or other methods to mitigate blackbird damage, we recommend hosting workshops alongside extension, seed supplier programs, or trade shows. Meeting the farmer at a location or event they already attend, in an environment they feel comfortable in, could increase the likelihood of more farmers incorporating damage management tools and methods into their farming practices. It could also increase exposure for resources that they have within the state, such as USDA-APHIS-Wildlife Services or involvement in university studies. Identifying certain characteristics of farmers that may be more willing to adopt a novel tool earlier could lead to a diffusion of information within a farming community. That is, if community leaders or early adopters are targeted they will share effective tools with others allowing use of the method to spread (Adrian *et al.* 2005).

Moving forward, a structured decision-making workshop between relevant stakeholder groups to evaluate the opportunity for cattail management to occur on a large scale could be beneficial. Cattail management is not an easy feat, especially within a landscape like the Prairie Pothole Region, but new technology is being developed to make use of harvested cattail (Svedarsky *et al.* 2019). Identifying obtainable management goals, across a variety of landholdings (e.g., state, federal, private, non-profit owned and operated land) would require a process that evaluates adaptable decision-making (Gregory *et al.* 2012). Cattail management ranked as the most effective blackbird management method, and it was the most frequently talked about when interacting with farmers, but the method remains elusive without collaborative action.

Understanding the impact blackbird damage has had on previous sunflower growers, meaning those who removed sunflower from their rotation due to blackbirds, should be a priority for future research. While our research focused on farmers who currently grow sunflower, many questionnaire respondents indicated they were no longer planting and specifically cited blackbirds as the reason. An evaluation of farming opportunity lost over time could predict future shifts in sunflower production levels in the Dakotas if blackbird issues were to remain the same or increase. Social evaluations of complex avian-agriculture conflicts are crucial for the development of novel mitigation methods, and the information gleaned from them can drive future research.

References

Adrian AM, Norwood SH, and Mask PL (2005) Producers' perceptions and attitudes toward precision agriculture technologies. *Computers and Electronics in Agriculture* **48**(3), 256-271. doi: https://doi.org/https://doi.org/10.1016/j.compag.2005.04.004.

Ampatzidis Y, Ward J, and Samara O (2015) Autonomous system for pest bird control in specialty crops using unmanned aerial vehicles. 2015 ASABE Annual International Meeting, New Orleans, LA, USA.

Bhusal S, Khanal K, Karkee M, Steensma KM, and Taylor ME (2018) Unmanned aerial systems (UAS) for mitigating bird damage in wine grapes. Proceedings of the 14th International Conference on Precision Agriculture Monticello, IL: International Society of Precision Agriculture, Montreal, Quebec, Canada.

Gregory R, Failing L, Harstone M, Long G, McDaniels T, and Ohlson D (2012) *Structured decision making: a practical guide to environmental management choices*. John Wiley & Sons, Incorporated, Hoboken, NJ, USA.

Klosterman ME, Linz GM, Slowik AA, and Homan HJ (2013) Comparisons between blackbird damage to corn and sunflower in North Dakota. *Crop Protection* **53**, 1-5.

Maas B, Fabian Y, Kross SM, and Richter A (2021) Divergent farmer and scientist perceptions of agricultural biodiversity, ecosystem services and decision-making. *Biological Conservation* **256**, 109065. doi: https://doi.org/https://doi.org/10.1016/j.biocon.2021.109065.

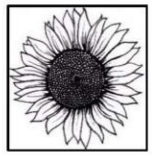
Madden F (2004) Creating coexistence between humans and wildlife: Global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife* **9**(4), 247-257. doi: https://doi.org/10.1080/10871200490505675.

Svedarsky D, Grosshans R, Venema H, Ellis-Felege S., Bruggman J, Ostlund A, and Lewis J (2019) Integrated management of invasive cattails (typha spp.) for wetland habitat and biofuel in the northern great plains of the united states and canada: A review. *Mires and Peat* **25**, 1-14.

APPENDIX: COVER LETTER AND QUESTIONNAIRE

Bird Damage to Sunflower Crops

A Survey of Sunflower Producers



Research conducted by:

North Dakota State University, Department of Biological Sciences

North Dakota State University and the National Sunflower Association appreciates you taking the time to fill out the following survey regarding bird damage to sunflower. Your responses will help us to understand the nature of the issue, economic impacts, and efficacy of current management techniques. We intend to use your feedback to direct future research addressing bird damage and improve sunflower production. Even if you do not experience bird damage, it is still crucial for us to hear from you.

The following survey will require approximately 15 minutes to complete. Please return your completed survey in the enclosed pre-paid envelope at your earliest convenience. Alternatively, you could complete an online version of the survey using the link or scanning the QR code below. Your participation is voluntary, and all responses are kept strictly confidential. You may decline to participate or leave blank any questions you do not wish to answer.

We sincerely thank you for taking the time out of your busy schedule to respond! Your input and involvement in this survey is incredibly valuable. In sharing your farming knowledge and expertise, you are contributing essential information for developing methods to combat bird damage.

If you are interested in participating in future sunflower/blackbird research, would like a summary of our findings, or if you have any questions or concerns, please contact us:

Morgan Donaldson
Graduate Researcher
morgan.donaldson@ndsu.edu

Mallory Gyovai White
Graduate Researcher
mallory.g.white@ndsu.edu

Page Klug
Faculty Advisor
page.klug@ndsu.edu
(701-630-3776)

North Dakota State University
Department of Biological Sciences
P.O. Box 6050, Department 2715
Fargo, ND 58102

Use the link or scan the QR code to access the online survey:
https://ndstate.co1.qualtrics.com/jfe/form/SV_1UoXI3SKIKGW8PH

Thank you for your help with this important study!

Your Farm and Farming Experience

1. Did you grow a sunflower crop on your farm in 2020? ☐ Yes ☐ No

   If no, what was the last year you planted a sunflower crop? ______________

2. Where was the majority of your sunflower crop planted in 2020?

   State(s): ________ County(s): ____________________ Zip Code(s): ____________

3. Provide your 2020 planting practices for each crop (Fill in the table below for the crops you produce. Write "0" in the Seeding Rate column if you do not grow that crop):

Crop	Seeding Rate (plants per acre)	Solid Seeded	Row	Row Spacing	Organic (mark if yes)
Confection	________	☐	☐	_____ in.	☐
Oilseed	________	☐	☐	_____ in.	☐
Conoil	________	☐	☐	_____ in.	☐

4. What other crops did you plant in 2020? (Mark all that apply.)

   ☐ Corn ☐ Soybean ☐ Small Grain ☐ Pulses ☐ Hay ☐ Other: _____________

5. How often do you grow at least one field with a sunflower crop?

   ☐ Annually ☐ Occasionally ☐ Rarely ☐ Never

6. Do you grow organic sunflower? ☐ No ☐ Yes, some ☐ Yes, all

7. What are your most important reasons for reducing or not planting sunflower in a given year? Rank (1 to 5) the following in order of importance (1 is most important, 5 is least important).

Blackbird Damage	Disease	Insects	Market Price	Weather
_____	_____	_____	_____	_____

8. Based on your 2020 growing season, please provide acreage and approximate damage by birds for each crop (Fill in the table below for the crops you produce. Write "0" in the acreage column if you do not grow that crop):

Crop	Acreage	Yield in 2020	% Yield Lost to Bird Damage	Approximate Date Planting Started	Approximate Date Harvesting Started
Confection	_______	_______ lbs/ac	_______	_________	_________
Oilseed	_______	_______ lbs/ac	_______	_________	_________
Conoil	_______	_______ lbs/ac	_______	_________	_________
Corn	_______	_______ bu/ac	_______	_________	_________

9. How did you arrive at % bird damage estimate in Question 8? (Mark all that apply.)

   ☐ Visual ☐ Combine (Yield Monitor) ☐ Expected Yield vs. Actual Yield ☐ Other: _______

10. Over the last 5 years, what is the average % yield lost to bird damage? __________%

11. Would you plant more sunflower acres if blackbird damage was not a concern? ☐ Yes ☐ No

    If yes, how many more acres would you plant in a given year? __________ ac

12. Did you reduce sunflower acreage in 2020 due to previous blackbird damage? ☐ Yes ☐ No

    If yes, list the crop and acreage planted instead:

    1. ____________ / ______ ac   3. ____________ / ______ ac

    2. ____________ / ______ ac   4. ____________ / ______ ac

13. What is your estimated cost of controlling bird damage to sunflower in 2020?
    Write "0" if you spent no money trying to control bird damage in 2020. $__________

14. Did you observe blackbird flocks in your sunflower in 2020? ☐ Yes ☐ No

    If yes, how many blackbirds would you estimate were in the largest flock observed?
    ☐ Less than 10,000 ☐ 10,000 – 100,000 ☐ More than 100,000

15. In your experience, what landscape features increase bird damage to sunflower? Rank (1-6) the following in order of importance (1 is most important, 6 is least important).

Wetlands	Trees	Power lines	Manmade structures	Adjacent corn	Adjacent sunflower
____	____	____	____	____	____

16. In your experience, what weather conditions increase bird damage to sunflower? Rank (1-4) the following in order of importance (1 is most important, 4 is least important).

Wet years	Dry years	Cool years	Hot years
____	____	____	____

Your Opinion on Blackbirds and Blackbird Damage

17. What are your general feelings toward blackbirds in/around the land that you farm?

    ☐ I have no particular feelings towards blackbirds
    ☐ I enjoy blackbirds AND I do not worry about the problems they may cause
    ☐ I enjoy blackbirds BUT I worry about the problems they may cause
    ☐ I do not enjoy blackbirds and regard them as a pest

18. Which statement best describes the current impact of blackbird damage to your sunflower production profits?

    ☐ Blackbird damage has little or no influence on profits in a given year
    ☐ Blackbird damage is one of several significant factors affecting profits in a given year
    ☐ Blackbird damage is the most significant factor affecting profits in a given year

19. Which statement best describes your opinion about blackbird damage to sunflower?

    ☐ Blackbird damage has been increasing over the past 5 years
    ☐ Blackbird damage has remained relatively stable over the past 5 years
    ☐ Blackbird damage has been decreasing over the past 5 years

20. Excluding blackbirds, what are your general feelings toward birds in/around the land that you farm?

    ☐ I have no particular feelings towards birds
    ☐ I enjoy birds AND I do not worry about the problems they may cause
    ☐ I enjoy birds BUT I worry about the problems they may cause
    ☐ I do not enjoy birds and regard them as a pest

Your Damage Control Techniques

21. Do you take any action to prevent or reduce bird damage to your crops? ☐ Yes ☐ No

22. Mark if you have used a method and your opinion of overall method effectiveness in sunflower. Please rate your opinion of effectiveness even if you have not used the method:

Method (Mark all that you have used)	**Not at all effective**	**Slightly effective**	**Moderately effective**	**Very effective**	**No opinion**
☐ **Crop Desiccation**	☐	☐	☐	☐	☐
☐ **Decoy Crops**	☐	☐	☐	☐	☐
☐ **Planting at Same Time as Neighbors**	☐	☐	☐	☐	☐
☐ **Cattail Management**	☐	☐	☐	☐	☐
☐ **Chemical Repellents (Avian Control)**	☐	☐	☐	☐	☐
☐ **Lethal Shooting (Shotgun)**	☐	☐	☐	☐	☐
☐ **Non-lethal Shooting (Rifle)**	☐	☐	☐	☐	☐
☐ **Propane Cannons**	☐	☐	☐	☐	☐
☐ **Pyrotechnics**	☐	☐	☐	☐	☐
☐ **Acoustics (Distress & Predator Calls)**	☐	☐	☐	☐	☐
☐ **Unmanned Aircraft Systems (Drones)**	☐	☐	☐	☐	☐
☐ **Other:** ________________________	☐	☐	☐	☐	☐

23. How do you determine effectiveness of a bird damage control method or tool? Rank (1-3) the following in order of importance (1 is most important, 3 is least important).

__ Visual reduction in the number of blackbirds in or around your crop

__ Increase in crop yield after the tool or method is implemented

__ The amount of time and effort taken to implement the tool

24. In your experience, what is the most important factor to consider when implementing bird damage control methods or tools? (Select one)

☐ Cost ☐ Labor Intensity ☐ Effectiveness ☐ Ease of use

25. What is your estimated annual cost ($) of controlling bird damage to sunflower? Write "0" if you spend no money trying to control bird damage. $______________

26. What is the most you are willing to spend ($) annually to control bird damage to sunflower? Write "0" if you are not willing to spend any money trying to control bird damage. $ ________

27. How often do you contact USDA Wildlife Services for assistance with blackbird damage?

☐ Every year ☐ Years I plant sunflower ☐ Years with severe damage ☐ Never

28. If you have ever contacted USDA Wildlife Services, how do you rate (1-5) your overall satisfaction with their customer service? (1 is "highly satisfied", 5 is "highly unsatisfied") ______

29. How could USDA Wildlife Services improve? ____

____

____

30. Has an Unmanned Aircraft System (drone) ever been flown on your property? ☐ Yes ☐ No

31. How willing are you to allow drone operations on <u>your property</u>? Mark one box per question.

Questions	Not Willing	Less Willing	Neutral	More Willing	Very Willing
How willing would you be to allow drones on your property to haze blackbird flocks?	☐	☐	☐	☐	☐
How willing would you be to allow a drone that applies a registered pesticide (example: Avian Control)?	☐	☐	☐	☐	☐
How willing would you be to operate a drone that applies a registered pesticide (requires obtaining FAA pt. 137 Agriculture Operations license)?	☐	☐	☐	☐	☐
How willing would you be to hire a licensed aerial applicator to operate a drone that applies a registered pesticide?	☐	☐	☐	☐	☐

Do you have any additional comments/ideas that you would like to share?

____

____

____

Additional Questions

32. What generation of farmer would you describe yourself as:

☐ 1st generation ☐ 2nd generation ☐ 3rd generation ☐ 4th generation or more

33. Is farming your primary occupation? ☐ Yes ☐ No

34. How many years have you been farming? ______________

How many of those years have you had a sunflower crop? __________________

35. Gender: ☐ Male ☐ Female ☐ Other: _____________

36. Age: _________

37. Highest level of education completed: ☐ High School ☐ College ☐ Graduate School