Human–Wildlife Interactions 16(3):Early Online, Winter 2022 • digitalcommons.usu.edu/hwi

Cultivation of industrial hemp on and near airports: implications for wildlife use and risk to aviation safety

Bradley F. Blackwell, USDA/APHIS Wildlife Services, National Wildlife Research Center, Ohio Field Station, 6100 Columbus Avenue, Sandusky, OH 44870, USA *bradley.f.blackwell@usda.gov*

Page E. Klug, USDA/APHIS Wildlife Services, National Wildlife Research Center, North Dakota Field Station, North Dakota State University, Department of Biological Sciences, 1340 Bolley Drive, Fargo, ND 58102, USA

Lee A. Humberg, USDA/APHIS Wildlife Services, Purdue University, Smith Hall, 901 W. State Street, West Lafayette, IN 47907, USA

Zachary T. Brym, University of Florida, Tropical Research and Education Center, 18905 SW 280 St., Homestead, FL 33031, USA

Bryan M. Kluever, USDA/APHIS Wildlife Services, National Wildlife Research Center, Florida Field Station, 2820 E. University Ave., Gainesville, FL 32641, USA

Jenna Edwards, USDA/APHIS Wildlife Services, National Wildlife Research Center, 4101 LaPorte Avenue, Fort Collins, CO 80521, USA

Abstract: Land-use planning on and near airports should consider possible revenue from land covers, associated maintenance costs, and potential for land covers to attract vertebrate species recognized as hazardous to aviation safety. The U.S. Federal Aviation Administration has expressed interest in recent attention given to industrial hemp (*Cannabis sativa* L.; hemp) as a revenue-producing land cover that might be cultivated on or near airports. Our purpose was to better understand the potential production value of hemp as well as its possible role in affecting aviation safety if cultivated on or near airports. Our objectives were to: (1) review the literature relative to a historical perspective of hemp cultivation in the United States, projected cultivation practices, and anticipated economic viability, (2) use our review to gather information on vertebrate use of hemp cultivars, and (3) revisit U.S. and international regulations on land covers near airports relative to attraction of species recognized as hazardous to aviation safety. We found, via review of peer-reviewed and gray literature, that hemp holds potential as an emerging crop in the United States, contributing to food, medicine, and biomass-derived products as well as evidence that birds will use, if not depredate, the crop. However, future markets promoting cultivation of hemp remain tentative. Further, there has been no objective quantification of bird and other wildlife use of hemp alone or as a component of a land cover matrix on or near airports and relative to implications for aviation safety. We make recommendations for future research on wildlife use of hemp and metrics necessary to inform aviation safety.

Key words: cannabidiol, *Cannabis sativa*, emerging crop, hemp, land cover, oilseed, wildlife strike hazard, wildlife strike risk

In its simplest perspective, wildlife use of land covers is intrinsically linked to food, water, and shelter required for survival. These 3 categories encompass our understanding of habitat selection, animal movements, population dynamics, and interactions, representing primary foci in some of the earliest syntheses involving wildlife management (Leopold 1933). Animal responses to land cover resources affecting survival, reproduction, and movements are also critical to the management of human–wildlife interactions (Conover 2002). By extension, efforts to understand, manage, and reduce negative wildlife interactions, such as hazards posed to aviation safety, rely on this same logic (DeVault et al. 2013*a*). Importantly, the application of integrated wildlife management methods (Conover 2002) toward mitigating hazards to aviation must also consider practices by multiple landowners and the dynamics of animal movement across the landscape and airspace (Blackwell et al. 2009, DeVault et al. 2013*a*).

From 1990 through 2021, 259,577 wildlife–aircraft collisions (hereafter strikes) were reported to the U.S. Federal Aviation Administration (FAA), of which bird strikes composed >94% of these incidents. These strikes represented >$200 million USD annually in direct and indirect losses to U.S. civil aviation, though these incidents and associated costs are likely underreported (Dolbeer et al. 2022). Wildlife strikes have claimed >301 lives and >298 aircraft (military and civil) since 1988 (Dolbeer et al. 2022). The 2009 emergency, forced landing of US Airways Flight 1549 into the Hudson River is a notable bird strike incident (Marra et al. 2009).

Wildlife strikes often occur near airports in association with approach and departure of aircraft. From 1990 through 2021, 82% of strikes occurred ≤457 m above ground level (AGL; Dolbeer et al. 2022). An aircraft descending on a 3° glideslope is ≤152 m AGL and approximately 3 km from the runway, which illustrates the potential contribution to strike likelihood and, ultimately, risk, by land covers that surround an airport (Flight Safety Foundation 2000, Blackwell et al. 2009). In the context of wildlife strikes, risk is a composite of species- or group-associated strike likelihoods with associated damage, currently quantified as species-specific relative hazard scores (DeVault et al. 2018). Essentially, wildlife using resources across various land covers and, possibly, flying through aircraft approach and departure corridors can pose substantial strike risk to aircraft. As such, land-use planning on and near airports should consider the airport as a component of the landscape and, therefore, that it contributes to and is subject to local- and landscape-scale factors that affect wildlife populations (Blackwell et al. 2009).

Blackwell et al. (2009) reviewed U.S. and international guidance regarding land-use planning on and near airports and encouraged additional research on land uses thought to affect airport operation safety, including agricultural crops (Iglay et al. 2017) and various tillage regimens (e.g., no-till seeding). Martin et al. (2011) suggested that novel changes in land use beyond the airport boundary not only reduce strike risk but include cost-share or other incentives to agricultural producers to convert to nongrain crop types (i.e., potential food resources) within a defined zone around airports (DeVault et al. 2013*a*, *b*). More specifically, Martin et al. (2013) recommended the establishment of land covers that simultaneously: (1) generate revenue rather than consume airport resources, (2) reduce strike risk, (3) reduce carbon footprint of airport operations, and 4) provide an attractive alternative to turfgrasses.

The FAA (2020) recognized a range of land uses considered as hazardous (DeVault et al. 2018) to aviation safety, including agriculture and, particularly, grain crops. Internationally, land uses contributing to wildlife hazards on or near (i.e., within 13 km) airports include agriculture and livestock feedlots (International Civil Aviation Organization [ICAO] 2002), the latter an operation that might also include nearby grain production (DeVault et al. 2009, Iglay et al. 2017). Interestingly, in the most recent estimate, airport properties in the contiguous United States included >330,000 ha of grassland, with mown areas (i.e., a non-revenue producing land cover) constituting 39–50% of airport property (Martin et al. 2011, DeVault et al. 2012). However, over the last decade, research and planners have reexamined the transition of managed grasslands (i.e., generally mown on a regular schedule) on and near airports to alterative, revenue-producing land covers (e.g., native warm season grass mixtures for biofuel or animal forage, solar arrays; Blackwell et al. 2009; Martin et al. 2011; DeVault et al. 2012, 2013*b*; see also FAA 2020). Still, the cautions observed by the FAA and ICAO are not well supported by data.

Changes in land use toward revenue-producing crops might be especially appealing at general aviation (GA) airports (facilities not certificated under 14 Code of Federal Regulations [CFR], Part 139.337, Subpart B - Certification [§§ 139.101 - 139.115]; see Blackwell et al. 2009) that often operate on limited budgets. Per the FAA (2022), "an airport must agree to certain operational and safety standards and provide for such things as firefighting and rescue equipment. These requirements vary depending on the size of the airport and the type of flights available." Intuitively, however, whether certificated or GA airport, balancing benefit:cost of land covers and aviation regulations with effective control and management of wildlife hazards and strike risk entails quantification of the relationship between wildlife and respective land covers as well as airspace use when considering flight patterns of birds across the landscape (DeVault et al. 2012, 2013*b*, 2014; Conkling et al. 2018; Pfeiffer et al. 2018).

An assessment of how a land cover contrib-

Figure 1. Diagram of industrial hemp (*Cannabis sativa* L.) plant, as shown in Tancig et al. (2021; *W. O. Müller, public domain*).

utes to strike risk entails standardized, objective surveys of wildlife use of all land covers on or near the airport, including a reasonable accounting of species use of airspace (e.g., ≤30.5 m; Blackwell et al. 2013). To reduce strike risk, a land cover would impart few resources to wildlife such that use is minimal and the likelihood of strikes and associated damage from species using that land cover is also reduced relative to similar metrics for other, proximate land covers (DeVault et al. 2014, Pfeiffer et al. 2018). To date, however, only DeVault et al. (2014) and Pfeiffer et al. (2018) have produced work that quantified multiple landscape or land cover metrics relative to wildlife strikes.

Given recent efforts to understand how airports and nearby communities might embrace economic opportunity via revenue-generating land covers, but not at the expense of aviation safety, we were asked by the FAA (J. Weller, FAA, personal communication.) to provide guidance on industrial hemp (*Cannabis sativa* L.; hemp; Figure 1) as a land cover on or near airports. Hemp is a crop that has gained attention with its multiple, agricultural commodities (i.e., oilseed, fiber, and cannabidiol [CBD]; Callaway 2004*a*, *b*). Hemp was historically produced for its strong fibers and preceded cotton (*Gossypium* sp.) as a widespread crop in the United States (Callaway 2004*a*).

Under pilot programs initiated in 2014, industrial hemp coverage in the United States went from zero to >36,421 ha by 2018, the greatest hemp coverage since 59,165 ha were planted in 1943 (Mark et al. 2020). The crop is a potential source for a variety of products, yet its cultivation, perhaps including grain yield (Martin et al. 2013), poses questions. For example, we understand little about the potential of the crop and its various cropping systems to serve as attractants to species recognized as hazardous to aviation safety (DeVault et al. 2018). Further, how might arable area and associated edge types influence wildlife use and, subsequently, strike risk?

Our purpose was to better understand hemp as an emerging, revenue-producing crop, but particularly its possible role in affecting aviation safety if cultivated on or near airports. Our objectives were to: (1) review the literature relative to a historical perspective of hemp cultivation in the United States, projected cultivation practices, and anticipated economic viability, (2) use our review to gather information on vertebrate use of hemp cultivars including medicinal, fiber, and oilseed, and (3) revisit U.S. and international regulations on land covers near airports (whether replacing seminatural grasslands or row crops) relative to attraction of species recognized as hazardous to aviation safety.

Methods

We conducted a comprehensive literature review from February through March 2, 2020, to inform our recommendations as to the market potential of hemp on or near airports as well as wildlife use of crop cultivars. Specifically, our efforts were not adherent to a formal systematic-map approach (James et al. 2016) wherein reproducibility of the review process as a method was desirable. Such an approach might be appropriate in the future, but current considerations for hemp cultivation in association with wildlife use and airport properties are relatively recent. Also, given that hemp represents new opportunities for crop-based products (see below), and not simply a historical crop in the United States and other countries, we developed a broad swath of search terms to ensure that we gathered information on wildlife use of the crop, while also gaining perspective on the potential for hemp as a revenue-producing land cover on or near airports.

We developed our search terms (Appendix 1) for use in common, peer-reviewed databases. We searched Scopus, DigiTop (within U.S. Department of Agriculture [USDA]), Google Scholar, and Digital Commons. We also searched government databases and reports via the USDA and Federal Depository Library Program.

Results

Our literature review returned 270 documents comprising books (*n* = 12), conference proceedings (*n* = 13), federal government publications (*n* = 8), peer-reviewed manuscripts (*n* = 145), publications in periodicals (*n* = 42), state government publications (*n* = 8), university publications (*n* = 28), and theses (*n* = 14). We categorized the sources for review of titles, abstracts, introductions, and tables of contents for any information on wildlife use of hemp and information pertinent to informing current market considerations for hemp cultivation. Our use of literature toward an opinion on the market potential of hemp products was subjective; we cite all sources recovered on specific, vertebrate wildlife use of hemp cultivars.

Hemp cultivation

History. Hemp is an annual plant originating from central Asia. The native range spans from South Asia (~20º N′) to Siberia (~50º N′), though the exact boundaries of origin are difficult to define because it was spread across Eurasia by prehistoric humans (Li 1974*a*, *b*; Clarke and Merlin 2013). Cultivated and feral hemp populations can currently be found on all inhabited continents (Clarke and Merlin 2013, Long et al. 2017). The plant is a historically important crop around the world for fiber, grain, and medicinal use (Fike 2016, Williams 2019). The variety known as hemp was introduced to the United States during the colonial era as a source of fiber (Paine 1776, Mosk 1939, Deitch 2003, Deitch and MacDonald 2003; Appendix 2).

Currently, the term hemp applies to *C. sativa* used for grain, fiber, and floral production with plant material containing <0.3% dry weight of delta-9-tetrahydrocannabinol (THC; Conaway 2018). Marijuana, also botanically *C. sativa*, has >0.3% THC (Appendix 2).

Market considerations. After decades of prohibition (Appendix 2), the U.S. hemp agricultural industry was expected to be financially rewarding for participants at all levels driven by demand for a wide variety of hemp-derived products ranging from oilseed and fiber to CBD oil-based products, although market volatility and recent price declines leaves the outcome for hemp profitability uncertain. The crop has been touted as a lucrative crop alternative for farm diversification and to boost farm income, though establishing a new industry carries with it many challenges and risks. The global industrial hemp market size was approximately $22.1 billion USD in 2022 and is expected to show revenue-based compound annual growth rate of 25.5% through 2030 (Grand View Research 2022).

Cropping systems and products. Though still tentative from a market standpoint (Appendix 2), hemp is forecast to be grown across the United States including regions that have not had a historic hemp industry. Its cultivation, across cultivar types, faces environmental challenges (Appendix 2), but the varied products and market potential might further impact production challenges. Fiber hemp, for example, is harvested for stem tissue that contain high-quality exterior and lower-quality interior fibers used for textiles and numerous other industrial purposes (Small and Marcus 2002). Seeds are planted at high density (0.1–1 million plants/0.40 ha) and must grow several meters tall to develop large amounts of high-quality fiber tissue. Harvest occurs before or shortly after flowering (Appendix 2) to coincide with optimal fiber quality (Da Costa et al. 2001).

Grain hemp, also considered an oilseed crop, is typically planted at lower density than fiber hemp (100,000–600,000 plants/0.4 ha). For grain hemp, the optimal time to spend in vegetative phase will vary among locations, varieties, and agricultural factors such as plant density and fertilizer treatments. Most grain hemp is planted in June, allowing at least 45 days before flowering in August or September (Appendix 2).

Hemp for cannabinoid and terpene-rich oil production (Appendix 2) is grown with a focus on unpollinated flower yield (Sawler et al. 2015, Grassa et al. 2018), thus indicating low risk of seed production. This hemp type has been in legal production for the least amount of time and therefore agronomic research on growing practices is limited. Hemp grown for flower production is commonly transplanted to the field from seedlings or cuttings, often on raised beds with irrigation. Plants are spaced at relatively low densities with each plant approximately a meter apart (1,200–20,000 plants/0.4 ha). This spacing encourages lateral growth of branches that will produce densely developing inflorescence. Higher density plantings may be direct seeded. Although the ideal time to harvest is variety dependent, cannabinoid hemp is typically harvested as flowers mature prior to exceeding a legal THC limit, typically 3–6 weeks after flowering. Market potential for this type of hemp might be greatly affected by early flowering and cannabinoid development (Amaducci et al. 2008, 2015; Williams 2019).

Wildlife use of hemp

Our understanding of how hemp cultivars might contribute to strike risk is based on anecdotal evidence and limited scientific studies. Some early avian granivore studies suggest a reasonable expectation for depredation of hemp seed. However, the preponderance of literature dealing with wildlife use of hemp focuses on invertebrate pests, with anecdotal reference to vertebrates. Importantly, invertebrate crop pests can serve as initial attractants to vertebrates (primarily birds) that might eventually depredate a crop at maturity, especially if it produces seeds (Dolbeer 1990). Limited methods for chemical protection of hemp from invertebrates are available and research continues, thus providing farmers balance among potential pests (Bakro et al. 2018, Cranshaw et al. 2019). But pesticide development to control invertebrate pests will likely hinge on profitability, sustainability of the crop, and associated products.

Granivorous birds have been observed to depredate hemp crops for seeds (Stephens 1920, Errington 1935, Gigstead 1937, McClure 1943, McPartland 1996, McPartland et al. 2004; see also Barker 2016, Harper et al. 2018, Baxter 2022). Hemp depredation by birds is considered a nuisance issue in Canada and Finland (Callaway 2004*b*, Vera and Hanks 2004). Ripened hemp seed and seed meal contain dietary oil along with fiber and protein, which can be attractive to wildlife (Callaway 2004*a*, *b*; McPartland et al. 2004). Birds will consume hemp seed when included in commercial bird seed mixes (Baicich 2015), which lends evidence to profit in the bird seed industry (Callaway 2004*a*, *b*). Bird attraction and damage during cultivation has yet to be quantified at the scale and rigor to predict seasonal species densities within hemp fields. Yet, evidence suggests that blackbirds (Icteridae), sparrows (Emberizidae), doves (Columbidae), finches (Fringillidae), and pheasants (Phasianidae) target grain hemp as a food resource (Stephens 1920, Gigstead 1937, McClure 1943), refugia, and nesting habitat (Bendire 1890, Henderson 1907). Further, because of the small amount of acreage dedicated to current hemp cultivars, these areas are not conducive to understanding how wildlife use might be affected by other, proximate land covers.

In recent qualitative observations of bird use of hemp cultivars in North Dakota and Florida, USA, from August to November 2020, Kotten et al. (2022) reported 22 families and 41 bird species directly in or using hemp. The most common birds observed in North Dakota where oilseed hemp predominated included mourning doves (*Zenaida macroura*), American goldfinches (*Spinus tristis*), house finches (*Haemorhous mexicanus*), and various sparrows (Passerellidae) consuming the hemp seed while perched in the canopy or foraging on the ground.

In Florida, CBD was the predominate crop, and the avian richness was less than North Dakota (North Dakota = 21, Florida = 8 species; Kotten et al. 2022), likely due to cultivar type. The authors suggested that flocks of approximately 40–116 birds using the small oilseed fields (116–324 m^2) was indicative that hemp could benefit bird conservation in agroecosystems or could be a potential decoy crop to protect other commodities from bird damage (e.g., sunflower [*Helianthus annuus*]; Hagy et al. 2008). If cultivated on or near airport properties, we contend that an assessment of strike risk would be necessary for oilseed or dual-purpose fiber varieties and perhaps additionally for the mismanagement of lower risk fiber and floral plantings.

For example, mourning doves (Kotten et al. 2022), as well as European starlings (*Sturnus vulgaris*), not observed in the recent surveys, but a common pest species associated with crops and grain sources (Linz et al. 2007, Homan et al. 2017), rank within the top-6 species posing the greatest strike risk to aircraft (DeVault et al. 2018). Large grazing birds (e.g., Canada geese [*Branta canadensis*]), which pose high strike risk (DeVault et al. 2018) and damage various crops at emergence (Montràs-Janer et al. 2020), might cause early season crop damage (McClure 1943). Vole (*Microtus* sp.) damage might also affect hemp at the seedling stage, and large numbers of small mammals will indirectly attract raptors (McClure 1943, Franklin et al. 2018), another group of birds that rank high in strike risk (DeVault et al. 2018).

In the United States, common nuisance species that are found to depredate row crops (e.g., corn and sunflower) are blackbirds, specifically red-winged blackbirds (*Agelaius phoeniceus*), brown-headed cowbirds (*Molothrus ater*), yellow-headed blackbirds (*Xanthocephalus xanthocephalus*), and common grackles (*Quiscalus quiscula*; Dolbeer 1990, Linz et al. 2003, Werner et al. 2005, Linz et al. 2017). Blackbirds can be seen in flocks as large as 500,000 individuals, which can be detrimental to crop production and aviation safety (Peer et al. 2003, Clark et al. 2020). Although these same species might damage industrial hemp, the full suite of birds that could act as pests, as well as those posing hazards to aviation safety, is unknown in this emerging crop. Speculatively, U.S. farmers might find that the attraction of birds to hemp fields could also cause negative effects to nearby crops that are vulnerable to bird damage (i.e., sunflower and corn). Alternatively, hemp planting might serve as a lure or decoy crop, subsequently reducing bird damage on other crops.

Aside from hemp acting as a wildlife food source, hemp grown for fiber consists of dense plantings of numerous small-stemmed plants that can provide ideal roosting and nesting habitat for some birds (Bendire 1890, Henderson 1907, Fike 2016). Hemp cultivar density can also serve as cover to small and large mammals (Iglay et al. 2018) and, indirectly, concentrate avian predators (e.g., McClure 1943, Franklin et al. 2018). Deer (*Odocoileus virginianus*) browsing has been qualitatively demonstrated as a pest pressure in commercial and experimental hemp plantings (Hamerstrom and Blake 1939). However, we emphasize the limited data to support the contention that hemp could serve as a significant wildlife attractant or prove relatively benign from the perspective of vertebrate use.

Regulation of land covers on and near airports

Land covers on and near an airport contribute to strike risk, and airports are mandated to manage wildlife use of land covers within the Air Operations Area (AOA). The AOA refers to paved and unpaved areas on the airport designated for takeoff, landing, and surface maneuvers of aircraft (CFR Part 139) and within FAA siting criteria for certificated airports (i.e., within 1.5 km of a runway for airports servicing piston-powered aircraft only and within 3.0 km of a runway for airports servicing turbine-powered aircraft; FAA 2020). Relative to land uses within the bounds of the AOA, the regulations state that "when considering proposed land uses, operators and sponsors of airports certificated under Part 139, local planners, and developers must take into account whether the proposed land uses, including new development projects, will increase wildlife hazards" (FAA 2020). In addition, for all U.S. airports, the FAA recommends 8 km between the farthest edge of the airport's AOA and the hazardous wildlife attractant if the attractant could contribute to wildlife movement into or across the approach or departure airspace. For example, from 1990 through 2021, 82% of wildlife strikes reported to the FAA occurred at or below 457 m AGL. This altitude falls within the separation distance noted above (Dolbeer et al. 2022). Internationally, the boundary for consideration of land uses considered as contributing to wildlife hazards to aviation safety extends out 13 km from runway edge (ICAO 2002). In either U.S. or international regulations, it is unclear as to whether these boundary distances include airspace to some preset altitude AGL.

According to CFR Part 139 Wildlife Hazard Management, a U.S.-certificated airport must take immediate action to alleviate wildlife hazards when detected. Note, the CFR does not delineate between detections arising from airport and off-airport properties. More specifically, airports must manage wildlife of a certain body size or at population aggregations capable of causing multiple strikes, substantial damage to aircraft, or engine ingestion of the animal(s) when wildlife have access to aircraft movement areas and flight patterns. As noted above, land uses near airports contribute to wildlife use of airport properties and airspace, or "access" as noted in the CFR. Importantly, management actions for off-airport properties are not necessarily dictated by law (depending upon the nation involved) but are developed based on planning and business relationships within respective municipalities (Blackwell et al. 2009).

The lack of detailed information on wildlife use of hemp cultivars underscores the need for future research if this crop is to be considered as a safe, alternative land cover near airports. As alluded to above, wildlife use of a land cover is but one issue regarding strike risk (Blackwell et al. 2009, DeVault et al. 2018); how those species use the approach and departure corridors in association with a land cover better informs our estimates of strike risk (Blackwell et al. 2009, 2013). For example, might cultivation of hemp types versus other grain crops lead to changes in how birds use airspace relative to aircraft movements versus other land covers and crop options?

We envision research that considers the landscape, including cultivar type, geographic location, crop area, and edge type. Assessments of wildlife should not only include birds, but mammals (Franklin et al. 2018, Iglay et al. 2018, DeVault and Iglay 2019) and seasonality of use for different taxa seeking refugia, nesting sites, and food resources (including invertebrate prey) at both emergence, flowering, and maturity, along with temporal variation in wildlife behavior and abundance across the annual cycle (e.g., migration). For instance, Florida permitted 53 km^2 in 2020 and 72 km^2 in 2021 to hemp cultivation (FDACS 2021, Tancig et al. 2021), yet >2 km^2 have been approved for harvest. With anticipation of future plantings and development of the industry, hemp crop surveys are critical. Where cultivation occurs near airports, surveys would be most informative if conducted in conjunction with airport wildlife surveys (Blackwell et al. 2013) to assess correlations in species crop use and use of the airport AOA.

Conclusions

Airports maintain properties beyond the AOA, and land covers therein represent not simply maintenance costs, but revenue opportunity (e.g., hemp production). Hemp cultivation offers potential revenue opportunities in the areas of animal feed as well as medicinal and industrial products. We contend that hemp production on and near airports for purposes of revenue remains a possibility. However, much of what we learned in this review relates to U.S. land covers and wildlife populations from decades past. Our understanding is, thus, limited relative to use of hemp by species that directly pose hazards to aviation safety or those that might serve as prey resources for species frequently struck by aircraft. Therefore, prior to cultivation on or near airport properties, wildlife use of hemp cultivars should be quantified relative to species aviation hazard scores. We stress that land cover contribution to strike risk does not pertain simply to its presence or absence. Rather, management of hemp production must also consider maintenance requirements (e.g., irrigation, pest control), harvest regimens, and ecology of local wildlife populations relative to use of crops as critical components to balancing revenue potential against strike risk.

Acknowledgments

The USDA Wildlife Services and University of Florida provided salaries. Our research was also supported by the FAA via Interagency Agreement with the USDA Wildlife Services, No: 692M15-19-T-00017. G. Linz, J. Weller, and J. Gervais provided reviews and helpful comments of earlier versions of this manuscript. We also appreciate comments provided by the HWI associate editor and anonymous reviewers. Findings and conclusions in this article are those of the authors and do not necessarily represent the views of the USDA or the FAA.

Supplemental material

Supplemental material can be viewed at https://digitalcommons.usu.edu/hwi/vol16/iss3/5.

Literature cited

Amaducci, S., M. Colauzzi, G. Bellocchi, and G. Venturi. 2008. Modelling post-emergent hemp phenology (*Cannabis sativa* L.): theory and evaluation. European Journal of Agronomics 28:90–102.

Amaducci, S., D. Scordia, F. H. Liu, Q. Zhang, H. Guo, G. Testa, and S. L. Cosentino. 2015. Key cultivation techniques for hemp in Europe and China. Industrial Crops and Products 68:2–16.

Baicich, P. J., M. A. Barker, and C. L. Henderson. 2015. Feeding wild birds in America: culture, commerce, and conservation. Texas A&M University Press, College Station, Texas, USA.

Bakro, F., K. Wielgusz, M. Bunalski, and M. Jedryczka. 2018. An overview of pathogen and insect threats to fibre and oilseed hemp (*Cannabis sati-*

va L.) and methods for their biocontrol. Integrated Control in Oilseed Crops IOBC-WPRS Bulletin 136:9–20.

Barker, B. 2016. Industrial hemp harvest and storage: best management practices. Ministry of Agriculture and Irrigation, Government of Alberta, Alberta, Canada, <https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop15539/$file/HempHarvestStorage.pdf?OpenElement>. Accessed August 9, 2023.

Baxter, W. J. 2022. Growing industrial hemp in Ontario. Ministry of Agriculture, Food, and Rural Affairs, Government of Ontario, Ontario, Canada, <https://files.ontario.ca/omafra-growing-industrial-hemp-in-ontario-22-020-en-2023-07-21.pdf>. Accessed August 9, 2023.

Bendire, C. E. 1890. Notes on *Pipilo fuscus mesoleucus* and *Pipilo aberti*, their habits, nests and eggs. Auk 7:22−29.

Blackwell, B. F., T. L. DeVault, E. Fernández-Juricic, and R. A. Dolbeer. 2009. Wildlife collisions with aircraft: a missing component of land-use planning for airports. Landscape and Urban Planning 93:1–9.

Blackwell, B. F., P. Schmidt, and J. A. Martin. 2013. Avian survey methods for use at airports. Pages 153–166 *in* T. L. DeVault, B. F. Blackwell, and J. L. Belant, editors. Wildlife in airport environments: preventing animal–aircraft collisions through science-based management. The Wildlife Society and Johns Hopkins University Press, Baltimore, Maryland, USA.

Callaway, J. C. 2004*a*. Hemp seed production in Finland. Journal of Industrial Hemp 9:97–103.

Callaway, J. C. 2004*b*. Hemp seed as a nutritional resource: an overview. Euphytica 140:65–72.

Clark, B. A., P. E. Klug, P. M. Stepanian, and J. F. Kelly. 2020. 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.

Clarke, R. C., and M. D. Merlin. 2013. Cannabis: evolution and ethnobotany. University of California Press, Berkeley, California, USA.

Conaway, K. M. 2018. H.R.2—115th Congress (2017–2018): Agriculture Improvement Act of 2018. U.S. Government, Washington, D.C., USA, <https://www.congress.gov/bill/115th-congress/house-bill/2>. Accessed August 8, 2023.

Conkling, T. J., J. L. Belant, T. L. DeVault, and J. A. Martin. 2018. Impacts of biomass production at civil airports on grassland bird conservation and aviation strike risk. Ecological Applications 28:1168–1181.

Conover, M. R. 2002. Resolving human–wildlife conflicts. Lewis, Boca Raton, Florida, USA.

Cranshaw, W., M. Schreiner, K. Britt, T. P. Kuhar, J. McPartland, and J. Grant. 2019. Developing insect pest management systems for hemp in the United States: a work in progress. Journal of Integrated Pest Management 10:1–10.

Da Costa, M. C., R. Deliza, A. Rosenthal, D. Hedderley, and L. Frewer. 2001. Influence of the growth stage of industrial hemp on the yield formation in relation to certain fibre quality traits. Industrial Crops and Products 13:49–56.

Deitch, R. 2003. Hemp—American history revisited: the plant with a divided history. Algora Publishing, New York, New York, USA.

Deitch, R., and N. MacDonald. 2003. Hemp and imperial defence: Canadian historical review. Algora Publishing, New York, New York, USA.

DeVault, T. L., M. J. Begier, J. L. Belant, B. F. Blackwell, R. A. Dolbeer, J. A. Martin, T. W. Seamans, and B. E. Washburn. 2013*b*. Rethinking airport land-cover paradigms: agriculture, grass, and wildlife hazards. Human–Wildlife Interactions 7:10–15.

DeVault, T. L., J. L. Belant, B. F. Blackwell, J. A. Martin, J. A. Schmidt, and L. W. Burger, Jr. 2012. Airports offer unrealized potential for alternative energy production. Environmental Management 49:517−522.

DeVault, T. L., B. F. Blackwell, and J. L. Belant, Editors. 2013*a*. Wildlife in airport environments: preventing animal–aircraft collisions through science-based management. The Wildlife Society and Johns Hopkins University Press, Baltimore, Maryland, USA.

DeVault, T. L., B. F. Blackwell, T. W. Seamans, M. J. Begier, J. D. Kougher, J. E. Washburn, P. R. Miller, and R. A. Dolbeer. 2018. Estimating interspecific economic risk of bird strikes with aircraft. Wildlife Society Bulletin 42:94–101.

DeVault, T. L., and R. B. Iglay. 2019. Improving safety and economics using switchgrass on military airfields—RC-201415. Version 1. Final report, Environmental Security Technology Certification Program, Alexandria, Virginia, USA.

DeVault, T. L., J. Kubel, O. E. Rhodes, Jr., and R. A. Dolbeer. 2009. Habitat and bird communities at small airports in the midwestern USA. Proceedings of the Wildlife Damage Management Conference 13:137–145.

DeVault, T., T. W. Seamans, J. A. Schmidt, J. L. Belant, B. F. Blackwell, N. Mooers, L. A. Tyson, and L. Van Pelt. 2014. Bird use of solar photovoltaic installations at US airports: implications for aviation safety. Landscape and Urban Planning 122:122–128.

Dolbeer, R. A. 1990. Ornithology and integrated pest management: red-winged blackbirds *Agelaius phoeniceus* and corn. Ibis 132:309–322.

Dolbeer, R. A, M. A. Begier, P. R. Miller, J. R. Weller, and A. L. Anderson. 2022. Wildlife strikes to civil aircraft in the United States 1990–2021. Serial report 28. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Washington, D.C., USA.

Errington, P. L. 1935. Winter-killing of mourning doves in central Iowa. Wilson Bulletin 47:159–160.

Federal Aviation Administration (FAA). 2020. Advisory Circular (AC) 150/5200-33C-Hazardous wildlife attractants on or near airports. Federal Aviation Administration, Washington, D.C., USA, <https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5200-33C.pdf>. Accessed August 3, 2022.

Federal Aviation Administration (FAA). 2022. What is Part 139? – Part 139 airport certification. Federal Aviation Administration, Washington, D.C., USA, <www.faa.gov/airports/airport_safety/part139_cert/what-is-part-139/>. Accessed August 8, 2023.

Fike, J. 2016. Industrial hemp: renewed opportunities for an ancient crop. Critical Reviews in Plant Science 35:406–424.

Flight Safety Foundation. 2000. Flight Safety Foundation approach-and-landing accident reduction briefing note 4.2—energy management. Flight Safety Digest. August–November, 75–80. Flight Safety Foundation, Alexandria, Virginia, USA.

Florida Department of Agriculture and Consumer Services Division of Plant Industries (FDACS). 2021. Current list of hemp cultivation permits. Florida Department of Agriculture and Consumer Services Division of Plant Industries, Tallahassee, Florida, USA, <https://www.fdacs.gov/Cannabis-Hemp/Hemp-CBD-in-Florida/Hemp-Cultivation-Licensing>. Accessed August 8, 2023.

Franklin, A. B., P. C. Carlson, A. Rex, J. T. Rockweit, D. Garza, E. Culhne, S. F. Volker, R. J. Dusek, V. I. Shearn-Bochsler, and M. W. Gabriel. 2018. Grass is not always greener: rodenticide exposure of a threatened species near marijuana growing operations. BMC Research Notes 11:94.

Gigstead, G. 1937. Habits of Wisconsin pheasants. Wilson Bulletin 49:28–34.

Grand View Research. 2022. Legal cannabis market size, share & trends analysis report by source (marijuana, hemp), by derivative (CBD, THC), by end use (medical use, recreational use, industrial Use), by region, and segment forecasts, 2023 - 2030. Grand View Research, San Francisco, California, USA, <https://www.grandviewresearch.com/industry-analysis/legal-cannabis-market>. Accessed August 8, 2023.

Grassa, C. J., J. P. Wenger, C. Dabney, S. G. Poplawski, S. T. Motley, T. P. Michael, C. J. Schwartz, and G. D. Weiblen. 2018. A complete Cannabis chromosome assembly and adaptive admixture for elevated cannabidiol (CBD) content. bioRxiv. October 31, 2018.

Hagy, H. M., G. M. Linz, and W. J. Bleier. 2008. Optimizing the use of decoy plots for blackbird control in commercial sunflower. Crop Protection 27:1442–1447.

Hamerstrom, F. N., Jr., and J. Blake. 1939. Winter movements and winter foods of white-tailed deer in central Wisconsin. Journal of Mammalogy 20:315−325.

Harper, J. K., A. Collins, L. Kyme, G. W. Roth, and H. E. Manzo. 2018. Industrial hemp production. Penn State Extension, The Pennsylvania State University, University Park, Pennsylvania, USA, <https://extension.psu.edu/industrial-hemp-production>. Accessed August 9, 2023.

Henderson, J. 1907. Nesting crossbills in Colorado. Auk 24:440−442.

Homan, H. J., R. J. Johnson, J. R. Thiele, and G. M. Linz. 2017. European starlings. Wildlife Damage Management Technical Series, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services National Wildlife Research Center, Fort Collins, Colorado, USA.

Iglay, R. B., B. N. Buckingham, T. W. Seamans, J. A. Martin, B. F. Blackwell, J. L. Belant, and T. L. DeVault. 2017. Bird use of grain fields and implications for habitat management at airports. Agriculture, Ecosystems, and Environment 242:34–42.

Iglay, R. B., K. B. Schwarz, J. L. Belant, J. A. Martin, G. Wang, and T. L. DeVault. 2018. Large mammal use of seminatural grasslands and implications for aviation strike risk. Journal of Fish and Wildlife Management 9:222–227.

International Civil Aviation Organization (ICAO). 2002. Land use and environmental control. Airport Planning Manual, Doc 9184 AN/902, Part 2. International Civil Aviation Organization, Montreal, Canada.

James, K. L., N. P. Randall, and N. R. Haddaway. 2016. A methodology for systematic mapping in environmental sciences. Environmental Evidence 5:1–13.

Kotten, E. A., I. Hennessy, Z. T. Brym, B. M. Kluever, B. F. Blackwell, L. A. Humberg, and P. E. Klug. 2022. Industrial hemp as a resource for birds in agroecosystems: human–wildlife conflict or conservation opportunity? Human–Wildlife Interactions 16(3).

Leopold, A. 1933. Game management. Charles Scribner's, New York, New York, USA.

Li, H.-L. 1974*a*. An archaeological and historical account of cannabis in China. Economic Botany 28:437–448.

Li, H.-L. 1974*b*. The origin and use of cannabis in eastern Asia linguistic-cultural implications. Economic Botany 28:293–301.

Linz, G. M., M. L. Avery, and R. A. Dolbeer. 2017. Ecology and management of blackbirds (Icteridae) in North America. CRC Press, Boca Raton, Florida, USA.

Linz, G., J. Homan, L. Penry, and P. Mastrangelo. 2003. Reducing blackbird–human conflicts in agriculture and feedlots: new methods for an integrated management approach. Crop Protection 6:56–60.

Linz, G. M., H. J. Homan, S. M. Gaukler, L. B. Penry, and W. J. Bleier. 2007. European starlings: a review of an invasive species with far-reaching impacts. Pages 378–386 *in* G. W. Witmer, W. C. Pitt, and K. A. Fagerstone, editors. Symposium 24. Managing vertebrate invasive species. National Wildlife Research Center, Fort Collins, Colorado, USA.

Long, T., M. Wagner, D. Demske, C. Leipe, and P. E. Tarasov. 2017. Cannabis in Eurasia: origin of human use and Bronze Age trans-continental connections. Vegetation History and Archaeobotany 26:245–258.

Mark, T., J. Shepherd, D. Olson, W. Snell, S. Proper, and S. Thornsbury. 2020. Economic viability of industrial hemp in the United States: a review of state pilot programs. U.S. Department of Agriculture, Economic Research Service, Economic Information Bulletin number 217.

Marra, P. P., C. J. Dove, R. A. Dolbeer, N. F. Dahlan, M. Heacker, J. F. Whatton, N. E. Diggs, C. F. France, and G. A. Henkes. 2009. Migratory Canada geese cause crash of US Airways Flight 1549. Frontiers in Ecology and the Environment 7:297−301.

Martin, J. A., J. L. Belant, T. L. DeVault, L. W. Burger, Jr., B. F. Blackwell, S. K. Riffell, and G. Wang. 2011. Wildlife risk to aviation: a multi-scale issue requires a multi-scale solution. Human–Wildlife Interactions 5:198−203.

Martin, J. A., T. J. Conkling, J. L. Belant, K. M. Biondi, B. F. Blackwell, T. L. DeVault, E. Fernández-Juricic, P. M. Schmidt, and T. W. Seamans. 2013. Wildlife conservation and alternative land uses at airports. Pages 117–128 *in* T. L. DeVault, B. F. Blackwell, and J. L. Belant, editors. Wildlife in airport environments: preventing animal–aircraft collisions through science-based management. The Wildlife Society and Johns Hopkins University Press, Baltimore, Maryland, USA.

McClure, H. E. 1943. Ecology and management of the mourning dove, *Zenaidura macroura* (Linn.), in Cass County, Iowa. Research Bulletin (Iowa Agriculture and Home Economics Experiment Station) 26:1.

McPartland, J. 1996. Cannabis pests. Journal of the International Hemp Association 3:49−52.

McPartland, J. M., S. Cutler, and D. J. McIntosh. 2004. Hemp production in Aotearoa. Journal of Industrial Hemp 9:105−115.

Montràs-Janer, T., J. Knape, M. Stoessel, L. Nilsson, I. Tombre, T. Pärt, and J. Månsson. 2020. Spatio-temporal patterns of crop damage caused by geese, swans and cranes—implications for crop damage prevention. Agriculture, Ecosystems and Environment 300:107001.

Mosk, S. A. 1939. Subsidized hemp production in Spanish California. Agricultural History 13:171–175.

Paine, T. 1776. Common sense. R. Bell, Philadelphia, Pennsylvania, USA.

Peer, B. D., H. J. Homan, G. M. Linz, and W. J. Bleier. 2003. Impact of blackbird damage to sunflower: bioenergetic and economic models. Ecological Applications 13:248–256.

Pfeiffer, M. B., J. D. Kougher, and T. L. DeVault. 2018. Civil airports from a landscape perspective: a multi-scale approach with implications for reducing bird strikes. Landscape and Urban Planning 179:38–45.

Sawler, J., J. M. Stout, K. M. Gardner, D. Hudson, J. Vidmar, L. Butler, J. E. Page, and S. Myles. 2015. The genetic structure of marijuana and hemp. PLOS ONE 10(8): e0133292.

Small, E., and D. Marcus. 2002. Hemp: a new crop with new uses for North America. Pages 284–326 *in* J. Janick and A. Whipkey, editors. Trends in new crops and new uses. American Society

for Horticulture Science Press, Alexandria, Virginia, USA.
Stephens, T. C. 1920. Bird records of the past two winters, 1818–1920, in the upper Missouri Valley. Proceedings of the Iowa Academy of Science 27:395−407.
Tancig, M., C. Kelly-Begazo, N. Kaur, L. K. Sharma, and Z. Brym. 2021. Industrial hemp in the United States: definition and history. Publication #SS-AGR-457. University of Florida, Institute of Food and Agricultural Sciences Extension, Homestead, Florida, USA.
Vera, C. L., and A. Hanks. 2004. Hemp production in western Canada. Journal of Industrial Hemp 9:79−86.
Werner, S. J., H. J. Homan, M. L. Avery, G. M. Linz, E. A. Tillman, A. A. Slowik, R. W. Byrd, T. M. Primus, and M. J. Goodall. 2005. Evaluation of Bird Shield™ as a blackbird repellent in ripening rice and sunflower fields. Wildlife Society Bulletin 33:251−257.
Williams, D. W., editor. 2019. Industrial hemp as a modern commodity crop. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, USA.

Associate Editor: David K. Dahlgren

Bradley F. Blackwell (photo unavailable) serves as field station and project leader for the USDA/APHIS Wildlife Services, National Wildlife Research Center, Ohio Field Station in Sandusky. Research at the Ohio Field Station is focused, primarily, on mitigating wildlife–aircraft collisions. He and the staff at the field station collaborate directly with the Federal Aviation Administration in the areas of sensory ecology and animal behavior as related to animal detection and avoidance of approaching aircraft, movements of large bird species on and near airports, unmanned aircraft system applications in survey and hazing contexts, and in developing estimates of wildlife–aircraft collision risk.

Page E. Klug is a research wildlife biologist and field station leader with the USDA, APHIS, Wildlife Services, National Wildlife Research Center. The USDA APHIS WS NWRC North Dakota Field Station is housed within the Department of Biological Sciences at North Dakota State University, where she is affiliated graduate/adjunct faculty. Research at the North Dakota Field Station is focused on developing methods and tools to manage bird damage to agriculture. She received her B.S degree in environmental science and policy from Drake University, M.S. degree in biology from the University of Nebraska at Omaha, and Ph.D. degree in biology from Kansas State University. She has investigated the impact of row-crop agriculture and rangeland management on wildlife as well as the impact of introduced species.

Lee A. Humberg is the state director for USDA, APHIS, Wildlife Services in Indiana. He earned his B.S. (2000) and M.S. (2006) degrees from Purdue University investigating wildlife crop depredation. For the last 16 years, he has worked for the federal government, including positions with the Department of the Army, U.S. Forest Service, and USDA Wildlife Services. He currently directs wildlife conflict mitigation programs associated with aviation safety, public utilities and infrastructure, human health and safety, agricultural damage, and natural resource protection.

Zachary T. Brym is an assistant professor in the Department of Agronomy working from the Tropical Research and Education Center in Homestead, Florida. His research and extension programs cover a broad range of topics related to agroecology with a focus on crop physiology, diversity, and management. The goal of these programs is to establish new cropping systems, such as hemp, that provide the complementary outcomes of crop production, environmental conservation, and community development. He is the state coordinator for the University of Florida / Institute of Food and Agricultural Sciences Hemp Program. He received his B.S. and M.S. degrees from the University of Michigan and Ph.D. degree from Utah State University.

Bryan M. Kluever is a supervisory research wildlife biologist within the USDA, APHIS, Wildlife Services, National Wildlife Research Center (NWRC). As the NWRC Florida Field Station Leader, he and his team of dynamic natural resource professionals employ observational, experimental, and captive animal/pen wildlife research to come up with robust, common sense solutions to human–wildlife conflict issues. He received his B.S. degree in wildlife and fisheries from the University of Nebraska, M.S. degree in rangeland ecology and management from the University of Arizona, and Ph.D. degree in wildlife biology from Utah State University.

Jenna Edwards (photo unavailable) is the assistant director of Information Services and Manuals with the USDA, APHIS, Plant Protection and Quarantine. She was previously a supervisory technical information specialist with the USDA, APHIS, Wildlife Services where she managed a team focused on searching, identifying, and disseminating research findings and mission centric information. Her focus is scientific and regulatory information management and utilizing data systems to organize and make available content to internal and external stakeholders. She has a B.A. degree from Miami University and M.A. degree from Wright State University.