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Black vulture conflict and management in the United States: damage trends, management overview, and research needs

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Abstract: Contrary to rapid declines of many vulture (Accipitridae, Cathartidea) species worldwide, black vulture (*Coragyps atratus*) populations are increasing and expanding their range in North America. Vultures exhibit complex behaviors and can adapt to any human-dominated landscape or land use. These traits, combined with population growth and range expansion, have contributed to increased human–vulture conflicts. Our goal was to summarize the current status and trends in human–black vulture conflicts (hereafter human–vulture conflicts), review available management strategies, identify knowledge gaps, and provide recommendations to enhance management and understanding of this species and the associated conflicts. We found human–vulture conflicts are increasing in agriculture (livestock), private and public property (both personal and infrastructure-based), and threats to human health and safety. The greatest increases in conflicts were reported in agriculture and private and public property damage. Regarding livestock depredation, good progress has been made toward assessing producer perceptions of the conflicts, including estimates of economic damage and mitigation strategies, but a basic understanding of the underlying mechanism driving the conflict and advancing strategies to mitigate damage is lacking. For damaged property, little information is available regarding economic losses and perceptions of stakeholders who are experiencing the damage, and most of the tools recommended for mitigating this damage have not been rigorously evaluated. Regarding human health and safety, recent research quantifying flight behavior of black vultures has direct implications for reducing aircraft collision risks. However, it is unclear what factors influence roost site selection and the most effective means to leverage the sensory ecology of the species to mitigate risks. We identify additional knowledge gaps and research needs that if addressed could increase managers' understanding of black vulture ecology and facilitate enhanced management of this species while simultaneously allowing for the species to provide valuable ecosystem services.

Key words: behavior, black vulture, *Coragyps atratus,* ecology, human health and safety, infrastructure, livestock depredation, property damage, range expansion, United States

Globally, many vulture species (Accipitridae and Cathartidea) have recently experienced population and/or distribution declines (Ogada et al. 2012*a*, Thiollay 2017, Santangeli et al. 2019). Sixty-nine percent of all vulture species occurring in Africa and Eurasia have been identified by the International Union for Conservation of Nature as near-threatened, threatened, endangered, or critically endangered (BirdLife International 2020). The causes of the continental-level declines vary. For example, in India and Pakistan, a veterinary drug known as dicoflenac has been identified as the primary driver (Green et al. 2004). In Africa, non-target mortality, poaching, and the incorporation of vulture parts in the traditional medicine trade have been implicated as factors contributing to declining vulture populations (Ogada et al. 2016, Botha et al. 2017).

New World and Old World vultures serve

similar ecological roles yet evolved from different species: New World vultures reportedly from storks (Ciconiidae) and Old World vultures from raptors (Campbell 2014). Vultures, by consuming carrion, provide valuable ecosystem services, including potentially reducing the pervasiveness of disease in wildlife (Ogada et al. 2012*b*, Beasley et al. 2015) and humans. Markandya et al. (2008) estimated $2.43 billion USD on average was spent annually on expenses related to human rabies transmitted from feral dog (*Canis lupus familiaris*) bites following the decline of Asian vulture species. In terms of ecosystem services, the turkey vulture (*Cathartes aura*) was estimated to remove $700 million USD worth of organic waste material per year (Grilli et al. 2019). Despite their valuable ecological roles, the same behavioral traits that have enabled some vultures to adapt to anthropogenic landscapes have also exacerbated human–vulture conflict in both rural and urban settings on several continents (Avery 2004, Toledo et al. 2013, Margalida et al. 2014, Washburn 2018, Duriez et al. 2019).

In the United States, extant vulture guild diversity is low when compared to South America, Eurasia, and Africa, comprising only 3 species, the California condor (*Gymnogyps californianus*), turkey vulture, and black vulture (*Coragyps atratus*). The California condor is listed as federally endangered in the United States and Mexico, persisting only in portions of California, Utah, Arizona, and Baja California, USA (Finkelstein et al. 2020). The turkey vulture is distributed seasonally throughout the majority of South America, Central America, Mexico, and the United States, extending northward to the southern portions of most Canadian provinces (Buckley 2020). Where black and turkey vultures co-occur, they may comingle generally while foraging, soaring, loafing, and roosting (Sweeney and Fraser 1986, DeVault et al. 2005), yet exhibit differences in fine-scale habitat selection (Holland et al. 2017). Thus, several of the knowledge gaps and opportunities we discuss in this paper for achieving a better understanding of black vulture ecology and management are also applicable to turkey vultures.

Black vultures, though not as widely distributed as turkey vultures, range throughout much of South America, Central America, and Mexico (Buckley 2020). Their northern distribution is more limited, and throughout much of the twentieth century, only the southeastern United States hosted large year-round populations (Avery 2004). In recent years, however, the species has undergone a distribution increase by expanding its range to the northeastern and midwestern United States (Zimmerman et al. 2019), and its range is predicted to reduce in certain areas of South America (Saenz-Jimenez et al. 2020). The reasons for the recent distribution changes in the United States have not been clearly identified, but potential contributing factors include increased food availability and climate change (Buckley 2020).

In addition to a spatial expansion, black vultures have increased in abundance, including in areas of historical occurrence. According to the Breeding Bird Survey (BBS), from 1966 to 2015 black vulture annual indices of abundance increased in the southeastern and midwestern portions of the United States by an average of 3.75% (95% CI 2.93–4.49) and 9.04% (95% CI 5.06–12.36), respectively. The reported largest and smallest black vulture populations estimated for a state are Florida and Ohio, USA with estimates of 1,149,817 and 4,569, respectively (Zimmerman et al. 2019).

The phrase "human–wildlife conflicts" describes any negative interactions between humans and wildlife, including those that are either real or perceived, economic or aesthetic, social or political (Messmer 2000, 2009). Human–wildlife conflicts can be categorized by the primary resource affected and/or the threat associated with the conflict. For instance, the broad categories of agriculture (e.g., crops, livestock), natural resources (e.g., threats to sensitive species), property (e.g., residential and industrial infrastructure), and human health and safety (e.g., wildlife–aircraft collisions) have been established as a means to identify and thereby guide efforts to address wildlife conflict (Conover 2001, Reidinger and Miller 2013). We have elected to use these categories to report on our findings regarding human–vulture conflict.

Here, we provide a synthesis on the current status of knowledge for human–vulture conflicts, with a focus on management and research in the United States. We focus on the black vulture (hereafter vultures; Figure 1) because the species population increase and range expan-

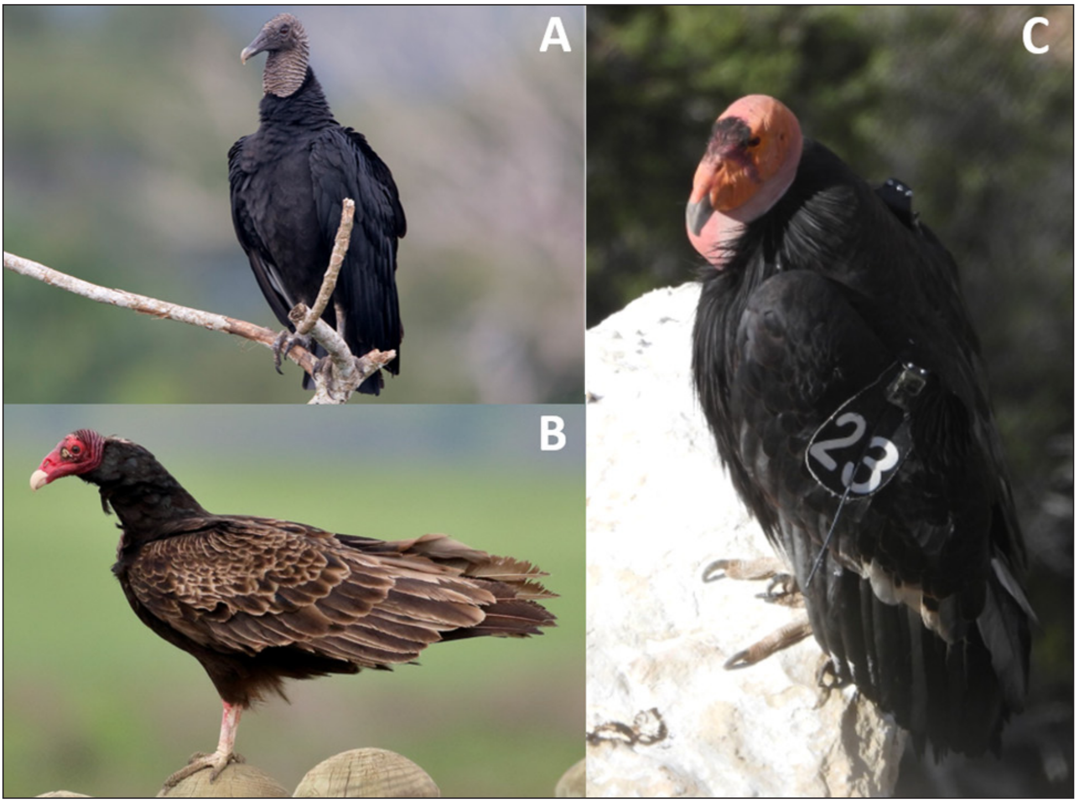

Figure 1. The 3 vulture species occurring in the United States, the black vulture (*Corogyps atratus*; A), the turkey vulture (*Cathartes aura*; B), and the California condor (*Gymnogyps californianus*; C). Images from the Cornell Lab of Ornithology Macaulay Library (*photos A, B, and C courtesy of B. Sullivan, A. Kambhampati, and K. Trouton, respectively*).

sion have resulted in more reports of conflicts than other vulture species occurring in the United States. Our objectives are to: (1) describe trends of human–vulture conflict, (2) summarize the conflict and management approaches by the major types of resources affected, and (3) identify basic and applied research needs that if carried out should increase knowledge of vulture ecology and biology, leading to enhanced management efficacy.

Methods

In May, 2020, we contacted the U.S. Department of Agriculture (USDA), Animal Plant and Health Inspection Service (APHIS), Wildlife Services (WS) Eastern Regional Office (Raleigh, North Carolina, USA) and requested all instances of requests for assistance relating to vulture conflicts within the jurisdiction of the U.S. Fish and Wildlife Service (USFWS) Southeast Region 4 (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee, USA) from 2010 to 2019. Data access was approved by R. L. Hudson and provided by J. M. Weiskittel by querying the Management Information System Database (MIS; accessed April 30, 2020). These data included a category for the type of resource being protected (e.g., aircraft, residential building, industrial building, swine [*Sus scrofa*], cattle [*Bos taurus*], etc.). From these data, we parsed the human–vulture conflict by the major resource categories described above.

We accessed the Federal Aviation Administration (FAA) Wildlife Strike Database (https://wildlife.faa.gov/home; accessed June 16, 2020) and searched for aircraft collisions involving only black vultures from 2010 to 2019, which included a monetary component. We selected 2010 as our earliest reporting year because reporting of damaging bird–aircraft collisions became more robust in the 2010s following the forced landing of Flight 1549 in the Hudson River in 2009 and the subsequent

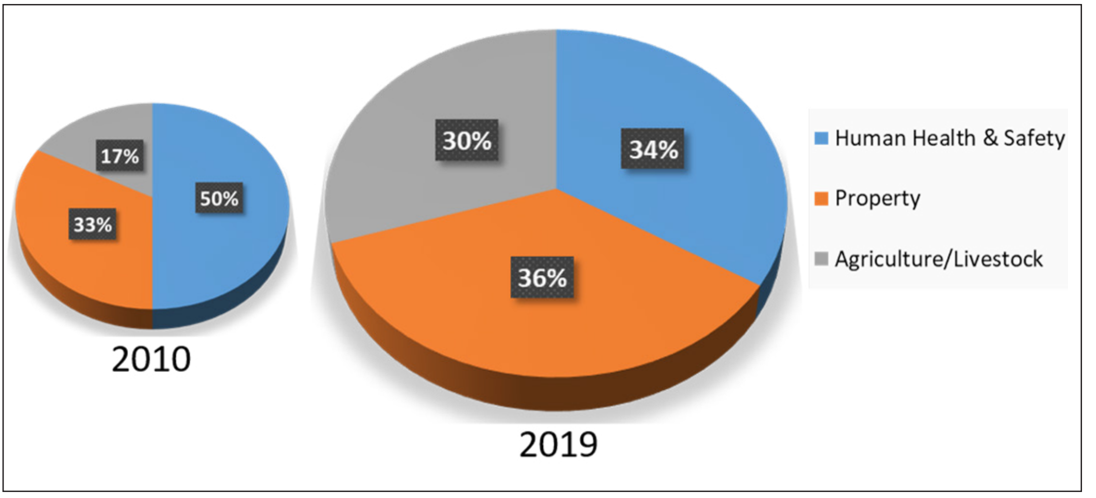

Figure 2. Requests for assistance relating to black vulture (*Coragyps atratus*) conflicts in the United States submitted to U.S. Department of Agriculture, Animal Plant and Health Inspection Service, Wildlife Services, parsed by major categories of resources affected for states within the jurisdiction of the U.S. Fish and Wildlife Service Southeast Region 4 (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee, USA) for 2010 (*n* = 115) and 2019 (*n* = 325). The resource category of natural resources protection is not displayed because calls for assistance were <1% for this category for both years.

awareness campaigns by the FAA and USDA (Dolbeer 2015).

Also in June 2020, we requested from the U.S. Navy (USN) and U.S. Air Force (USAF) the reported vulture strikes to military aircraft for the same temporal span (2010–2019). The USN provided this information by way of the Naval Safety Center (accessed June 22, 2020), and the USAF provided this information by way of their USAF Automated System database (accessed June 22, 2020). A. L. Bowe, D. P. Sullivan, B. R. Burnham, and J. E. Higgins provided military bird strike summary data.

In May, 2020, we contacted the USFWS Migratory Bird Program (Falls Church, Virginia, USA) and requested summary information for the number of USFWS depredation permits issued for vultures nationwide from 2015 to 2019. The USFWS monitors depredation permits by way of their Service Permit Issuance and Tracking System Database (SPITS). E. L. Kershner provided the summary data (accessed May 14, 2020).

To report on the current state of the literature regarding human–vulture conflict and management in the United States, we searched 2 internet-based literature databases, Google Scholar and Web of Science, from August 15 to September 15, 2020. For each database, we conducted initial keyword searches using the search terms "black vulture" and "*Coragys atratus*." From these records, we next queried 1 of 2 additional keywords: "management" and "conflict." We examined >100 papers and used expert elicitation to select what we felt were the most germane papers for inclusion. Because we were interested in both historical and contemporary works on black vulture management, we did not set a date range for our searches.

Results and discussion

Requests for technical assistance and depredation permits

According to the USDA, APHIS, WS, MIS, in 2019 there were 325 requests to WS to provide technical assistance to mitigate human–vulture conflict in the aforementioned states. This represents nearly a 3-fold increase in requests since 2010 (*n* = 115). The resource categories most affected by human–vulture conflict are human health and safety, property, and livestock (Figure 2). According to MIS data, vultures do not pose a threat to natural resources (e.g., adversely affecting a species of conservation concern) because reports were <1% of the total. In addition, there appeared to be a transition taking place where a greater proportion of requests for technical assistance were associated with the property and agriculture resource categories than human health and safety (Figure 2). In 2019, according to the SPITS database, USFWS issued 435 depredation permits authorizing lethal take of vultures nationwide, a 26% increase from 2015.

Agriculture

Although black vultures are predominantly scavengers, they have been observed to consume live prey including sea turtles (Dermochelyidae, Cheloniidae), skunks (Mephitidae), opossums (Didelphidae), birds, fish, and livestock (Baynard 1909, McIlhenny 1939, Mrosovsky 1971, Dickerson 1983, Lowney 1999). Black vultures have been identified by U.S. livestock producers as a threat through depredation of neonate cattle, horses (*Equus ferus caballus*), sheep (*Ovis aries*), goats (*Capra aegagrus hircus*), domestic swine, and farm-raised deer (*Odocoileus virginianus*; Lowney 1999, Avery and Cummings 2004). For cattle, black vulture predation has reportedly occurred in 18 U.S. states located in the southeast and southwest United States (Spires 2014). In Florida, 38% of surveyed cattle ranchers reported experiencing vulture predation that, on average, exceeded $2,000 USD of damage (Milleson et al. 2006). Also, in Tennessee, a survey of agricultural extension agents revealed that 89% of counties had recurring issues of vulture predation on livestock (Spires 2014). In Texas, where black vultures have historically occurred and also expanded (Parmalee 1954, Avery and Cummings 2004), a shift by livestock producers from wool varieties of sheep to hair breeds, capable of lambing multiple times per year, has made year-round breeding more commonplace (Morgan 2016), increasing the likelihood of encounters between black vultures and lambs.

In areas where black vultures have expanded their range, less is known regarding impacts to livestock. Although for states in the northeast United States that generally produce less livestock than the states black vultures have historically occurred, reported losses due to predatory birds have been low (USDA 2015). Latteman (2019) reported that vulture livestock depredation was occurring in the Midwest. In addition, vulture depredation has been definitively identified as the cause of mortality for several calves in southern Indiana (G. Burcham, Heeke Animal Disease Diagnostic Laboratory, Purdue University College of Veterinary Medicine, personal communication).

Reports of vulture livestock depredations may be confounded by the predatory behavior of the species. Black vultures have been described as inefficient predators, with some predation events lasting 6 hours (average 3 hours and 26 minutes) from the start of the interaction to the death of a lamb (Ballejo et al. 2020). An alternative explanation of a long duration associated with subduing prey could be that it is part of a predatory strategy of wearing down prey. While not examined here, it is important to note that human perceptions of scavengers have been shown to influence the degree of perceived vulture conflict (Duriez et al. 2019, Ballejo et al. 2020).

Integral to managing vulture livestock depredations is a better understanding of behavioral ecology of the species. Specifically, black vultures exhibit bolder behaviors than other vulture species (Buckley 1996). For example, black vultures routinely displace turkey vultures and/or alter the social hierarchy at carcasses when both species are present, including when turkey vultures are numerically dominant at sites (Haskins 1972, Buckley 1996). Further, black vultures participated in more interactions with neonate livestock than any other avian scavenger observed during 311 hours of field observations in lambing season (Ballejo et al. 2020). Depredation of neonate livestock by vultures may be a combination of active predatory behavior, where neonates attempt to avoid being preyed upon but are still pursued, or a "case of mistaken identity" where neonates are listless to the point that vultures perceive them as carrion (Duriez et al. 2019). Whether predatory behavior exhibited by vultures is learned or innate is unknown.

The indirect effects of predation and predation risk have received much attention in the ecological literature, but research has primarily focused on wild ungulate-large carnivore systems (Creel and Christianson 2008, Laundre et al. 2014). Evaluating indirect effects of livestock depredation has been reported as a research priority (Howery and DeLiberto 2004). Cattle have been shown to temporarily decrease foraging behavior following depredation of neonates by mammalian carnivores (Kluever et al. 2008), and wolf (*Canis lupus*) depredation risk can affect cattle weight gain (Steele et al. 2013).

For vultures, and raptors in general, knowledge of the indirect effects of predation and predation risk is lacking. In Brazil, Toledo et al. (2013) found the presence of vultures at cattle birthing sites altered the behavior of cows and calves; contact time between cattle and calf decreased and cattle vigilance increased. In Florida, Humphrey et al. (2004) observed a single event of a cow engaging in antipredator behavior to thwart black vultures from depredating its calf.

Mitigating agriculture depredation

Multiple strategies have been employed to mitigate the threat of livestock depredation by vultures at livestock parturition areas. These include harassment/hazing of birds using pyrotechnics, propane exploders, shooting near birds, effigies, chasing with vehicles and lasers, the elimination of food attractants by livestock producers, lethal removal of a subset of black vultures through trapping or shooting via permitted take, and dispersal of vultures from known nocturnal roost sites in proximity to parturition sites (MIS, unpublished data). An integrated approach, where multiple tools are used simultaneously or sequentially implemented, is the standard practice if the mitigation is employed by WS, and lethal removal is not authorized by the USFWS unless used in tandem with nonlethal approaches (i.e., as a reinforcing stimuli; USFWS Form 3-200-13). This integrated approach is also recommended to producers who elect to mitigate the damage themselves. Harassment and lethal shooting coupled with effigy display is one of the most commonly implemented integrated approaches employed by livestock producers.

However, what is known of the efficacy of livestock depredation mitigation strategies for vultures is largely based on producer surveys rather than field-based investigation conducted in a robust manner. In Florida, only a small number of cattle producers employed guard dogs, but this technique was the most effective strategy reported, with attractant removal and shooting being the second and third most effective, respectively (Milleson et al. 2006). In Wyoming, USA, producers reported the most effective strategies for mitigating depredation of cattle and sheep by avian species, and although data had high variance, shooting and removal by way of trapping appeared the most effective for both stock types; guard dogs appeared more effective for sheep whereas stalling animals at night was more effective for cattle (Scasta et al. 2018). The spatial extent, vegetation cover types adjacent to and comprising operations, husbandry practices employed, and local abundance of vultures likely all contribute to both the magnitude of black vulture depredation risk and the efficacy of mitigation strategies.

Mitigating human health and safety risks

Compared to reporting vulture damage to livestock, documentation of collisions between aircraft and vultures is relatively comprehensive given the possibility that a collision might result in the loss of human life (Blackwell and Wright 2006, Pfeiffer et al. 2018*a*). Between 2010 and 2019, 188 black vulture strikes, including 6 vulture carcasses found in air operation areas of civil airports, were voluntarily reported to the FAA Wildlife Strike Database. Most of these strikes occurred with aircraft traveling within the United States; however, 6 observations were from inbound flights from Honduras and Panama to the United States. There were 9 human injuries related to 4 vulture strike incidents during this time period. In addition to human injuries, structural damage to the aircraft itself from bird strikes can threaten human safety. Black vulture strikes with civil aircraft have resulted in $10,287,190 USD of reported damage between 2010 and 2019. During the same time period, black vultures were involved in 264 collisions with USAF aircraft, which resulted in no human injuries but $27,106,300 USD in damage according to data from USAF mandatory mishap reporting. For the USN, 63 black vulture strikes were reported, which resulted in $85,716,438 USD in damage. Black vulture strikes were responsible for $123,109,928 USD to civil and military aviation from 2010 to 2019.

Given these statistics, black vultures have the third highest relative hazard score (metric that estimates the probability of damage from a bird strike) for military aircraft (Pfeiffer et al. 2018*a*) and ranked in the top 11 riskiest species (based on severity and probability of a bird strike) for civil aviation (DeVault et al. 2018). In conjunction with their population and range expansions, the number of reported black vulture strikes to the FAA Wildlife Strike Database is also increasing (Figure 3).

Prevention of black vulture strikes with aircraft is difficult because most vulture strikes

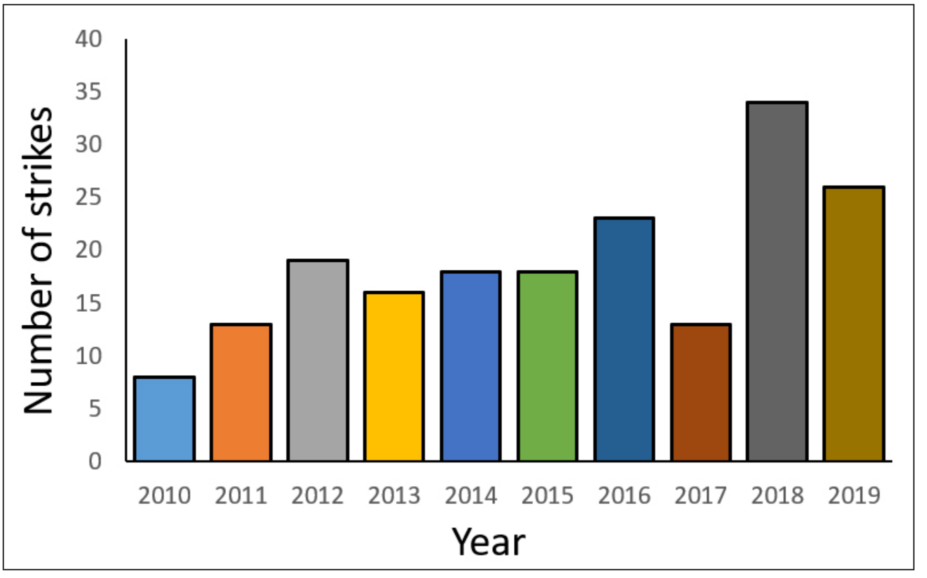

Figure 3. Frequency of black vulture (*Coragyps atratus*) bird strikes with civil aviation in the United States according to Federal Aviation Administration Wildlife Strike Database, 2010–2019.

occur outside of the airport environment, or ≥152 m above ground level, which is common for vultures (DeVault et al. 2005, 2016). In fact, the highest recorded bird–aircraft collision was with a Rüppell's vulture (*Gyps rueppelli*) at 11,278 m (Laybourne 1974). Therefore, promising mitigation methods include landscape modification (Pfeiffer et al. 2018*b*, although see Pfeiffer et al. 2020 in regard to landfill locations) and aircraft lighting that increases detection of the oncoming aircraft by the vulture and evokes an avoidance behavior (Blackwell et al. 2012, Goller et al. 2018). Identification of management areas by quantifying incursions of vulture and aircraft flight paths is another current management option (Avery et al. 2011, Novoselova et al. 2020). On-the-ground methods such as dispersal of roosts close to the airport using pyrotechnics and effigies and collection of carcasses still need to be evaluated in terms of changes in strike risk.

Mitigating property damage

The ingestion of non-food items has been recorded for multiple vulture species (Houston et al. 2007, Mee et al. 2007). Explanations of this behavior include: (1) misidentification of materials as bone fragments used for diet supplements, (2) to facilitate pellet formation, and (3) exploration of food options (Houston et al. 2007, Mee et al. 2007). Further, regurgitation of non-food items is transmitted to nestlings (Mee et al. 2007, Pfeiffer et al. 2017). However, it is uncertain if black vultures are ingesting or simply manipulating material. Most of the material that vultures have damaged emit the following compounds: hexanal, octanal, undecane, and nonanal, which are common in vinyl and plastic (Mauldin et al. 2003).

Specific items observed being damaged by vultures include but are not limited to seat cushions, roof shingles, caulking sealant, and the rubber portion of windshield wiper blades (Mauldin et al. 2003). Complaints about damage by black vultures commonly include damage to industrial and residential rooftops and vehicles at or near commonly used loafing and roosting sites. Vulture damage to boats from tearing upholstery in Virginia from 1994 to 1996 resulted in $19,600, or $3,217 per incident (Lowney 1999).

Due to the myriad types of property and site-specific characteristics that can be associated with vulture damage to property, the types of mitigation tools employed are variable. Tubemen (Lindell et al. 2018) and motion-activated sprinklers (Evans 2013) have been utilized, but their reported efficacy remains anecdotal. For the latter, the sudden onset of a sprinkler triggered by the vultures' movement can startle them and increases their latency to return to the site. The sound of the sprinkler, sight of the water stream, and unpredictability of the stimulus may cause a synergistic deterrent effect. Sprinklers have been successful against vultures on roofs of houses, on boat docks, and around backyard patios (Avery and Lowney 2016). Effigies can be but are not always effective at dispersing offending black vultures from the area where property is being damaged if a roost site is in proximity of the area/objects being damaged (Tillman et al. 2002). Traditional harassment methods utilizing sound as the primary deterrent coupled with lethal shooting as reinforcement are still the most commonly utilized techniques.

Knowledge gaps and research needs

Despite being one of the most abundant raptor species in the United States, black vultures are identified as an understudied species (Buckley 2020). Recent advancements toward increasing our understanding of vulture ecology and management have been achieved and include efforts focused on vulture movements (Avery et al. 2011, Holland et al. 2019), development of allowable take models to help inform the decisions of migratory bird management agencies (Zimmerman et al. 2019), the ecological role of vultures (Hill et al. 2018), and genetic diversity and population connectivity (Wostenberg et al. 2019). In spite of these works, given the rise of conflict with humans, there is still a need to fill basic knowledge gaps on life history and ecology, to better understand the drivers of the various conflicts, and to test existing and develop new management strategies.

Current modeling approaches can both identify factors contributing to changes in species distribution and predict further change (Snow et al. 2017, Tombre et al. 2019, Saenz-Jimenez et al. 2020). The BBS and Christmas Bird Count, longitudinal data sets comprising a large North American spatial extent, have been used to document and describe the North American black vulture distribution expansion (Latteman 2019, Zimmerman et al. 2019). Climate change is forecast to indirectly reduce the black vulture range in South America by way of facilitating increased interspecific competition with Andean condors (*Vultur gryphus*) and favoring more mountainous regions (Saenz-Jimenez et al. 2020); however, the factors contributing to changes in North America have not been clearly identified for this species. Such efforts are needed for vultures in North America to forecast potential future distribution increases, and in turn, areas where conflict may occur. Similarly, the behavioral and movement ecology of black vultures inhabiting range expansion areas have not been explored. Because factors such as resource availability may differ in these areas, birds may use these landscapes differently than areas of historical use. Further, individuals of avian populations undergoing a distribution expansion and occurring toward the periphery of the species distribution have been shown to be more aggressive than more insular occurring conspecifics (Duckworth and Badyaev 2007). Determining whether this phenomenon occurs in black vultures is germane, as more aggressive birds may more frequently conflict with humans.

Vultures often congregate at large communal roosts (Prather et al. 1976), the behavior facilitating the transfer of food patch knowledge, thermoregulation, and reducing the risk of predation (Beauchamp 1999). This behavior can also lead to increased conflict in areas within proximity of the roosts (Blackwell et al. 2007). Vulture roosts can contain >500 vultures (Prather et al. 1976). However, to date, investigations focused on understanding vulture selection criteria for these "mega-roosts" are absent (Sweeney and Fraser 1986). Anecdotal evidence suggests vultures may preferentially select roost sites (Rabenold 1987), but to our knowledge a use versus availability framework has not been employed to investigate vulture roost selection.

Tools such as distribution modelling have the potential to determine preferred landscape characteristics (Martens et al. 2020), which would be important for planning urban roost dispersal. More specifically, it may be possible that newly developed models for identifying and predicting avian nest locations (Bracis et al. 2018, Picardi et al. 2020) can be leveraged to gain a firmer understanding of roost selection. Understanding why vulture roosts appear and where they might appear in the future can help managers plan for a dispersal event following roost management activities and help determine areas on the landscape more likely to contain roosts in the future.

Population estimates and allowable take models (Runge et al. 2009) for black vultures have been recently generated for the United States where the species occurs (Zimmerman et al. 2019). However, in these estimates there is greater uncertainty (i.e., variance) in areas where black vultures have become established more recently. This is primarily attributed to less data being available as model inputs. If vultures continue to increase numerically and expand spatially into states such as Pennsylvania and Indiana, currently available population and allowable take estimates may be misrepresentative, by way of underestimation. This bias represents a management challenge that could potentially be rectified by generating more spatially specific population estimates using mark-resight techniques and models (McClintock et al. 2009). This technique has been employed to robustly estimate abundance and density for several avian species (Hurley et al. 2013) including raptors (Smith et al. 2015), but this method has not been validated for a gregarious wide-ranging raptor species like black vultures (Monadjem et al. 2014). We recommend this approach be explored for black vultures because if successful, resultant recalibration of population and allowable take estimates could provide greater management flexibility.

Vulture damage to property due to their affinity for damaging synthetic materials remains poorly understood. Mauldin et al. (2003) identified and collected the volatile compounds emitted by several vulture-damaged items and attempted to develop a synthetic materials mimic (SMM), but SMM bioassay trials were inconclusive. Determining whether this behavior is olfactory, aural, or tactile driven will allow researchers to develop and test novel mitigation strategies. Recent advancements in volatile compound research can offer pathways toward better understanding whether this behavior is olfactory based (Lubes and Goodarzi 2007). Further, contemporary strategies aimed at mitigating this damage type, including automated sprinkler systems and inflatable tubemen (Lindell et al. 2018) on flat roofs need to be robustly evaluated.

Myriad opportunities exist for better understanding and managing the vulture livestock depredation conflicts. Investigators have been successful at comparing loss estimates of both crops and livestock measured by producers and field investigations (Breck et al. 2011, Elser et al. 2019). Research focused on doing the same for vultures and livestock producers could be used to validate and/or develop correction factors for producer-generated estimates of loss, which could ultimately affect livestock indemnity programs. Gaining a better understanding of producer perceptions of the vulture–livestock conflicts, especially in areas where black vultures have recently become established, is also warranted. Movement and resource investigations focused on vultures in agricultural, urban, and suburban dominated landscapes is also needed, as nearly all black vulture space use investigations to date have had an airport/airfield nexus. Finally, robust testing of new strategies to reduce black vulture livestock depredation, damage to property, and risks to human health and safety are needed.

Bridging research and management

The need for applied research to conduct investigations in a manner that creates robust, defensible science can create research findings that are not immediately translational to management efforts or tool development. Managers often apply the sensible practice of using an integrated damage mitigation approach, where a suite of damage mitigation tools is used in concert or proceeding one another based on site-specific considerations (Conover 2001, Reidinger and Miller 2013). This strategy does not always lend itself well to providing data capable of being analyzed in a manner that provides inference regarding the individual and/or synergistic effectiveness of each tool.

For vultures, an emblematic example is research conducted to date on roost site dispersal, whereby investigators have largely examined the singular effects of important mitigation tools such as effigies (Avery et al. 2002, Tillman et al. 2002) but have not included treatments incorporating multiple contemporarily employed mitigation tools or stimuli such as initial roost dispersal by way of pyrotechnics and lasers followed by placement of effigies. Without incorporating multiple experimental treatments including both integrative and singular stimuli, the ability to defensibly determine the most effective tool combinations and quantify if synergistic effects of integrative approaches are occurring will continue to be elusive. Several advancements and adoptions, including the practice of modeling messy field-based data using Bayesian approaches that rely on previous knowledge (Jessop 2020) have the potential to help bridge this gap along with a robust study design that incorporates a novel and control stimuli.

Conclusions

Based on our synthesis of the current status of black vulture management and research in the United States we contend that important advancements in research have been achieved in recent years that have increased management efficacy. However, the general upward trajectory of human–vulture conflicts warrants additional investigations that shed new light on knowledge gaps regarding biology and ecology of the species and applied works aimed at developing novel or improving existing damage mitigation strategies. Performing the latter in close coordination with vulture damage management practitioners can help ensure these works are translational (i.e., adaptable by field personnel).

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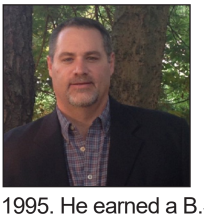

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