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Review

Limitations of population suppression for protecting crops from bird depredation: A review

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ABSTRACT

Blackbirds (Icterinae) in North America, and dickcissels (*Spiza americana* Gmelin), eared doves (*Zenaida auriculata* Des Murs), and monk parakeets (*Myiopsitta monachus* Boddaert) in South America can cause serious economic damage to grain crops. Farmers frequently advocate lethal bird damage abatement measures based on the perceived need to take immediate action to avoid serious economic losses. In comparison, wildlife managers must make informed decisions based on a multitude of factors, including local, state, and national environmental laws, administrative restrictions, logistics, costs, expected outcome, and cultural considerations related to wildlife stewardship. In this paper, we focus on practicality, environmental safety, cost-effectiveness and wildlife stewardship to evaluate efforts to manage avian crop damage using lethal control. In each case where a lethal program was initiated, at least one of these four tenets was violated and there was temporary relief at best.

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1. Introduction

In South America, eared doves (*Zenaida auriculata* Des Murs), monk parakeets (*Myiopsitta monachus* Boddaert), and dickcissels (*Spiza americana* Gmelin) often forage in crops and can cause economically significant damage (Bruggers and Zaccagnini, 1994; Bruggers et al., 1998; Basili and Temple, 1999a; Canavelli et al., 2008; Vitti and Zuil, 2012; Bernardos and Farrell, 2013; Bucher and Aramburú, 2014). In the United States (US), red-winged blackbirds (*Agelaius phoeniceus* L.), common grackles (*Quiscalus quiscula* L.), yellow-headed blackbirds (*Xanthocephalus xanthocephalus* Bonaparte), and brown-headed cowbirds (*Molothrus ater* Boddaert) cause damage to sprouting and ripening crops. The Prairie Pothole Region (PPR) in the northern Great Plains states of the US and southern Canada hosts millions of breeding and migrating blackbirds that damage ripening crops (Peer et al., 2003). In the southern US, blackbirds damage newly seeded and ripening crops, especially rice (Cummings et al., 2005).

Generally, wildlife professionals elect to evaluate all available management options to develop an integrated strategy for resolving crop depredations (e. g., Wildlife Services, 2009). But, the expense and perceived lack of efficacy of nonlethal techniques often frustrate growers urgently trying to protect their crops. This frustration is then manifested when growers exert pressure on government agencies to initiate population reduction programs, or even conduct their own illegal local population reduction campaigns to reduce crop depredations. An accumulation of practical experience and research studies has shown that lethal control alone is not an effective or appropriate response to alleviate crop damage caused by granivorous birds. In this paper, we discuss the ecology of these granivorous birds in relation to the practicality, environmental safety, cost-effectiveness, and wildlife stewardship

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of using lethal population control strategies (Slate et al., 1992).

2. Eared dove (Columbidae) in South America: biology and economics

The eared dove is probably the "worst" bird pest in South America because of its broad geographic distribution, high population levels, and the widespread damage reported in some areas. Crop damage includes mostly ripening sorghum and sunflower but may also affect emergent soybean seedlings, wheat, barley and rice. While farmers consider damage by eared doves to be very high, the few statistically reliable assessments indicate limited damage (≤5%) in most cases, with locally severe damage (>25%) in some regions or crop fields within a region (Canavelli et al., 2008; Bernardos and Farrell, 2013).

Eared doves are nomadic, open woodland species found throughout South America with exception of the Amazonian tropical forest. Eared doves are capable of breeding during the whole year, taking advantage of their ability to detect and exploit food and water sources within 100 km of a roost (Murton et al., 1974; Bucher and Bocco, 2009). Of particular importance is the species' potential for producing significant population outbreaks where rapid expansion of the cultivated area leads to changes in key land cover variables, as observed in central Argentina after introduction of grain sorghum in the 1960's (Murton et al., 1974; Bucher and Ranvaud, 2006). At that time, eared doves congregated in breeding and roosting colonies of up to 10 million birds (Bucher and Ranvaud, 2006). Similar population outbreaks occurred in other areas of Argentina and later in Colombia, Brazil, Uruguay, Bolivia and Paraguay. Outbreaks can be expected in areas where the regional landscape include >3% of grain sorghum or >10% of other suitable grain crops combinations and availability of >100 ha of contiguous breeding and roosting habitat (Bucher and Ranvaud, 2006).

2.1. Eared dove: population management challenges

During the initial dove population increases in Argentina in the 1960s, lethal control gained wide support among farmers (Bucher and Ranvaud, 2006). Pressure from farmers claiming heavy crop losses prompted government agencies to implement large scale lethal control campaigns which included dispersal of poisoned grains, poisoning water sources, aerial spraying of breeding colonies with highly toxic insecticides, burning of the vegetation in the breeding-roosting colonies, promotion of industrial processing of dove meat, and incentives for hunting, particularly international hunting tourism. After >4 years of marked operation effort and economic expenditures the population remained high (Table 1; Bucher and Ranvaud, 2006). During a 1990s dove population irruption in Sao Paulo state, Brazil, a nest and egg destruction program was implemented in an attempt to reduce crop damage.

Table 1
Temporal changes in sorghum-cultivated area and numbers of eared doves in colonies in Cordova, Argentina (Bucher and Ranvaud, 2006).

Year	Sorghum area (ha × 10^3)	Number of colonies
1960–1965	292	2.0
1966–1970	568	3.6
1971–1975	939	7.6
1976–1980	778	7.4
1981–1985	730	4.4
1986–1990	290	2.6
1991–1995	247	1.6
1996–1997	271	1

This strategy also was ineffective and abandoned as the principal method of managing crop damage (Bucher and Ranvaud, 2006).

In Brazil, government agencies compromised between agricultural interests and those of the general public by allowing destruction of nests and eggs but not of adult doves. In Uruguay, from 1975 to 1981 lethal control through toxic bait dispersal was very popular both because of mass killing of doves, and because it was conducted and financed by the government (Bruggers et al., 1998). However, due to increasing environmental concern, lethal control through bait dispersal is currently banned in Uruguay. Since 2000, lethal control options for managing pest birds have been limited to hunting (Ministry of Livestock, Agriculture and Fisheries, decree N° 164/96, May 2nd 1996 and subsequent modifications).

Bucher and Ranvaud (2006) found that the key factor controlling eared dove populations was the food supply (mostly cultivated grain) as long as forest fragments of suitable size to hold breeding colonies were available. Eared doves are capable of long-distance, nomadic movements, and thus can rapidly concentrate in areas where grain is available (Bucher and Bocco, 2009). Further, Bucher and Ranvaud (2006) concluded that density-dependent effects (population factors whose magnitude change according to the population level) lead to rapid compensation of control-induced mortality, neutralizing lethal control efforts. For example, reducing the population could result in less competition for food resulting in decreased mortality and increased natality (Newton, 1998).

3. Monk parakeet (Psittacidae) in South America: biology and economics

The monk parakeet, also known as the Quaker parakeet, is native to South America, occurring from central Bolivia and southern Brazil south to central Argentina (Bucher and Aramburú, 2014). It is considered an agricultural pest throughout its native range in South America (Fallavena and Silva, 1988; Aramburú, 1995). Most losses occur to sunflower, corn, and sorghum, but wheat, soybean (emerging seedlings), rice, and fruit in orchards are also damaged (Bruggers and Zaccagnini, 1994; Spreyer and Bucher, 1998). Crop damage solely attributable to monk parakeets is difficult to estimate because other pest birds also damage the same crops. On a regional level, monk parakeet damage is not considered economically significant (Canavelli et al., 2008; Vitti and Zuil, 2012). Locally, however, damage may exceed 25% (Bucher, 1992; Canavelli et al., 2008).

At the beginning of the 20th century, the monk parakeet colonized across the Pampas grasslands following agriculture expansion and the introduction of *Eucalyptus*, a highly preferred nesting tree (Bucher and Aramburú, 2014). Through the pet trade, the monk parakeet has been introduced to many countries beyond its native range, and populations are now established in North America and Europe. The species lacks some characteristics of an "efficient" bird pest, because it is a resident, non-migratory species that has a seasonally fixed, single-clutch (typically 5–6 eggs) breeding effort and a proportion of the population may not breed every year (Bucher et al., 1991; Bucher, 1992; Navarro et al., 1992; Martin and Bucher, 1993). However, the monk parakeet's unique ability to build its characteristic large compound nests provides great flexibility regarding nesting habitat requirements, as compared with all other parrot species which depend on cavities in trees or cliffs (Forshaw and Cooper, 1989; Spreyer and Bucher, 1998). Breeding and non-breeding parakeets roost in and maintain these nests year round.

3.1. Monk parakeet: population management challenges

Population models suggest that the monk parakeet's ecological

characteristics and population dynamics make them vulnerable to control, and even local eradication, provided that a well-organized and sustained effort using lethal techniques can be implemented (Pruett-Jones et al., 2007; Conroy and Senar, 2009). Additionally, population control strategies, including reproductive and lethal control, are the most preferred tactics by farmers to decrease crop damage by monk parakeets (Canavelli et al., 2013). During the first half of the 20th century, control of the monk parakeet was based on lethal methods and nest destruction. Government agencies paid for parakeet legs as an incentive for control on the regional scale (Long, 1981). In addition, nest destruction by each land-owner was enforced legally.

During the second half of the 20th century, government agencies in Argentina and Uruguay implemented nest spraying with toxic insecticides as the approved control method. Control campaigns were organized by government agencies and implemented by trained control teams paid by the farmers. Since 1980, agencies have managed parakeet populations by smearing a mixture of grease and a toxic insecticide (e.g., carbofuran) around the nest openings (Rodriguez and Tiscornia, 2002). The birds die from ingesting the toxicant as they preen the paste from their feathers. In practice, control campaigns maintained the monk parakeet population at a lower level than the carrying capacity of the area (Bucher et al., 1991). These campaigns were designed to systematically cover large areas but the population was able to recover in a few years (Bucher et al., 1991). This necessitated the need to periodically monitor and retreat whole regions which increased costs substantially.

In 1981–1982, the Uruguayan government and local farmers were involved in a control campaign that aimed to reduce the monk parakeet population in a heavily damaged agricultural area in the western part of the country. During those two years, eight people monitored and lethally controlled monk parakeets over a 509,600 km^2 area for a total cost of US$147,684 (E. Rodriguez, Unpublished data). The number of parakeets taken was estimated to be about 250,000 but the amount of damage reduced was not documented (E. Rodriguez, Personnel communication). The cost-effectiveness of this campaign could not be determined nonetheless a low benefit/cost ratio constrains the potential use of lethal control of monk parakeets, especially when overall damage level is low. Where local damage is high, attempting to reduce the population at the regional level is impractical, because of monk parakeet abundance, mobility, and wide distribution.

Currently, there are no pesticides specially registered for bird control in Argentina. Thus, treatment of nests with toxic chemicals is done with insecticides, usually carbofuran, which is allowed by local regulation. However, toxic chemicals for controlling monk parakeets, including carbofuran, are increasingly restricted in Argentina. Additionally, opposition by conservation organizations to lethal control is growing, having reached the courts in the province of Buenos Aires, Argentina (Canavelli et al., 2012). In Uruguay, the purchase and use of this pesticide is strictly controlled and monitored by the Ministry of Livestock, Agriculture and Fisheries (Decree 343/002, August 29, 2002). Treatment of nests creates serious risks for non-target species, including several birds and mammals that use nests for breeding or refuge (Martella et al., 1985) and scavengers that may ingest poisoned dead parakeets (Keith, 1991).

4. Dickcissels (Cardinalidae) in Americas: biology and economics

Dickcissels breed in the grasslands of central North America where pair formation occurs from late May through June, soon after the female arrives on a male's territory (Temple, 2002). In the breeding season, dickcissels are highly insectivorous as they meet physiological demands for breeding and as they provision rapidly growing nestlings. From late July to early September, post-breeding flocks form and southward movement is evident (Temple, 2002). Most migration occurs at night. Some migrating flocks linger in Central America for weeks and feed on abundant sorghum and rice crops (Temple, 2002). Other flocks move directly to wintering grounds in Venezuela where arrivals occur during September–October (Basili and Temple, 1999b). Most dickcissels spend about 7 months in the Venezuelan llanos, principally in the grain-producing states of Portuguesa, Cojedes, and Guárico, although some dickcissels winter in Colombia and Trinidad (Basili and Temple, 1999b). The dickcissel's mobility and communal roosting habit enable it to exploit food crops and other resources scattered in time and space. Birds in a communal roost have the benefit of the collective knowledge in determining where to find profitable foraging sites. Flightlines leaving a communal roost often radiate in several directions as birds return to sites where they foraged successfully the previous day, and less successful foragers presumably follow. Flightlines change during the course of the season as some sites become depleted and other locations emerge as prime feeding areas.

Dickcissels begin to migrate northward in late March-early April (Basili and Temple, 1999a). In preparation for spring migration, dickcissels become hyperphagic and add 10–15 g (33–50%) to their body mass (Basili and Temple, 1999b). During hyperphagia, dickcissels cause disproportionately more damage than during other months; consequently conflicts with farmers also increase (Basili and Temple, 1999a).

Farmers in Venezuela have been clashing with dickcissels for decades (Basili and Temple, 1999a). On their winter range in Venezuela, dickcissels take advantage of crop availability, particularly rice and sorghum. Seeds from these two crops were the most abundant food items found in a sample of dickcissels examined in Venezuela (Basili and Temple, 1999b). Although no precise damage assessments were available in the 1960s at the regional level, the general impression was that crop damage (mostly in sorghum) was low on average. In most cases, costs of the large-scale control campaigns appeared to exceed crop losses. Basili and Temple (1999a) estimated that depredation by dickcissels to the Venezuelan rice crop was 0.73% and the loss in the sorghum crop was 0.37%. Combined, the annual economic impact from dickcissel crop depredations was estimated to be US$1.87 million, with some producers incurring substantial losses (Basili and Temple, 1999a).

4.1. Dickcissels: population management challenges

The North American dickcissel breeding population declined dramatically in the 1960's and 1970's, but it has remained relatively stable, although at greatly reduced levels, for the past 30 years (Sauer et al., 2014). The mechanisms underlying both the previous population decline and the current status are not fully understood. However, research in Venezuela during the 1990's revealed controversial (and illegal) lethal control measures had been implemented on the wintering grounds during the period in question (Basili and Temple, 1999a,b). Investigators concluded that mortality on the wintering grounds could have accounted for the approximately 40% population decline during 1966–1978, when high dickcissel populations and low crop yields combined to fuel persecution of dickcissels by Venezuelan farmers anxious to protect their crops. Crop production increased in the 1980's and the regional impact of dickcissels on crop production probably decreased, but lethal control efforts did not stop and presumably they continue today, although documentation is lacking (Basili and Temple, 1999b). The extreme sociality of the dickcissel in winter,

which contributes to its success, also increases its vulnerability to devastating lethal control actions. Large winter roosts, sometimes consisting of millions of birds, make relatively easy targets for those attempting to protect their crops by killing large segments of the local dickcissel population. This behavior puts them at risk for large scale mortality from application of organophosphate chemicals or other toxicants (Basili and Temple, 1999a). The concentration of dickcissels wintering in Venezuela is remarkable, with winter roosts comprising >1 million birds common. Approximately 30% of the entire worldwide dickcissel population can roost together in a single sugar cane field (Basili and Temple, 1999a). Catastrophic mortalities have thus far been avoided, but with such consistently large, accessible aggregations vulnerability exists.

Previously, the preferred method for reducing a local bird population was illegal application of agricultural pesticides (Basili and Temple, 1999a). The frequency with which such illegal acts continue today has not been documented to our knowledge. The indiscriminate spraying of winter roosts in Venezuela not only jeopardizes the dickcissel population, but endangers other species using the roosts, including bobolinks (*Dolichonyx oryzivorous*), barn swallows (*Hirundo rustica*), and bank swallows (*Riparia riparia*; Basili and Temple, 1999b). Moreover, there is no evidence to suggest that large-scale mortality of dickcissels actually benefits farmers in Venezuela; the continued use of lethal measures is yet to be justified on economic grounds.

5. Blackbirds (Icteridae) in North America: biology and economics

The sheer number (~500 million) of blackbirds (Icteridae) in North America is daunting for wildlife managers charged with managing damage to ripening crops, especially corn, rice, and sunflower (Meanley and Royall, 1976; Linz et al., 2011). All three crops provide a readily available source of energy needed to undergo annual feather replacement and premigratory fattening needed for red-winged blackbirds, common grackles, and brown-headed cowbirds to migrate to wintering areas in the southern US and for yellow-headed blackbirds migrating to central Mexico (Lowther, 1993; Twedt and Crawford, 1995; Yasukawa and Searcy, 1995; Peer and Bollinger, 1997). The history of intensive study of blackbirds in relation to crop damage dates back to at least 1919 when blackbird damage to rice drew the attention of scientists (Meanley, 1971).

Rice is considered a minor crop in the US, although about 1 million hectares are planted annually (Meanley, 1971; Cummings et al., 2005). Ripening rice is available for blackbirds prior to fall migration whereas, sprouting rice is exploited by nesting blackbirds and spring migrants. Reliable regional bird damage estimates are scare due, in part, to difficult logistics associated with moving through ripening rice and newly planted flooded fields. Cummings et al. (2005) surveyed rice growers and estimated that blackbird damage to ripening and sprouting rice in Louisiana, Arkansas, Texas, California and Missouri was US$13.4 million, or about 1% of the total value of the crop.

Corn is a major crop in the US, with about 14 million ha planted annually. In 1957, an intense research effort was initiated to alleviate blackbird damage to field corn in Ohio (Stockdale, 1967). Blackbird damage was estimated to be US$15 million at that time. Scientists recognized that national damage was <1% but local damage near roost sites could be economically significant with 5–15% damage quite common near roost sites. Based on grower surveys, Wywialowski (1996) estimated bird damage in the top ten corn-producing states in 1993 and found a loss of 0.19% valued at US$25 million. Losses are likely ameliorated because corn is vulnerable only during the milk and dough development stages (3–4 weeks).

Sunflower is also a minor crop in the US, with about 597,000 ha planted annually (NASS, 2014). Ripening sunflower is particularly vulnerable to blackbirds because the crop is susceptible from early seed-set in mid-August until harvest in mid-October, a period of 8 weeks (Linz et al., 2011). Over a 2-year study in the Prairie Pothole Region of North Dakota, Klosterman et al. (2013) found that blackbird damage averaged US$1.3 million (0.2%) for corn and US$3.5 million (2.7%) for sunflower. None of the surveyed cornfields surpassed 5% damage whereas, 15% of ripening sunflower reported >5% damage.

5.1. Blackbirds: population management challenges

Over the past century, a wide array of blackbird damage management techniques have been assessed, including lethal control and harassment (Meanley, 1971; Linz et al., 2011). Currently, cost effective nonlethal methods of reducing damage to ripening crops are not available for grain growers. For that reason, corn, rice and sunflower growers historically advocated that government agencies reduce the blackbird population with whatever means are available (Stockdale, 1957; Meanley, 1971; Kleingartner, 2003). In the Lake Erie region of Ohio, Snyder (1961) attempted to reduce blackbird numbers with strychnine sulfate-treated cracked corn but was unsuccessful because the bait failed to attract the birds away from corn in the milk-stage of development. In the 1960s, the US Fish and Wildlife Service developed a surfactant (PA-14) for lethal control of blackbirds that was subsequently used at winter roosts but environmental concerns led to abandonment of this surfactant (Heisterberg et al., 1987; Dolbeer et al., 1997).

Similarly, in 1989, Heisterberg et al. (1990) sprayed an avicide (a.i., 3-chloro-p-toluidine hydrochloride, also 3-chloro-4-methylbenzenamine hydrochloride) on a roost of 330,000 blackbirds and European starlings (*Sturnus vulgaris* L.). About 3% of the pretreatment population died in the roost but total mortality could not be fully discerned. This study, which followed two other unpublished trials with a similar compound, was the last attempt with an aerially applied avicide (Heisterberg et al., 1990). Lack of efficacy and environmental concerns with aerially spraying a pesticide over a large area and potential for killing nontarget birds resulted in the termination of this practice.

An alternative to aerially spraying avicides is to broadcast avicide-laced baits. Glahn and Wilson (1992) broadcast DRC-1339 avicide (a.i., 3-chloro-p-toluidine hydrochloride, also 3-chloro-4-methylbenzenamine hydrochloride) treated rice baits near a large spring blackbird roost in Louisiana and killed an estimated 4 million blackbirds. A subsequent survey of rice producers estimated that damage to sprouting rice was reduced 83% compared to previous years. This suggested that lethal control of local blackbird populations might reduce local crop damage, but Glahn and Wilson (1992) concluded that such toxic baiting programs "should be reserved for similar severe-damage problems where other methods have failed". Also, a quantitative damage survey was not conducted to substantiate the results of the farmer survey. Data gathered since Glahn and Wilson (1992) alerted managers that nontarget birds may also eat the treated rice and die (Pipas et al., 2003). Consequently, DRC-1339 Concentrate Staging Area label (US Environmental Protection Agency Reg. No. 56228-30) must be carefully followed with particular attention to observing prebaited sites for nontarget birds (Eisemann et al., 2003).

Glahn and Wilson (1992) results prompted sunflower growers in the in the northern Great Plains to request an evaluation of the potential for using avicides along a major spring migration route in central US for reducing damage (Homan et al., 2004). Linz et al. (2003) showed that large numbers of blackbirds could be

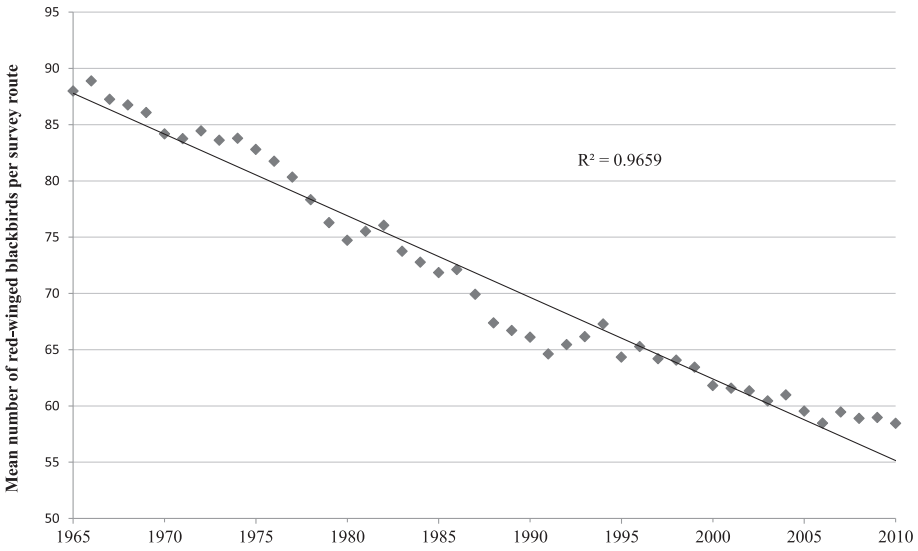

Fig. 1. Data collected from the North American breeding bird survey shows that the red-winged blackbird population has declined significantly between 1966 and 2012 (Sauer et al., 2014). The decline is likely due to habitat loss resulting from changes in agricultural practices (Blackwell and Dolbeer, 2001).

attracted to rice-baited plots in stubble corn fields but there was a risk that nontarget birds could eat the baits. Moreover, as part of the evaluation process, Blackwell et al. (2003) used a mathematical model to assess the potential population effects and cost-benefit ratio removing up to 2 million red-winged blackbirds annually under a 5-year program of baiting with DRC-1339 treated rice. They found that the cost-benefit ratio ranged from 1:2.3 to 1:3.6. Additionally, removing 2 million blackbirds from a spring-migrating population of roughly 50 million blackbirds likely would not result in a measurable reduction in sunflower damage (Peer et al., 2003). Given the large number of blackbirds and the potential variability in the effectiveness of the baitings and associated costs, the benefits of managing spring migrating blackbirds appeared to be negligible. Due to risks to nontarget birds and costs, an operational spring baiting program was not initiated.

Finally, DRC-1339 and related compounds were tested for reducing flocks of fall migrating blackbirds feeding on ripening sunflower (Cummings et al., 1990; Linz et al., 2011, 2012). Although some blackbirds were killed, these authors concluded that the majority of blackbirds preferred to feed on the ripening achenes (i.e., the crop) rather than forage on dry grains treated with DRC-1339 and placed on the ground or elevated bait trays.

6. Conclusions and solutions

Bird damage to agricultural crops is an economically important international problem, especially to a small percentage of growers that suffer most of the damage (Klosterman et al., 2013). For decades grain growers have consistently appealed to their respective management agencies for the development of methods for reducing depredating bird populations (Murton et al., 1974; Basili and Temple, 1999a; Linz et al., 2011). Our review showed that lethal management of granivorous bird populations has shortcomings, including public resistance, low cost-effectiveness, difficult logistics, and potential environmental risks, especially to nontarget birds. Additionally, overall changes in land-use patterns (e.g., wetland drainage, grassland conversion) and climate change are more likely to drive a sustained long-term bird population decline than are lethal programs (Blackwell and Dolbeer, 2001; Forcey et al., 2007). For example, Blackwell and Dolbeer (2001) suggested that changes in farm practices in Ohio caused the red-winged blackbird population to decline 53% between 1966 and 1996. Further, from 1966 to 2011, the annual breeding bird survey shows that the US national red-winged blackbird population has declined about 38% (Sauer et al., 2014; Fig. 1).

Managing bird population numbers does not necessarily imply killing birds; non-lethal approaches including reproductive inhibitors should be investigated (Avery et al., 2008). We hasten to add that many potentially effective non-lethal methods are rendered virtually useless in the face of overwhelming numbers of depredating birds. Because of inherent time lags associated with physiological or behavioral processes underlying the activity of many non-lethal methods, large populations of depredating birds can inflict serious damage before non-lethal measures can take effect. In these cases, population reduction prior to implementation of repellent or contraceptive methods might be considered. Regardless, contraceptive methods and lethal control share several limiting factors that constrain their use, including: a) the cost and operational difficulties of maintaining long-term control, b) defining what is the desired population level, c) applying management actions to the birds actually causing the crop damage, and d) immigration from non-treated areas that compensates for reduced natality or increased mortality.

Lethal methods should not be viewed as open-ended, but should be implemented with specific goals, objectives, and rationale. The ultimate management goal should be crop damage reduction, not bird mortality. Progress toward the objectives should be monitored and evaluated to ensure resulting mortality is commensurate with stated goals of the overall management effort. We caution that in situations where birds (e.g., dickcissels, eared doves) roost in large numbers, irrational approaches to population management can have grave consequences for the overall population.

Our investigation using practicality, environmental-safety, cost-effectiveness and wildlife stewardship as screens revealed no circumstances where population management alone was an acceptable alternative to nonlethal damage reduction methods. Crop losses can potentially be mitigated through changes in agronomic practices. For example, recommendations to alter planting and harvesting schedules to minimize overlap of ripening crops with dickcissels' winter residency could benefit Venezuelan farmers (Basili and Temple, 1999b). Similarly, growers can minimize

damage by juvenile monk parakeets by altering harvest time and modifying the density of plants (Bucher, 1992; Canavelli, 2011; Canavelli et al., 2012). To avoid late season bird damage, many growers can expedite harvest by applying a desiccant and subsequently hasten dry-down (Linz et al., 2011). Growers also can use pyrotechnics or other nonlethal measures, such as sirens or horns or harassment patrols, to successfully scare birds from their crops (Basili and Temple, 1999b; Linz et al., 2011). We caution, however, that birds quickly habituate to these devices. Roost dispersal methods might be especially effective for diminishing concentrations of blackbirds near susceptible crops but other granivores, such as eared doves, might not respond equally well. Spreading the birds among numerous smaller roosts might also spread the damage and economic impacts among more growers so that the burden is not concentrated on a few producers.

Another option is to screen crop varieties for bird resistant characteristics. Dolbeer et al., (1982, 1986) suggested that screening corn hybrids based on husk, ear, and kernel characteristics known to be correlated with bird damage would be useful for growers with bird damage. In the 1980s, plant breeders unsuccessfully attempted to develop an economically viable bird resistant sunflower (Linz et al., 2011). Even so, a grading system of commercially available sunflower hybrids that show bird resistance might be more economically feasible. Alternative food sources (e.g., perennial sunflower) planted on marginal farmlands and wildlife refuges could also increase the effectiveness of repellents, and coordinated, regional management efforts to provide depredating birds with refuges could contribute to a stable, long-term solution (Avery et al., 2001; Linz et al., 2011).

Responsible wildlife damage management decisions must take into account laws, policies, biology, economics, environmental and social considerations, and practicality (e.g., Slate et al., 1992). We encourage the development and implementation of innovative, integrated management approaches using all available and acceptable techniques tailored for specific crop damage scenarios. The availability of efficacious non-lethal tools for granivorous bird management would reduce pressure to use lethal methods for managing damage. We expect that the development of consistently reliable nonlethal methods of managing damage will take time and significant monetary and human resources.

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