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Review

A review of nonlethal and lethal control tools for managing the damage of invasive birds to human assets and economic activities

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Abstract

Invasive birds cause damage to economies, natural resources, and human safety across the globe. In the United States, rock doves (*Columba livia*), Eurasian collared doves (*Streptopelia decaocto*), rose-ringed parakeets (*Psittacula krameri*), monk parakeets (*Myiopsitta monachus*), common mynas (*Acridotheres tristis*), European starlings (*Sturnus vulgaris*), and house sparrows (*Passer domesticus*) are among the invasive and often harmful small-bodied birds inhabiting periurban habitats. The destructive nature of these species warrants a review of methods to reduce or eradicate populations along with methods to reduce damage when population eradication cannot be achieved. We reviewed damage management literature from these species' native and introduced ranges. Additionally, we used the behavior and ecology of these species to inform tool recommendations and potential efficacy under various damage scenarios, while being sensitive to cultural preferences and location of implementation (residential, commercial, and agricultural). Although this review focuses on invasive birds in the United States, it is applicable to other pest species across the globe. Our review highlights areas where research is needed to validate promising damage management methods (lethal control, fertility control, habitat modification, exclusionary methods, frightening devices, and chemical repellents). Where birds are invasive, integrated pest management techniques should focus on eradication or population reduction (toxicants, shooting, and trapping) to keep populations at levels where nonlethal tools can reduce damage. We acknowledge the efficacy of an eradication campaign depends on biological, environmental, and economic factors, along with social license for lethal removal. We recommend integrated pest management strategies including lethal and nonlethal tools specific to the damage problem. Sustained efforts to reduce invasive populations should be used along with integrated deterrent strategies for short-term damage relief.

Key words: agriculture, damage management, global invader, introduced bird, nonnative avifauna, tourism, urban management

Introduction

Invasive species are introduced, nonnative species that spread rapidly and are hazardous to native ecosystems, agricultural systems, and human health and safety (Iannone et al. 2021; Mack et al. 2000; Paini et al. 2016). Invasive birds have unique impacts (Martin-Albarracin et al. 2015) with three species included on the list of the 100 of the world's worst invasive species (Lowe et al. 2004). The success of avian invaders is due to a generalist diet, high fecundity, tolerance of humans, dispersal capabilities, and prevalence in the pet trade (O'Connor 1986; Sol et al. 2017; Evans et al. 2018; Gippet and Bertelsmeier 2021). The rock dove (*Columba livia*), Eurasian collared dove (*Streptopelia decaocto*), rose-ringed parakeet (*Psittacula krameri*), monk parakeet (*Myiopsitta monachus*), common myna (*Acridotheres tristis*), European starling (*Sturnus vulgaris*), and house sparrow (*Passer domesticus*) are examples of such avian invaders (Invasive Species Compendium 2012; Dyer et al. 2017). Although not a comprehensive list, it encompasses smaller-bodied birds that inhabit urban and periurban habitats, thus species that simultaneously impact agricultural and urban economies along with natural resources (Klug et al. 2019). Most of these species are widespread and ubiquitous across the globe, while also encompassing the suite of harmful nonnative birds in the United States (Downs and Hart 2020; Pruett-Jones 2021). Most of these species can form large flocks while foraging and roosting, reaching numbers that increase negative interactions with the public (Shirley and Kark 2009).

Birds that roost in urban settings and forage in agricultural environments are of particular concern (Coombs et al. 1981; Yap et al. 2002; Hetmański et al. 2011; Avery and Lockwood 2017; Avery and Shiels 2018; Linz et al. 2018). Invasive birds are reservoirs and vectors of human, wildlife, and livestock diseases (Pimentel et al. 2000) and can impact native wildlife though disease transmission, resource competition, aggression, and predation (Kumschick and Nentwig 2010; Baker et al. 2014; Martin-Albarracin et al. 2015; Hernández-Brito et al. 2018). Birds flocking near airports are a hazard to human safety through airplane strikes, with invasive birds ranking high on strike risk (rock dove = 4^{th}, European starling = 6^{th}, common myna = 43^{rd}, house sparrow = 57^{th}; DeVault et al. 2018). Urban nighttime roosts result in noise complaints and unsanitary conditions, which despoil buildings and increase the risk of disease transmission (Spennemann et al. 2017; Linz et al. 2018; Shiels and Kalodimos 2019; Mori et al. 2020). Risk of foodborne illness also increases when flocks interface with livestock facilities or contact food for human consumption (Carlson et al. 2011a, b; Mori et al. 2018; Chandler et al. 2020). Birds can become pests in agroecosystems due to consumption of crops and feeding behaviors that increase the severity of crop damage, such as dropping food and discarding partially eaten food (Toor and Ramzan 1974; Ali et al. 1981;

Tillman et al. 2000; Sebastián-González et al. 2019). Some birds completely consume fruits, while others cause partial damage which increases spoilage and reduces marketability (Carlson et al. 2013). Invasive birds also consume stored grains and unripe fruit, extending the temporal damage window (Chakravarthy 2004; Bhargava and Kumawat 2010; Woods et al. 2022).

The destructive nature of invasive birds warrants methods for damage reduction in addition to population suppression (Shiels et al. 2020). Olsen (1998) emphasizes a focus on damage reduction, not just reducing pest numbers, and outlines steps of successful management plans, including 1) setting clear objectives (e.g., reducing damage to an acceptable level), 2) identifying management options, 3) selecting control tools, and 4) establishing criteria for monitoring efficacy. Previous work has focused on eradication of specific species of invasive birds (Pruett-Jones et al. 2007; Johnson and Donaldson-Fortier 2009; Bednarczuk et al. 2010; Phillips et al. 2012; Bunbury et al. 2019; Feare et al. 2021a) or the global trends and impacts of invasive birds (Menchetti and Mori 2014; Pitt et al. 2017; Shivambu et al. 2020; Downs and Hart 2020), but few have included a comprehensive evaluation of nonlethal damage management methods and tools for situations where eradication is not possible or delayed (Braysher 2017; Conover 2002; Tracey et al. 2006; Linz et al. 2018). Thus, our objective was to complete a comprehensive review of nonlethal techniques to reduce damage while also highlighting management methods for lethally controlling populations of invasive birds commonly found to cause damage in the United States. Although important, we do not focus on preventing the introduction of nonnative species through international trade nor implications of such regulations. We reference avian behavior and ecology to inform tool recommendations and efficacy in various damage scenarios (i.e., urban, periurban, and rural). If methods lack field implementation or testing on invasive species, we reference studies on other birds to gauge potential efficacy. We identify candidate tools for evaluation and provide guidelines for actions that can be taken to protect resources. We also briefly address the importance of human dimensions in strategic plans to reduce disagreements among people concerning strategies and methods to decrease bird damage.

Population Control

Criteria for attempting eradication include: 1) removal rate exceeds replacement, 2) immigration can be prevented, 3) all reproductive animals are accessible for removal, 4) detection is possible at low densities, 5) a favorable cost:benefit ratio, and 6) a suitable sociopolitical environment (Bomford and O'Brien 1995; Olsen 1998). Frequently, all these conditions cannot be met and therefore species eradication is often impractical. However, population suppression may be feasible for reducing damage if well-funded, sustained, and broad-scale control plans are established (Feare et al. 2021a) within the bounds of cost-benefit ratios (Bomford and O'Brien 1995). Additionally, cooperative approaches coordinated at broad landscape scales are better than individual attempts (Olsen 1998). Innovative studies have focused on identifying the subset of birds responsible for the damage to cull (Khatri-Chhetri et al. 2020), identifying the best habitat or locations to perform lethal control (D'Amico et al. 2013; Klug and Homan 2020), or population connectivity to inform if local control will be effective (Woolnough et al. 2006; Rollins et al. 2009; Jacob et al. 2015). Rash, poorly planned, and poorly executed culling could hamper an effective shooting campaign (Grarock et al. 2014; Bunbury et al. 2019). Safe, discrete methods to lethally take invasive birds are available while they are foraging, loafing, nesting, roosting, and along flight paths (Conroy and Senar 2009; Avery and Feare 2020). In a lethal campaign, birds may change behavior to avoid risky areas after flock mates have been removed (Invasive Species Compendium 2012; Anderson et al. 2022a). Thus, swift action is needed to remove the most birds prior to behavioral changes (e.g., change in roosting locations) and ongoing monitoring programs are necessary to pinpoint new locations. Established populations of invasive birds are likely impossible to eradicate at the continental scale given population suppression has been shown to be limited for large populations of native species at broad landscape scales (Linz et al. 2015). Furthermore, most successful eradications of invasive species are limited to islands with small populations or scenarios on the mainland where small population are contained (Olsen 1998).

Numerous examples of eradication campaigns exist, which highlight scenarios and methods that bolster success. In the Seychelles, eradication of 545 rose-ringed parakeets on the 157-km^2 island of Mahé cost approximately US$1 million and took five years (Bunbury et al. 2019), lending evidence to the expense of complete eradication (Menchetti et al. 2016). Saavedra and Medina (2020) also successfully eradicated 175 rose-ringed parakeets from La Palma, Canary Islands. Eradication of 1,477 rock doves from the Galápagos took seven years but the cost was relatively less due to the species' association with humans (Phillips et al. 2012). Additional successful eradications include 750–1,000 common mynas removed from the Seychelles with trapping and shooting (Canning 2011; Feare et al. 2017, 2021b) and 310 wild turkeys (*Meleagris gallopavo*) removed from Santa Cruz Island over six years (Morrison et al. 2016). Eradication of 13 house crows (*Corvus splendens*) from Socotra Island, Yemen, took 15 days of professional marksmanship compared to many years of a bounty program removing > 550 eggs and chicks (Suliman et al. 2010). In an eradication attempt on Robinson Cruise Island, elusive house sparrows remained, and reinvasion is likely due to lack of biosecurity measures (Hagen et al. 2019). Attempts to suppress large, established invasive populations have been unsuccessful or ended prior to complete eradication (e.g., house sparrows from Mauritius;

Bednarczuk et al. 2010; Avery and Feare 2020). Populations of mitred conures (*Psittacara mitratus*) on Maui Island, Hawaii, USA, have been reduced to lows of 20 birds mainly though shooting techniques and extensive public outreach (Radford and Penniman 2014). Sol and Senar (1995) found that removal of urban rock doves in their native range resulted in rapid immigration of individuals from areas where no control was exerted despite limited home ranges. Controlling European starlings over continental scales has proven difficult (Woolnough et al. 2005, 2006; Campbell et al. 2016), but genetic evaluation has pinpointed where local control is the most effective (Rollins et al. 2009) or how local control can prevent range expansion (Rollins et al. 2011). Thus, factors including avian population size, geography, movement behavior, habitat and terrain, and association with humans all influence success along with the timeline and cost of the culling campaigns.

Shooting (Shotguns and Rifles)

Firearms are regularly used to dispatch invasive birds in culling campaigns (Millett et al. 2004; Suliman et al. 2010; Canning 2011; Phillips et al. 2012; Table 1, Figure 1, see Supplementary material Table S1, Appendix 1). The proper selection of firearms increases culling efficacy, while being sensitive to public perception. For coordinated shooting campaigns, a CO_2 air rifle can be used when birds are perched at foraging, loafing, nesting, and communal roosting sites. The quiet accuracy of an air rifle can reduce public attention and flushing of conspecific birds (Blanvillain et al. 2020). A pellet caliber of .22 is preferred for lethality, but smaller .177 pellets may be a better safety option for small birds at close range. A silenced conventional .22 rifle along with high quality subsonic ammunition can be as quiet as an air rifle and allow more efficiency at various distances with reduced need for a rangefinder (Per-Arne Åhlén, Swedish University of Agricultural Sciences, *personal communication*, 2021). The rifle could be accurately sighted for shooting individual birds via a green laser or a red spotlight to not disturb adjacent birds (Klug et al. 2021). Alternatively, night vision rifle scopes can be used to reduce alarm by birds and attention of onlookers. While studies on mammals use forward looking infrared (FLIR) to detect the body heat of animals in vegetated areas, Christiansen et al. (2014) found that body size and low contrasts in temperature limit the application of thermal sensors in small endotherms (e.g., birds). Extreme care should be taken in identifying line of sight, target, and backdrop to avoid property damage, injury, and ricochet. A 12-gauge shotgun is ideal for culling birds in flight along regular flight lines or upon arrival at foraging areas but should be limited at loafing and roosting sites to prevent abandonment or lessen behavioral shifts in site use. Alternatives to lead pellets or shot should be prioritized to avoid environmental contamination.

Table 1. Current and potential management options for damage situations involving invasive birds. We include citations if the method has been tested in the native or introduced ranges of the following birds considered invasive in the United States: Rock doves (*Columba livia*; RODO), Eurasian collared doves (*Streptopelia decaocto*; EUCD), rose-ringed parakeets (*Psittacula krameri*; RRPA), monk parakeets (*Myiopsitta monachus*; MOPA), common mynas (*Acridotheres tristis*; COMY), European starlings (*Sturnus vulgaris*; EUST), and house sparrows (*Passer domesticus*; HOSP). We include the number of studies pertaining to each invasive species for a tool; § = study type of field (F), lab (L), or modeling (M); ‡ = response variable for field studies that report reduction in bird abundance (A), reduction in damage (D), or bird behavior (B) including movement or habitat use (references listed in Supplementary Material). All tools and methods vary in efficacy depending on pest species, landscape, and deployment strategy (e.g., reduce habituation by switching, combining, and moving both lethal and non-lethal devices. All methods and tools should be operated in accordance with local, regional, and national regulations, including depredation permits, firearm laws, and pesticide regulations.

POPULATION CONTROL TOOLS AT NESTING, FORAGING, LOAFING, AND ROOSTING SITES							
Tool or method	Short description	Advantages	Disadvantages	Pest bird	Number of studies	Study type§	Response variable‡
Shooting (n = 25)	Lethal removal by firearm; shotguns for incoming birds at foraging sites and air rifles for precise removal while perched at foraging sites or roosting in trees or on buildings	• Quick humane euthanasia • Access to individuals with trap neophobia • Avoids nontarget species	• Potentially scares away conspecifics • Public acceptance (safety) in urban areas • Small-bodied birds hard to target • Requires skilled marksmen • Intelligent species learn of threat	RODO EUCD RRPA MOPA COMY EUST HOSP	4 0 4 4 8 3 2	3^F, 1^M 3^F, 1^M 2^F, 2^M 8^F 2^F, 1^M 2^F	3^A 3^A 2^A 8^A, 2^D 2^A, 1^B 2^A
Traps & Nets (n = 58)	Euthanasia after capture with live-traps or spring-loaded traps on ground or platform; hand-held nets or mist nets	• Effective for gregarious species (live decoy) • Effective with established feeding stations • Access to gun-shy animals or locations • Avoids nontarget species	• Limited in urban roosts due to ineffective lure • Limited on foraging areas due to alternative food • Long-handled hand nets limited to accessible roosts (low tree branches or ledges) or nests • Labor intensive to operate, monitor traps • Intelligent species learn of threat	RODO EUCD RRPA MOPA COMY EUST HOSP	7 0 5 6 22 9 9	7^F 5^F 3^F, 3^M 22^F 8^F, 1^M 9^F	6^A, 2^B 4^A, 1^B 3^A, 1^D 20^A, 3^B, 3^D 8^A 8^A, 3^B, 2^D
Avicides (n = 62)	Lethal control with toxic bait, wetting agents, or frightening agents. Toxicants currently registered for EUST, RODO, EUCD, and HOSP, but not MOPA, RRPA, or COMY in the United States (e.g., DRC-1339)	• Effective for flocking species (foraging) • Effective with established feeding stations • Effective for roosting species (surfactants) • Capable of high take numbers	• Limited in urban roosts due to ineffective lure • Limited on foraging areas due to alternative food • Restricted use under pesticide regulations • Requires certified pesticide applicator, labor intensive • Public acceptance for pesticides varies • Effort needed to avoid nontargets • Use restricted to cold temperatures (wetting agents)	RODO EUCD RRPA MOPA COMY EUST HOSP	8 0 3 7 7 24 13	5^F, 4^L 1^F, 3^L 6^F, 1^L, 1^M 6^F, 1^L 20^F, 6^L, 1^M 6^F, 7^L	5^A, 2^B 1^D 5^A, 1^B, 2^D 6^A, 1^D 18^A, 3^B, 1^D 5^A, 2^B, 2^D
Fertility Control (n = 52)	Population control by limiting fertility and reproduction via contraceptives (Diazacon and Nicarbazin), nest destruction, egg oiling, or nest box modification (e.g., hole size)	• Effective for small, urban populations • Effective with established feeding stations • Increased public acceptance	• Limited in urban roosts due to ineffective lure • Limited on foraging areas due to alternative food • Effort needed to avoid nontargets (contraceptives) • Daily ingestion before breeding (Nicarbazin) • Requires limited breeding season • Nests need to be accessible for destruction • Regulatory burdens (contraceptives)	RODO EUCD RRPA MOPA COMY EUST HOSP	13 0 5 11 8 6 9	7^F, 6^L, 2^M 3^F, 3^L 7^F, 4^L, 2^M 8^F 6^F 7^F, 2^L	7^A, 3^B 3^A, 2^B, 1^D 5^A, 5^B 8^A, 3^B, 1^D 6^A, 2^B 6^A, 4^B, 1^D

Table 1. (Continued).

Natural Predators (n = 14)	Use falconry or provide predator habitat (e.g., nest boxes, perches) to attract natural predators; protector dogs; human scarers	• Promoting native predators aids conservation • Creates risky landscape for prey species • Increased public acceptance	• Expensive, labor intensive (falconry) • Passive methods are site specific (nest boxes, perches) • Does not control pest populations	RODO	4	4^{F}	4^{A}
				EUCD	0		
				RRPA	0		
				MOPA	3	3^{F}	3^{A}, 1^{B}, 2^{D}
				COMY	1	1^{F}	1^{B}
				EUST	5	5^{F}	2^{A}, 4^{D}
				HOSP	1	1^{L}	

NONLETHAL DAMAGE MANAGEMENT AT URBAN NESTING, FORAGING, LOAFING, AND ROOSTING SITES

Tool or method	Short description	Advantages	Disadvantages	Pest bird	Number of studies	Study type§	Response variable‡
Modify Habitat (n = 99)	Reduce habitat suitability; replace landscaping with native species unsuitable for roosting; alternative building designs; reduce supplemental food	• Promoting native plants aids conservation • Natural habitat less prone to invasive birds • Less trash is aesthetically pleasing	• Trimming roost trees weakens trees • Replacing buildings often not feasible • Public compliance needed to reduce access to food	RODO	16	15^{F}, 1^{L}	13^{A}, 10^{B}
				EUCD	4	4^{F}	4^{A}, 2^{B}
				RRPA	10	10^{F}	6^{A}, 8^{B}, 3^{D}
				MOPA	27	27^{F}	18^{A}, 22^{B}, 1^{D}
				COMY	11	11^{F}	11^{A}, 8^{B}
				EUST	17	17^{F}	16^{A}, 10^{B}
				HOSP	14	14^{F}	14^{A}, 10^{B}
Exclusion (n = 11)	Antiperch tools reduce appeal of roost or reduce perch space; net roost sites; use water spray or electric shock to cause birds to reflexively withdraw	• Does not harm vegetation • Not labor intensive once installed	• All tools require maintenance • Netting not practical on large roosts • Nets, spikes are not aesthetically pleasing • Small birds can avoid devices	RODO	7	5^{F}, 2^{L}	3^{A}, 2^{B}
				EUCD	0		
				RRPA	0		
				MOPA	0		
				COMY	0		
				EUST	3	2^{F}, 1^{L}	2^{A}
				HOSP	1	1^{F}	1^{A}
Visual Deterrents (n = 14)	Deploy dead bird effigies, predator models, scarecrows, hawk eyes or novel objects (reflective, wind-propelled, drones, lasers)	• Initial affordability (scarecrows, ribbons, etc.) • Inexpensive operation, maintenance • Portability • Drones are mobile, reach inaccessible areas • Lasers capable of covering larger areas	• Habituation without reinforcement (shooting) • Need to routinely move devices • Limited range for stationary devices • Tools not aesthetically pleasing • Public acceptance for drones varies • Lasers potential eye hazard (safety)	RODO	6	5^{F}, 1^{L}	5^{A}, 3^{B}
				EUCD	0		
				RRPA	0		
				MOPA	1	1^{F}	1^{A}, 1^{B}
				COMY	1	1^{F}	1^{B}
				EUST	5	4^{F}, 1^{L}	3^{A}, 2^{B}
				HOSP	1	1^{F}	1^{B}
Auditory Deterrents (n = 19)	Deploy loud sounds (e.g., cannons, pyrotechnics); bioacoustics (e.g., species-specific distress/alarm calls, predator noises), or sound to avian mask communication (i.e., sonic nets)	• Initial affordability (cannons) • Inexpensive operation, maintenance (cannons) • Portability (cannons, pyrotechnics) • Bioacoustics reduce habituation • Creates risky landscape for prey (sonic net) • Effective with alternative food, predators (sonic net)	• Fire hazards (cannons, pyrotechnics) • Habituation without reinforcement (shooting) • Need to routinely move devices • Limited range for stationary devices • Reduced range in adverse weather • Noise pollution in human-inhabited areas	RODO	5	5^{F}, 1^{L}	3^{A}, 3^{B}
				EUCD	0		
				RRPA	0		
				MOPA	0		
				COMY	6	6^{F}	6^{B}
				EUST	7	7^{F}	6^{A}, 6^{B}
				HOSP	1	1^{F}	1^{A}

Table 1. (Continued).

Chemical Repellents (n = 9)	Spray chemical repellent onto surfaces or as a fogger to act as irritant; use odor repellent in nest boxes to increase risk perception	• Fogging effective in enclosed spaces • Accessible application methods	• Fogging not practical around humans (odor) • Fogging registered for areas not growing food • Surface application may damage substrate • Animal welfare (sticky substances) • Constant application or reapplication required • High active ingredient residues needed, expensive	RODO EUCD RRPA MOPA COMY EUST HOSP	3 0 0 0 0 5 1	3^{F} 3^{F}, 2^{L} 1^{F}, 1^{L}	2^{A}, 3^{B} 2^{A}, 2^{B} 1^{B}, 1^{D}
NONLETHAL DAMAGE MANAGEMENT AT AGRICULTURAL FORAGING SITES							
Tool or method	Short description	Advantages	Disadvantages	Pest bird	Number of studies	Study type[§]	Response variable[‡]
Modify Crop & Habitat (n = 57)	Reduce crop vulnerability by eliminating early- and late-maturing crops in same locality, selecting bird-resistant varieties; alter agricultural timing with delayed planting/advanced harvest; place vulnerable crops away from flight lines, loafing sites, and night roosts; use large fields, reduce space between plots (damage > at field edges); manage habitat surrounding crop fields and provide alternative forage (e.g., lure crops, delay disking); enclose barns or change pellet size for livestock	• Inexpensive implementation • No operation, maintenance expenses	• Compromises agricultural diversity (not growing crop) • May reduce yield or crop quality (crop varieties, timing) • Limited by landscape configuration and property lines • Limits flexibility/crop choice for farmers	RODO EUCD RRPA MOPA COMY EUST HOSP	3 0 7 14 1 15 17	3^{F} 7^{F} 14^{F} 1^{F} 10^{F}, 5^{L}, 1^{M} 17^{F}	1^{B}, 3^{D} 3^{A}, 1^{B}, 6^{D} 11^{A}, 1^{B}, 6^{D} 1^{D} 5^{A}, 8^{B}, 7^{D} 1^{A}, 5^{B}, 16^{D}
Exclusion (n = 17)	Enclose crops or trees using temporary or permanent netting or overhead wires; place bags over fruiting body during damage period	• Netting offers complete exclusion if installed properly for specific pest species • Bagging effective with alternative food • Bagging is inexpensive on small plots	• Netting can be expensive, labor intensive • Small birds maneuver through overhead wires • Bagging is labor intensive • Bagging can cause insects, mold • Only viable on small fields	RODO EUCD RRPA MOPA COMY EUST HOSP	0 0 3 0 4 8 2	 3^{F}, 1^{L} 4^{F} 7^{F}, 1^{L} 2^{F}	 3^{D} 1^{A}, 4^{D} 5^{A}, 1^{B}, 5^{D} 1^{A}, 1^{B}, 1^{D}
Visual Deterrents (n = 32)	Deploy dead bird effigies, predator models, scarecrows, hawk eyes, or novel objects (e.g., reflective, wind-propelled, drones, lasers)	• Initial affordability (scarecrows, ribbons, etc.) • Inexpensive operation, maintenance • Portability (scarecrows, ribbons, etc.) • Drones are mobile, reach inaccessible areas • Lasers capable of covering larger areas	• Habituation without reinforcement (shooting) • Need to routinely move devices • Limited range for stationary devices • Tools not aesthetically pleasing • Public acceptance for drones varies • Lasers potential eye hazard (safety)	RODO EUCD RRPA MOPA COMY EUST HOSP	1 0 6 2 4 13 6	1^{F} 6^{F} 2^{F} 4^{F} 11^{F}, 2^{L} 6^{F}, 1^{L}	1^{D} 1^{A}, 1^{B}, 6^{D} 2^{A}, 2^{D} 2^{A}, 1^{B}, 4^{D} 5^{A}, 4^{B}, 8^{D} 2^{A}, 1^{B}, 5^{D}

Table 1. (Continued).

Auditory Deterrents (n = 20)	Deploy loud sounds (e.g., cannons, pyrotechnics); bioacoustics (e.g., species-specific distress/alarm calls, predator noises), or sound to avian mask communication (i.e., sonic nets)	• • Initial affordability (cannons) • Inexpensive operation, maintenance (cannons) • Portability (cannons, pyrotechnics) • Bioacoustics reduce habituation • Creates risky landscape for prey (sonic net) • Effective with alternative food, predators (sonic net)	• Fire hazards (cannons, pyrotechnics) • Habituation without reinforcement (shooting) • Need to routinely move devices • Limited range, especially in adverse weather • Noise pollution in human-inhabited areas	RODO EUCD RRPA MOPA COMY EUST HOSP	0 0 4 1 1 10 4	 4^{F} 1^{F} 1^{F} 6^{F}, 4^{L} 4^{F}, 1^{L}	 2^{A}, 4^{D} 1^{A}, 1^{D} 1^{A}, 1^{D} 4^{A}, 3^{B}, 1^{D} 2^{A}, 1^{B}, 3^{D}
Chemical Repellents (n = 67)	Spray chemical repellent to act as irritant near harvest; seed treatment coating at planting; Methyl anthranilate for foliar application and anthraquinone for seed treatment registered in United States for select crops	• Complete coverage possible (seed treatments) • Accepted, conventional agronomic practice	• Primary repellents must contact bird • Secondary repellents must be ingested • Effective field application depends on crop • Temporary effects • High active ingredient residues needed, expensive	RODO EUCD RRPA MOPA COMY EUST HOSP	9 0 2 2 2 33 19	1^{F}, 8^{L} 2^{L} 2^{F} 2^{F} 7^{F}, 26^{L} 8^{F}, 11^{L}	1^{D} 2^{A}, 2^{D} 1^{A}, 2^{D} 5^{A}, 2^{B}, 7^{D} 3^{A}, 8^{D}

Lethal removal can occur on foraging grounds including row-crop agriculture, livestock facilities, backyard gardens, urban parks, fruit farms, and natural areas (Shiels et al. 2018). Understanding species-specific feeding activity and breeding behavior in space and time will identify the best season and time of day for deploying control tools (Morrison et al. 2016). To reduce crop damage, an air rifle or sniper rifle may be advantageous when birds are perched (Shafi et al. 1986). Flock size can range from a few to thousands of birds; thus, shotguns are preferred in row-crops or when flocks are first approaching the area to be protected. Removing the first birds to approach a foraging area (i.e., sentinels) may effectively stop the flock if the aim is to reduce damage rather than increase take (e.g., rose-ringed parakeets; W. Bukoski, USDA-WS, *personal observation*, 2021; J. Young, Kani Wildlife Control, LLC, *personal communication*, 2021). Lethal control at foraging sites can be performed year-round with specific areas targeted as preferred foods become available (Shiels et al. 2018).

Many invasive birds have large, stationary nighttime roosts, which are accessible for population reduction. However, roosts are often located in urban areas where culling activities are scrutinized (Butler 2003; Khan 2003; Avery and Shiels 2018). Thus, the timing of culling activities not only depend on animal behavior but human activity. Communal roosting species are active from dawn to dusk, leaving and returning to roosts in a reliable manner (Mabb 1997; Khan 2002; Kotagama and Dunnet 2007; Luna et al.

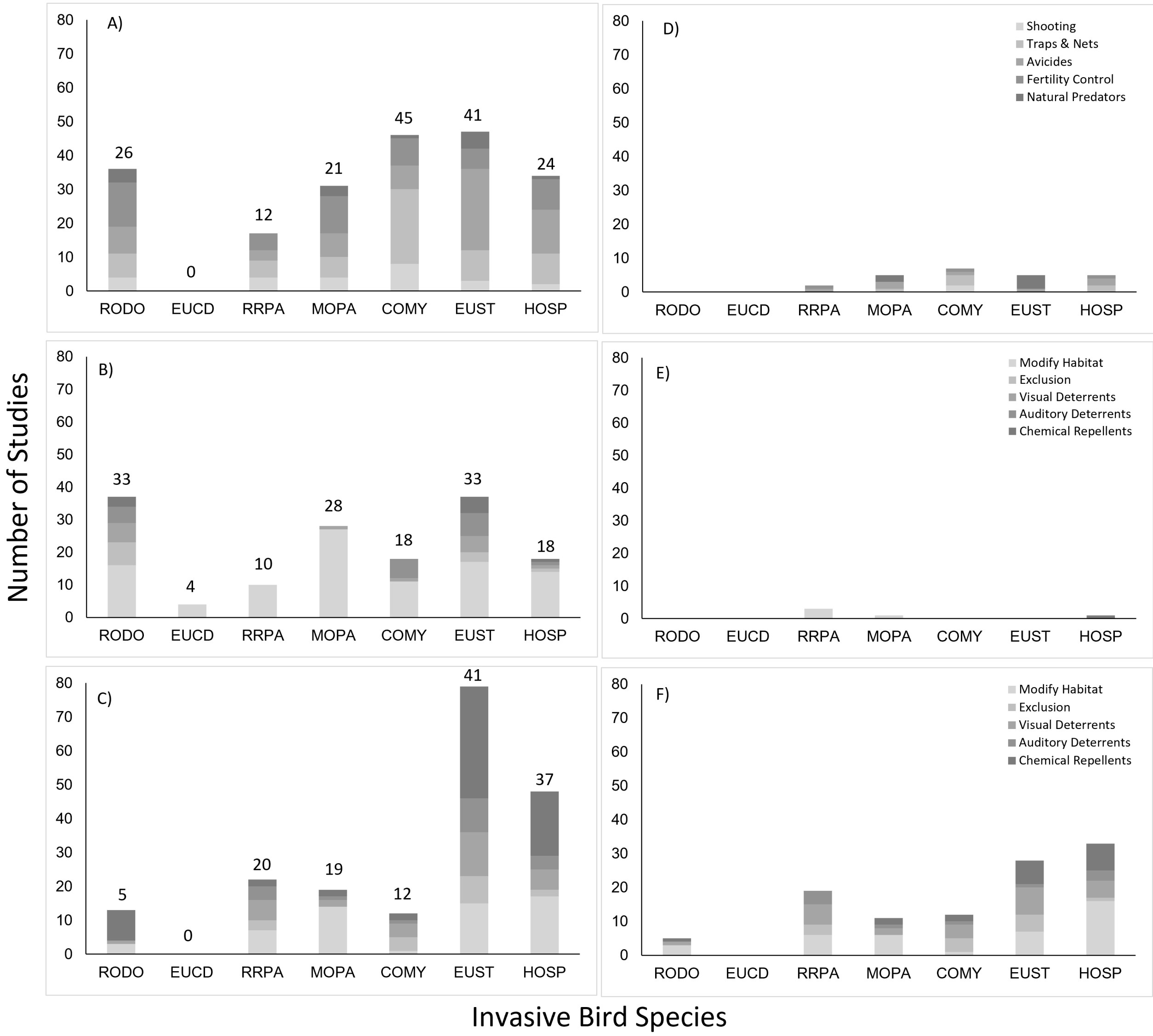

Figure 1. The number of studies (i.e., field, lab, and modeling) using A) lethal methods to control populations at nesting, foraging, loafing, and roosting sites, B) nonlethal methods to control damage at urban nesting, foraging, loafing, and roosting sites, and C) nonlethal methods to control damage at agricultural foraging sites, including those conducted in the native or introduced ranges of the following birds considered invasive in the United States: rock doves (*Columba livia*; RODO), Eurasian collared doves (*Streptopelia decaocto*; EUCD), rose-ringed parakeets (*Psittacula krameri*; RRPA), monk parakeets (*Myiopsitta monachus*; MOPA), common mynas (*Acridotheres tristis*; COMY), European starlings (*Sturnus vulgaris*; EUST), and house sparrows (*Passer domesticus*; HOSP). Above each column on the left-hand side is the number of studies that were conducted in the field (i.e., not laboratory or modeling studies; if a study used multiple tools it was counted for each tool). The right-hand side is the subset of field studies for each category (D–F) that included damage assessments in the results.

2017). Birds are less likely to be disturbed on dark nights, thus moonless nights may be preferred for culling. Birds may loaf before settling down, providing opportunities to remove high-ranking individuals and breeders as indicated by antagonistic interactions with other birds and habitat selection, such as use of the optimal perch substrate or height by dominant birds.

Population suppression should focus on sexually mature adults, otherwise breeding pairs will replace nonbreeding individuals removed by culling (Grarock et al. 2014). We recommend collecting sex and age data of birds removed to identify preferred locations of females, socially dominant birds, and optimal seasons to locate these individuals for targeted population reduction. Population suppression should occur prior to or during breeding to limit annual recruitment. We recommend locating nesting areas to destroy nests or reproductive adults, but cost-effectiveness of this practice is species- and site-specific and depends on if breeding pairs are colonial or preferred nesting habitat is accessible. Locating areas with abundant nesting habitat through habitat evaluation or observed mating behaviors increases the ability to remove breeders and provides locations for repeated management. Managers tasked with lethal removal should be aware of sex-specific behaviors to target females (e.g., mating behavior, timing of incubation, and male provisioning; Radford and Penniman 2014; Klug et al. 2019). If nests are inaccessible or hard to find, flight lines between foraging areas and nesting colonies may allow for removal of breeders (e.g., mitred conure nesting on cliffs; Radford and Penniman 2014).

Capture Devices (Traps and Nets)

Invasive birds have been trapped using various trap designs (Table 1, Figure 1, see Table S1, Appendix 1). Although labor-intensive, community-based volunteer programs can increase spatial scale of trapping while reducing cost (Grarock et al. 2014; Linley et al. 2017; Blanvillain et al. 2020). Modified Australian crow traps have been used to capture rose-ringed parakeets, house sparrows, common mynas, and European starlings (Bashir 1979; Montplaisir et al. 2006; Copsey and Parkes 2013; Thiele 2020) but can be less successful in environments with abundant alternative food year-round (Gaudioso et al. 2012; Bunbury et al. 2019). Remotely triggered, spring-loaded traps and Potter walk-in traps can be deployed if regular feeding stations can be established (Phillips et al. 2012; Avery and Lindsay 2016). Placing traps on top of preferred food (e.g., corn at the milky stage) or using live decoy birds within traps may increase capture rates (Conover and Dolbeer 2007; Campbell et al. 2012a; Peck et al. 2014; Saavedra and Medina 2020). Decoy traps were identified as the most effective tools to remove common mynas (Canning 2011), but social cues can also inform conspecifics about the threat of traps (Diquelou and Griffin 2019) or in other cases increase capture rates (Copsey and Parkes 2013). The most effective capture methods are species- and site-specific, including the location, timing, and type of bait (Tidemann 2005; Saavedra 2010; Canning 2011; Linley et al. 2017; Feare et al. 2021a). Seasons with reduced alternative food and high energetic demands (e.g., migration) would be the most productive for trapping (Feare et al. 2017). Long-handled nets have been used for removing monk parakeets from nests (Avery and Lindsay 2016) and rose-ringed parakeets from low roosting branches (Gaudioso et al. 2012). Dip nets have been used to capture individual starlings (Spencer and De Grazio 1962), whereas floodlight traps capture larger numbers of birds at marsh roosts (Mitchell 1963). Avery and Shiels (2018) suggested elevated mist nets to capture birds upon arrival or departure from roost sites after flight lines are identified. Whereas Tidemann (2010) considered enclosing preferred roosting trees with nets to capture large numbers of mynas, and Strubbe and Matthysen (2011) placed mist nests around established feeders to capture rose-ringed parakeets. In some cases, trapping and hand capture of urban rock doves has been successful, but in other scenarios were ineffective due to trap neophobia (Phillips et al. 2012; Farfán et al. 2019). We classify such live-capture techniques as lethal removal because the only practical recourse for trapped birds is almost always euthanasia.

Avicides (Toxicants and Wetting Agents)

There is a long history of testing avicides in both lab and field conditions for pest species (Table 1, Figure 1, see Table S1, Appendix 1). The primary difficulty with toxicants is establishing a delivery system that avoids negative impacts on nontarget animals while attracting target birds, especially where alternative food is abundant (Linz and Bergman 1996; Avery and Shiels 2018). Although prototype devices for excluding nontarget birds have been tested on parakeets and are operational for rock doves (Tillman 2016; Senar et al. 2021; Anderson 2022b), public sentiment and the inability to lure target birds and deter nontargets to bait limits effectiveness. As a result, exclusion of nontarget animals and reduced environmental impacts are primarily achieved through label use restrictions limiting the type of use sites, timing of bait applications, and requiring the monitoring and cleanup of use sites by certified applicators.

3-Chloro-p-toluidine hydrochloride (CAS No. 7745-89-3; also known as DRC-1339 or Starlicide®) is a slow-acting avicide registered for control of invasive starlings, rock doves, and Eurasian collared doves with the United States Environmental Protection Agency (USEPA) but is not registered for common mynas or parrots in the United States (Besser et al. 1967; USDA-APHIS-WS 2001a; Eisemann et al. 2003). Starlicide has been tested and implemented outside of the United States for European starlings, common mynas (Millett et al. 2004; Feare 2010; Copsey and Parkes 2013; Avery and Eisemann 2014), monk parakeets (Rodríguez and Tiscornia 2002), house sparrows, rock doves (Fisher et al. 2012), and house crows (Suliman et al. 2011).

Other lethal pesticides registered for birds in the United States include chemical frightening agents and wetting agents. 4-aminopyridine (CAS No. 504-24-5; also known as Avitrol®) is a frightening agent and causes erratic flight, distress calls, and death when ingested, which may cause entire flocks to disperse due to an antipredator response. 4-aminopyridine is registered by the USEPA to target European starlings, rock doves, and house sparrows for use in or on structures and other non-crop areas used as feeding, nesting, loafing, and roosting sites (Dolbeer and Linz 2016; USEPA 2022). Wetting agents destroy insulating properties of feathers and leave birds susceptible to hypothermia at temperatures < 41 °F (Byrd et al.

2009), thus are only effective in temperate regions where applications coincide with cold weather. Sodium lauryl sulfate (CAS No. 151-21-3) is classified as a minimum risk pesticide active ingredient by the USEPA and, therefore, its use as a wetting agent for starlings is exempt from federal registration under FIFRA section 25(b) (40 CFR 152.25(f); USDA-APHIS-WS 2012). However, spray applications at roosting sites negatively impact vegetation (Byrd et al. 2009).

Additional toxicants with potential future use in the United States include alpha-chloralose (CAS No. 15879-93-3), which is a sedative that can act as an acute toxicant at higher doses (Nelson 1994). Alpha-chloralose is registered for house mice in the United States but is not yet registered as an avicide. The US Federal Drug Administration previously authorized research on its use for immobilization and live capture of certain bird species under an Investigational New Animal Drug file (INAD 6602; O'Hare et al. 2007), but the INAD file was closed in 2019 and those uses are no longer authorized. Alpha-chloralose is currently used as a stupefying agent and avicide for controlling invasive bird populations in Australia and New Zealand. It has also been used in eradication campaigns but is considered labor-intensive and in some scenarios ineffective (Belant and Seamans 1999; Bednarczuk et al. 2010; Phillips et al. 2012). Sodium nitrite (CAS No. 7632-00-0) is an acute toxicant for European starlings and rock doves (Shapiro et al. 2017; Werner et al. 2021); thus, it may be a future direction in the development of new avicides.

Fertility Control (Contraceptives and Nest Destruction)

Reproductive inhibition is often considered when conventional control is not feasible or culling of charismatic animals is viewed unfavorably (Fagerstone et al. 2010; Table 1, Figure 1, see Table S1, Appendix 1). Nicarbazin (CAS No. 330-95-0; also known as OvoControl®) is a multi-feed contraceptive that affects egg hatchability by altering yolk pH. It is non-toxic, reversible, and cleared from the body after 48 hours, but requires daily ingestion prior to and during egg laying (Avery 2014). Nicarbazin is the only contraceptive currently registered in the United States for birds and it can be used to target rock doves, European starlings, and common mynas (Avery et al. 2008a; USEPA 2022). Nicarbazin is effective in aviary settings for rock doves (Avery et al. 2008a) and eared doves (Olivera et al. 2021) but varied in its ability to reduce feral rock dove populations (Giunchi et al. 2007; Albonetti et al. 2015; Senar et al. 2021).

Another potential multi-feed contraceptive for use in invasive birds is 20,25-Diazacholesterol dihydrochloride (CAS No. 1249-84-9; also known as DiazaCon and Ornitrol), which reduces fertility by reducing blood cholesterol and cholesterol-dependent hormones to disrupt egg production. 20,25-Diazacholesterol dihydrochloride was previously registered for rock doves, but the registration was voluntarily cancelled by the registrant in

2003 and is not currently registered in any other products (USEPA 2022). Lambert et al. (2010) indicated that 10 days of dosing at 18 mg kg^{-1} reduces fertile eggs across the breeding season and causes rose-ringed parakeets to incubate infertile eggs for 3× the normal period, but it has not been tested in the wild. 20,25-Diazacholesterol dihydrochloride was found to reduce monk parakeet clutch size in an aviary and by 68.4% in a field setting (Yoder et al. 2007; Avery et al. 2008c). In house sparrows, 20,25-Diazacholesterol dihydrochloride reduces hatching success but is not registered for the species (Mitchell et al. 1979).

Although fertility control appears promising, managers need to establish bait stations for target species and limit nontarget exposure (Tillman 2016; Anderson et al. 2022b), requiring free-ranging target birds to reliably feed at these stations (Peck et al. 2014; Avery and Shiels 2018). Bait stations may work for small populations of urban birds (i.e., rock doves; Pellizzari 2017) but remain questionable where birds have dispersed into rural settings with abundant alternative food (Lambert et al. 2010). Surgical sterilization is a fertility control option used in longer-lived, large-bodied vertebrates. Endoscopic vasectomy of male feral rock doves resulted in reduced fertilized eggs in rock dove housing (Heiderich et al. 2015), but it is an impractical method to reduce wild populations. Barriers to chemical contraception include lack of products for permanent sterilization, large breeding populations, long lifespans (e.g., parakeets), risks to nontarget species, cost, and regulatory requirements.

Manipulating the nesting environment or destroying eggs reduces reproductive success (Ridgway et al. 2012; Table 1, Figure 1, see Table S1, Appendix 1). Corn oil (CAS No. 8001-30-7) is a minimum risk pesticide active ingredient under 40 CFR 152.25(f) that can be used for oiling and suffocating eggs in pest bird nests (USDA-APHIS-WS 2001b; Fagerstone et al. 2002). Oiling or addling eggs (i.e., shaking to destroy viability while leaving the shell intact) is often preferred over removing or smashing eggs, given that birds will continue to incubate, resulting in delayed renesting and continued occupancy of the nest site (Lambert et al. 2009; Fernandez-Duque et al. 2019). However, finding adequate nests to impact populations is often labor-intensive and logistically difficult, especially given the nest site characteristics of many invasive species (e.g., high cavities in tall trees or buildings).

Removal of preferred nesting habitat has been suggested to limit invasive birds, while considering the regional assemblage and requirements of native birds (e.g., removal of invasive trees to limit breeding cavities; Khan 1999; Yap et al. 2002; Gaudioso et al. 2012; Dodaro and Battisti 2014; Table 1, Figure 1, see Table S1, Appendix 1). Preferred nesting cavities could be filled to restrict breeding (i.e., artificial building cavities not conducive to nesting by native birds) or natural entrance holes modified to limit access to invasive birds while maintaining function for native species (Strubbe and Matthysen 2009; Charter et al. 2016; Le Roux et al. 2016). Nest boxes can also be used as traps to remove breeding birds or destroy eggs (Jacquin et al. 2010; Canning 2011; Tidemann et al. 2011; Campbell et al. 2012b). Feral rock doves responded to egg removal by renesting with implications for reduced female body condition due to the extra resources required for renesting, which may also increase a bird's susceptibility to disease (Jacquin et al. 2010). Nest removal was considered inefficient for reducing monk parakeets, even though their colonial nests are easy to locate and allow destruction of multiple clutches (Conroy and Senar 2009). Burgio et al. (2014) suggest excluding monk parakeets from electrical lines adjacent to utility poles to reduce nest building.

Deterrence Methods

Deterrence to reduce damage is appropriate when eradication of invasive species is not feasible (i.e., habitat modification, exclusion, frightening devices, and chemical repellents; Table 1, Figure 1, see Tables S2, S3, Appendix 1). In most cases, deterrence is short-lived and requires constant perseverance in moving and combining devices to create novel environments that birds find alarming (Avery and Werner 2017). A persistent deterrence campaign may be cost effective; however, such economic valuations are not always possible. Although nonlethal methods are required for the immediate protection of valued resources, such methods may shift bird damages to neighbors or other resources. Ultimately, population reduction is preferred, given fewer birds result in less damage (e.g., less fecal matter or less crop loss). Unless invasive populations can be eradicated, integrating nonlethal damage management with population reduction measures is necessary. Nonlethal methods are often given preference by the public out of concern for animal welfare (Crowley et al. 2019; Ribeiro et al. 2021). However, the use of nonlethal methods alone does not always result in cost-effective damage management when bird numbers are overwhelming, along with the decline in tool efficacy over time (e.g., habituation) and the limited extent of tool effectiveness over space (Linz et al.2015; Klug 2017).

Exclusion, Camouflage, and Repellent Methods

Complete (e.g., netting) or partial exclusion (e.g., overhead wires that obstruct landing) can protect crops and roost structures (Taber 2002; Table 1, Figure 1, see Tables S2, S3, Appendix 1). Farmers report that netting is effective but labor-intensive and expensive (Reddy and Gurumurthy 2003; Koopman and Pitt 2007). The spacing of overhead wires needs to be close enough to deter birds from passing through but wide enough to limit cost (Agüero et al. 1991). Small-bodied birds are agile and often not excluded by wires (Pochop et al. 1990). Nets have effectively kept European starlings out of livestock barns (Medhanie et al. 2015) and protected fruit crops from starlings, mynas, parakeets, and sparrows (Curtis et al. 1994; Abd El-Aal et al. 2006; Wang et al. 2020). Fewer studies exist that evaluate the use of nets or lines in urban or periurban areas (Andelt and Burnham 1993).

Covering fruiting bodies of crops with plastic containers or paper bags inhibits birds from detecting and selecting the crop or acts as a protectant to make crops inaccessible (Ruelle and Bruggers 1982; Conover 1987; Patel et al. 2002; Table 1, Figure 1, see Table S3, Appendix 1). Although effective, the practice is labor-intensive and cannot be implemented at a broad scale (Conover 1987). The availability of natural, alternative food is also be needed to reduce pressure on the wrapped plots (Dhindsa et al. 1992). Depending on environment, crop, and timing of management, the practice may also increase insects and mold (Dhindsa et al. 1992).

Physical devices to deter perching include sharp spikes, wire barriers, unstable systems of coils, and electrified cables by creating an uncomfortable or painful surface (Andelt and Burnham 1993; Haag-Wackernagel 2000; Seamans et al. 2007; Gorenzel and Salmon 2008; Seamans and Blackwell 2011; Bergman and Washburn 2018; Andres et al. 2020; Table 1, Figure 1, see Table S2, Appendix 1). Antiperch devices, such as spikes, have mainly been evaluated for urban rock doves (Harris et al. 2016) or other urban pests. Water can function to reduce visibility or cause birds to reflexively withdraw due to direct water pressure or wet feathers (Bishop et al. 2003). For example, a sprinkler activated by a motion detector can be set up to startle pest animals (Heidenreich 2007; McLellan and Walker 2021). Perch deterrents have reduced larger-bodied birds (i.e., rock doves) inside human structures and raptors on antennas (Seamans et al. 2007), but smaller birds can avoid these devices (Bishop et al. 2003).

Tactile repellent products containing polybutene (CAS No. 9003-29-6) are sticky pastes or gels that induce a negative reaction when touched and are registered as perch and roost repellents for rock doves, European starlings, and house sparrows (USEPA 2022; Table 1, Figure 1, see Table S2, Appendix 1). Gel repellents for feral rock doves have shown temporary, local efficacy, but concerns for animal welfare have been raised (Stock and Haag-Wackernagel 2014; Gagliardo et al. 2020). Under lab conditions, DeLiberto et al. (2020) evaluated three tactile, surface-application repellent formulations that reduced fecal accumulations under perches from European starlings under lab conditions (i.e., anthraquinone-based repellent Airepel® HC with castor oil; Airepel HC with castor oil excluding anthraquinone; and MS2 a novel inert formulation with a tacky, oily texture).

Anthraquinone (AQ; CAS No. 84-65-1) is a registered repellent for geese at non-residential turf use sites and for use as a corn seed treatment to repel starlings and other birds (USEPA 2022; Table 1, Figure 1, see Tables S2, S3, Appendix 1). AQ is a secondary repellent with a post-digestive antifeeding effect that is registered for use on starlings (Clapperton et al. 2012; DeLiberto and Werner 2016) but may also have potential as an urban roost repellent (DeLiberto et al. 2020). AQ products are not available close to harvest for crops intended for the food stream but are available as a seed treatment at planting (Barzen and Ballinger Jr. 2018; DeLiberto et al. 2020). Anthraquinone has been tested as a feeding deterrent for monk parakeets, European starlings, rock doves, and house sparrows (Table 1, Figure 1, see Table S3, Appendix 1).

Methyl anthranilate (MA; CAS No. 134-20-3) is a registered repellent for rock doves, European starlings, house sparrows, and house finches and is sold as volatilizing paint-on liquids, blocks, and pouches, or as a fog or spray for perches and roosts (Table 1, Figure 1, see Tables S2, S3, Appendix 1). It can also be applied to a variety of crops and is aversive to birds by acting as an irritant on the trigeminal nerve (Mason et al. 1989; Avery et al. 1996; Linz et al. 2011; USEPA 2022). Although ineffective field application methods limit residues and thus efficacy (Kaiser et al. 2021). Application of repellents at crop emergence has been shown to be effective to reduce rock dove and house sparrow damage (Moran 2001; Esther et al. 2013). Near crop maturity, aerosolized treatment may be more effective than direct application to the crop (Stevens and Clark 1998), given aerosolized MA influenced avian flight lines at airports (Engeman et al. 2002). Monk parakeet behaviors indicated sensitivity to aerosolized MA but did not cause abandonment of established nests (Avery et al. 2006). Systems that deliver aerosolized MA are not recommended for public areas due to an adverse smell and the general application on fruit may influence how the crop tastes to humans.

Other chemicals have been tested to reduce feeding at planting through seed treatments or on turf (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Methiocarb (CAS No. 2032-65-7) is still registered by the USEPA, but only for limited use as an aversive conditioning egg treatment (repellent) for crows and ravens (Corvidae) preying on the nests of protected species (Eisemann et al. 2011). Another example is thiram (CAS No. 137-26-8; Kennedy and Connery 2008), which is currently registered as a turf repellent for geese in the United States (USEPA 2022). Thiram products are registered as mammalian repellents and could be used for pest birds when applied in accordance with FIFRA Section 2(ee). Mannitol, an organic carbon derived from seaweed (ScudoSeed), and aluminum and ammonium sulfate (Eurodif) have been tested as seed treatments in Europe (Furlan et al. 2021), but these active ingredients are not registered for birds in the United States. Natural plant derivatives (e.g., mint, caffeine, and cinnamon) have been tested with some classified as minimum risk pesticide active ingredients and sold as repellents. However, variable efficacy in the lab and a lack of economic incentives result in few commercial products (Crocker et al. 1993; Gill et al. 1998; Hile et al. 2004; Linz et al. 2011; Day et al. 2012).

Auditory and Visual Frightening Devices

Frightening devices offer temporary protection of days to weeks but are not long-term solutions (Avery and Werner 2017; Table 1, Figure 1, see Tables S2, S3, Appendix 1). Success is limited by avian fidelity to established feeding areas and habituation to nonrandom noise, as well as device shortcomings including extent of effectiveness, static location, and labor intensity (Gilsdorf et al. 2002). Early implementation and random presentation of a variety of sounds and visual deterrents used in combination or reinforced by a negative stimulus such as shooting is recommended (Baxter and Allan 2008; Linz et al. 2011). Most frightening devices have not been objectively tested in the field and when tested the appropriate replication and controls are not easily achieved (Bomford and O'Brien 1990). Definitive statements about tool effectiveness are not feasible given the unpredictable nature of wildlife damage that varies with pest species, protected resource, tool's mode of action, and surrounding landscape and habitat.

Bioacoustics include predator sounds (e.g., barking dogs, raptor calls, human noise) and avian distress and alarm calls (Gorenzel and Salmon 2008; Table 1, Figure 1, see Tables S2, S3, Appendix 1). When natural vocalizations are used as opposed to nonnatural auditory deterrents, habituation may be delayed because antipredator communication between birds is conditioned with actual predator threats. Ribot et al. (2011) tested broadcast alarm stimuli in orchards and found reduced activity of crimson rosellas (*Platycercus elegans*), a pest parrot species within its native range in Australia. Rose-ringed parakeets have been temporarily deterred from crops in both invasive (Hawaii; CJ Anderson, *personal observation*, 2021) and native ranges (India and Pakistan; Khan et al. 2011; Mahesh et al. 2017) using species-specific alarm calls and predator calls. Although distress calls can repel conspecifics and reduce crop damage (e.g., starlings; Conover and Perito 1981; Berge et al. 2007; Delwiche et al. 2007), distress calls may draw in some species (Conover 1994), a behavior that should be considered when attempting to deter pest birds but also when lethally removing invasive species through shooting or trapping. In addition, distress calls may repel nontarget passerine species, potentially impacting their behavior and space use. Despite documented success of bioacoustics, results are short-lived, and a continual rotation of tools is needed to prolong deterrence (Heidenreich 2007; Cook et al. 2008). Enos et al. (2021) found that compared to passerines, parrots and doves are less represented in the literature evaluating biologically salient frightening devices, suggesting continued testing on a variety of pest birds.

Land managers use scarecrows to mimic human predators in appearance and movement (Marsh et al. 1992; Table 1, Figure 1, see Tables S2, S3, Appendix 1). Inflatable "wavy men" have been reported as effective by landowners, but limited replication in studies revealed uncertain or minor effectiveness (Steensma et al. 2016; Lindell et al. 2018b). The addition of unpredictable loud sounds coupled with motion can increase effectiveness of scarecrows, but most birds habituate if deployed in established foraging grounds (Cummings et al. 1986). Wildlife species may begin to tolerate the appearance of human harassers when no painful stimulus is included (Griffin and Boyce 2009), thus reducing the efficacy of hazing (Grant et al. 2011). Alternatively, wildlife can become sensitized to actual threats, which allows for fear conditioning or the paring of painful and benign stimuli (e.g., modeling scarecrows after humans performing aversive actions; Blumstein 2016). Dead bird effigies (e.g., real feathers) have been used to disperse vultures and crows from roosts (Avery et al. 2002b, 2008b), but monk parakeets did not respond to parakeet effigies at nest sites (Avery et al. 2002a).

Falconry, native predators, raptor models, humans, and protector dogs create an environment that prey birds perceive as risky (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Hawk kites are suspended predator models that move in the wind, but efficacy is limited to directly below the model (Hothem and DeHaven 1982; Conover 1983, 1984). Passive encouragement of natural predators (e.g., nest boxes and raptor perches) capitalizes on natural predator-prey systems (Kross et al. 2012; Harris et al. 2018; Lindell et al. 2018a; Peisley 2017). The response of monk parakeets to raptors was more pronounced when not associated with stork nests, which impacted nest locations (Hernández-Brito et al. 2020). Endangered falcons reintroduced to vineyards have resulted in reduced crop damage and pest birds, including European starlings (Kross et al. 2012). Although increased predation is often insufficient to reduce population growth (Bendjoudi et al. 2013), it is unknown if increased predator abundance reduces damage due to a "landscape of fear" (Laundré et al. 2001). Falconry has been used as a controlled predator method for starlings (Daugovish and Yamomoto 2006) and monk parakeets (Rodríguez and Tiscornia 2005), but the high cost and temporary responses of pest birds are limitations (Erickson et al. 1990). Rock doves have been successfully deterred from structures with a combination of falconry and shooting (Ryzhov and Mursejev 2010; Heck and Schwartze 2020). The most successful hazing strategies for Canada geese (*Branta canadensis*) was a combination of border collies (*Canis familiaris*) and remote-controlled boats, which allowed for hazing in areas inaccessible to dogs (Holevinski et al. 2007). The use of protector dogs to disperse invasive birds may be possible in row-crops and have successfully reduced other vertebrate pest damage (e.g., deer deterred from fruit and vegetable farm; VerCauteren et al. 2005). Limitations of dogs to deter birds are inherent at roosts and orchards due to the perching locations and flight abilities of birds. Uncrewed aircraft systems (i.e., drones) can be used as dynamic hazing devices that reduce human safety risks and operation costs compared to crewed aircraft, while overcoming mobility limitations of stationary devices to reach refugia used by birds (Klug 2017). The efficacy of drones depends on species-specific responses to drone type and flight dynamics and is influenced by flock size and landscape context (Egan 2018; Wandrie et al. 2019; Egan et al. 2020; White 2021). Drones have been tested to move rock doves from buildings (Schiano et al. 2021) and starlings and mynas from vineyards (Wang et al. 2019, 2020). Some species may mob drones (e.g., rose-ringed parakeets; Shiels and Kalodimos 2019), suggesting the possibility of moving birds toward other control tools (i.e., within shotgun range).

Pyrotechnics include products that produce flashes of light and whistles, whereas propane cannons produce a loud (e.g., 160 dB) directional blast (Bomford and O'Brien 1990). Loud noises have mainly been tested in rural areas and include studies on rose-ringed parakeets, starlings, and house sparrows (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Advantages of combustion devices are initial affordability, portability, and inexpensive operation and maintenance. Disadvantages include fire hazards, habituation without reinforcement by negative stimuli such as lethal removal, the need to routinely move devices, reduced range in adverse weather, and inability to use in human-inhabited areas due to noise complaints (Linz et al. 2011). Auditory deterrents are limited in range with suggestions of one cannon per 2–3 acres (Avery and Werner 2017). A Vortex Ring Accelerator Deterrent (VRAD) propels exhaust through a vortex ring generator via combustion which then passes through an accelerator creating a high-velocity vortex ring of air movement that is propelled up to six miles at speeds up to 200 mph, frightening or dispersing birds with sound and a non-lethal physical concussion. The device has been considered for keeping waterfowl out of mine tailings (Opar 2017) but has not been tested. The sound intensity and physical concussion effect makes the VRAD an unlikely method for urban roosting sites or periurban agricultural sites.

Understanding the auditory physiology of pest birds and how it influences social interactions and antipredator behavior will inform the use of sound deterrents (Table 1, Figure 1, see Tables S2, S3, Appendix 1). The auditory sensitivity of most birds is between 2–5 kHz with an upper limit of < 10 kHz, thus most birds cannot hear ultrasonic sound (> 20 kHz; Beason 2004; Jenni-Eiermann et al. 2014). Sonic devices used in abandoned buildings for feral rock doves did not reduce their populations (Haag-Wackernagel 2000) but did show temporary changes in behavior (Woronecki 1988). A "sonic net" produces sound that masks avian communication (2–10 kHz at 80 dB SPL) to effectively displace pest birds (i.e., European starlings; Mahjoub et al. 2015; Swaddle et al. 2015; Woods et al. 2022). When birds cannot communicate or hear predators, risk perception increases, resulting in abandonment of foraging grounds. The deterrent response is enhanced with real predatory threats and alternative food resources (Werrell et al. 2021). The sonic net is not feasible in urban areas due to the noise being audible to humans.

Novel objects can temporarily repel birds (e.g., tape, streamers, flags, balloons, mirrors, and lights; Table 1, Figure 1, see Tables S2, S3, Appendix 1). The reflectance, physical barrier, and sound of wind through the lines elicits a fear response that varies by species and environment (Bruggers et al. 1986; Dolbeer et al. 1986; Tobin et al. 1988; Conover and Dolbeer 1989; Firake et al. 2016). Large gaps between devices allow access, thus narrow spacing and routine maintenance influences efficacy, but increases cost (Bishop et al. 2003). Reflecting ribbons, plastic bags, and silver plates attached directly to plants have limited parakeet damage in sunflower (Basappa 2004; Shivashankar and Subramanya 2008) and dove damage in soybeans (Firake et al. 2016). Flags have been successfully used against birds that are considered pests in their native ranges, such as red-billed quelea (*Quelea quelea*) in rice, blackbirds (Icteridae) in corn, snow geese (*Chen caerulescens*) in winter wheat, gulls (*Larus* spp.) in loafing areas, and corvids in roost trees (Cardinell and Hayne 1945; Manikowski and Billiet 1984; Gorenzel and Salmon 1992; Mason et al. 1993; Belant and Ickes 1997). Eyespot balloons trigger a fear of being observed by predators. The influence is context- and species-specific and often short-lived (Greer and O'Connor 1994; Bishop et al. 2003; Fukuda et al. 2008) with mixed success at reducing bird activity at foraging and roosting sites (Shirota et al. 1983; Tipton et al. 1989; McLennan et al. 1995). Lasers along with rotating, strobe, and barricade lights are silent deterrent options for pest birds (Blackwell et al. 2002; Gorenzel and Salmon 2008), but light pollution and human safety should be considered. Lasers have been used to temporarily deter rose-ringed parakeets from roost trees in Hawaii (Klug et al. 2019), rock doves from buildings (Matsyura 2018), and reduce blackbird and starling damage in sweet corn (Brown and Brown 2021). Monk parakeets are sensitive to red lasers (50 mm aperture, 650 nm, 50 mW [class3 IIIb]) and their use reduced birds at a nesting colony but did not reduce overall numbers in the area (Avery et al. 2002a). Automated laser models are available, which spatially and temporally confine laser beams to increase safety and reduce labor. Lasers may be an option for moving birds out of tall trees or buildings or encouraging movement closer to control tools (i.e., within firearm range or towards mist nets).

Modification of Crops and Surrounding Habitat

Modification of roosts and foraging habitat can reduce pest bird presence and damage (Table 1, Figure 1, see Tables S2, S3, Appendix 1). In North Dakota, cattail roosts were modified to disperse large blackbird flocks (Linz and Homan 2011). Managers can also remove loafing sites surrounding crop fields to reduce habitat suitability (Klug et al. 2019) including trees for rose-ringed parakeets (Schäckermann et al. 2014) monk parakeets (Canavelli et al. 2014), European starlings (Lyon and Caccamise 1981), and house sparrows (Benras et al. 2019). Habitat surrounding airports can have tall as opposed to short grass to limit foraging by monk parakeets and European starlings (Marateo et al. 2015). Modification of urban roosting sites may not be possible due to building design or established landscaping (Klug and Homan 2020), but suggestions for rock doves include minimizing holes and using specific ledge widths and angles for new buildings to deter perching (Haag-Wackernagel and Geigenfeind 2008).

Crop damage varies due to field location or timing of maturity (Khan and Ahmad 1983), thus changing location or size of fields may reduce damage (Table 1, Figure 1, see Table S3, Appendix 1). Changing the sowing times, planting depth, or distance between seeds reduces damage at emergence among rose-ringed parakeets (Mahli 2000), house sparrows (Alizadeh 2009; Abd El-Gawad et al. 2010), and rock doves (Nasu and Matsuda 1976; Lawson 1979; Firake et al. 2016). Mukherjee et al. (2000) found crop damage was more severe at edges of sunflower fields, thus using larger fields or reducing the space between plots may limit preferred foraging spots where birds can maneuver and be vigilant to threats (Subramanya 1994). However, it is important to note that smaller plots allow better access for deployment of control tools (Linz et al. 2011). Small, diversified farms may be at greater risk because birds can meet their nutritional needs in one location as a different crop is continually ripening throughout the year. It is suggested to coordinate planting time with neighbors to eliminate early and late-maturing crops in the same locality (Linz et al. 2011). Advancing the harvest date reduces the damage window and yield loss from birds (Clark et al. 2020). In cereal crops, harvest date can be advanced two weeks by desiccating the crop without compromising quality or yield (Linz et al. 2011). Advancing harvest can also be practiced in some fruit crops.

Bird resistant crop varieties have been tested for rose-ringed parakeets (Ejaz-ul-Hassan et al. 1994), monk parakeets (Castro et al. 2022), European starlings (Dolbeer et al. 1986; Woronecki et al. 1988), and house sparrows (Tipton et al. 1970; Seiler and Rogers 1987; Alizadeh 2009; Khaleghizadeh 2011; Table 1, Figure 1, see Table S3, Appendix 1). In many cases crops bred to be bird resistant are not preferred by producers due to reduced crop yield or quality. At livestock operations, changing to enclosed barns or troughs (Feare and Swannack 1978; Medhanie et al. 2015) and altering feed type, size, shape, or placement may reduce consumption by European starlings (Feare and Wadsworth 1981; Glahn and Otis 1986; Depenbusch et al. 2011).

"Trap crops" or "decoy crops" have been suggested to lure in pest birds to prevent damage on higher-value crops (Iqbal et al. 2001; Kubasiewicz et al. 2016), although the concept has not been directly tested on any of the included invasive species. Fields positioned closest to the roosts are ideal locations for decoy crops (Khan et al. 2006; Hagy et al. 2008), but in some situations decoy crops should be positioned close to the field to be protected. Birds feeding in the decoy crop should not be harassed. Understanding the feeding physiology and behavior of the pest species will inform crop selection for decoy plots (Kotten et al. 2022). Decoy crops are more feasible where tillable land is available and alternative food is enticing. Additionally, alternative food can be provided by delayed disking of grain fields or delayed removal of unharvested fruits (Linz et al. 2011). Alternatively, supplemental food in urban or periurban areas has been shown to support rose-ringed parakeets (Clergeau and Vergnes 2011; Borray-Escalante et al. 2020), monk parakeets (Hyman and Pruett-Jones 1995; Borray-Escalante et al. 2020), Eurasian collared doves (Coombs et al. 1981), rock doves (Senar et al. 2017; Soh et al. 2021), European starlings (Crick et al. 2002; Galbraith et al. 2015; Klug and Homan 2020), common mynas (Galbraith et al. 2015; Soh et al. 2021), and house sparrows (Galbraith et al. 2015; Bernat-Ponce et al. 2018, 2022). Thus, removal of supplemental food, including human wastes, may reduce bird damage in cities by reducing invasive populations (Table 1, Figure 1, see Tables S2, S3, Appendix 1).

Human Dimensions

Public support of invasive bird management programs can be critical to their success; culling programs of invasive parakeets were halted in Britain (Crowley et al. 2019), Spain (M. Sabaté *personal communication*), and the United States (Eaton-Robb 2005; Pruett-Jones 2021) due to public backlash. Conversely, programs that have incorporated public education and participation as part of the management process have attributed these efforts to their success (Bunbury et al. 2019; Saavedra and Medina 2020). Steps should also be taken to promptly locate and remove dead birds to avoid alarming the public (Klug and Homan 2020). Societal preferences for tools to decrease wildlife damage are often related to sociopsychological and demographic factors. In Argentina, attitudes about native monk parakeets, perception of damage, and knowledge of tool effectiveness were important in management preferences (i.e., lethal vs nonlethal alternatives; Canavelli et al. 2013). Although education programs work to inform the public about invasive species, sometimes attitudes do not change because of intervention (Braun et al. 2010). Thus, eradication programs targeted at charismatic species can face public opposition (Blackburn et al. 2010), especially in urban areas where gregarious birds are a novelty (Burger and Gochfeld 2009). The longer a species is present, the more difficult eradication campaigns may become as positive public sentiment increases (Papworth et al. 2009). Conversely, Mori et al. (2020) found that number of loud calls negatively influenced human tolerance of rose-ringed parakeets in Italy and not time since introduction. Belaire et al. (2015) also found that European starlings and house sparrow were known for negative qualities including loud calls and damage to personal property. In urban environments it was shown that public education programs to limit supplemental feeding reduced feral rock dove populations (Senar et al. 2017). Emphasis should be placed on campaigns informing the public about the harm caused by invasive birds, while being sensitive to animal rights groups and exploring positive collaborations when possible (Perry and Perry 2008). For example, Crowley et al. 2019 suggest reconfiguring management approaches to be more anticipatory, flexible, sensitive, and inclusive to minimize conflicts. Lindell (2020) concluded that clear guidelines about effectiveness and feasibility of implementation increase farmer adoption of sustainable management tools, while also indicating the importance of markets, government policies, and research priorities of commodity groups. We suggest further research on perceptions of nonlethal damage management tools for use in integrated pest management strategies from urban to rural settings, including individuals directly affected by the damage as well as other concerned stakeholders (e.g., Herrnstadt et al. 2016; Sausse et al. 2021).

Conclusions

Rock Doves

Of the studies designed to reduce rock dove populations, four used shooting, seven used trapping, eight used avicides, 13 used fertility control, and four used natural predators (Table 1, Figure 1, see Table S1, Appendix 1). The most common damage management tools investigated for rock doves included methods where feeding areas can be established that do not impact nontarget species (e.g., contraceptives; Table 1, Figure 1, see Tables S1, S2, S3, Appendix 1). Given the relationship of doves to predators, we identified four studies that used falconry or raptor sign to control bird numbers. Due to the behavior of rock doves inhabiting urban areas, we found numerous studies evaluating what building designs promoted or deterred birds, what tools worked as antiperch devices, and the impact of supplementary food (Table 1, Figure 1, see Table S2, Appendix 1). We did not find as many studies focused on agriculture (n = 13), but those identified evaluated avicides (n = 1), chemical repellents (n = 9), cultural practices (n = 3), or visual deterrents (n = 1) that may reduce crop damage (Table 1, Figure 1, see Table S3, Appendix 1). Only studies conducted in agriculture evaluated damage (cultural practices = 3, visual deterrent = 1, chemical repellent = 1), not just numbers of birds, indicating the need to understand if declines in urban damage (e.g., reduced fecal matter or public complains) occur after implementation of population reduction or nonlethal management.

Eurasian Collared-Doves

All the studies concerning invasive Eurasian collared doves focused on habitat use or their unprecedented range expansion in the United States (Table 1, see Table S2, Appendix 1). No studies have evaluated lethal techniques to reduce bird populations (Table 1, Figure 1, see Table S1, Appendix 1), likely due to the species not reaching large numbers nor evidence of negative impacts to native species, human health and safety, or economies. If negative impacts are identified, future studies could focus on lethal and nonlethal techniques to minimize damages. Until then, we recommend more studies evaluating potential negative impacts of Eurasian collared doves as a nonnative bird in the United States.

Rose-ringed Parakeets

Three culling campaigns have been reported in the literature for rose-ringed parakeets (Hawaii, USA; Seychelles, Canary Islands) with all campaigns using shooting and trapping to capitalize on the roosting and flocking behavior of this gregarious species (Table 1, Figure 1, see Table S1, Appendix 1). Although lab studies have been conducted on the efficacy of avicides and fertility control, field implementation is not feasible for these approaches until nontarget species can be excluded. All nonlethal damage management tools (i.e., exclusion, visual deterrents, and auditory deterrents) investigated for rose-ringed parakeets occurred in agricultural systems in their native range (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Most studies evaluating nonlethal management in agriculture focused on modifying the crop or surrounding habitat with exclusion or visual deterrents available for small-scale agriculture (e.g., ribbons, bagging crops, and nets). When invasive parakeets are impacting agriculture (e.g., Hawaii), nonlethal tools should be evaluated in concert with lethal methods (e.g., establishing population sizes in which nonlethal methods are effective since eradication is not likely). We did not identify any studies testing exclusion devices, visual deterrents, auditory deterrents, or chemical repellents to reduce urban damage aside from assessments of habitat use or food sources (Table 1, Figure 1, see Table S2, Appendix 1). Thus, more studies are needed to evaluate if declines in urban damage (e.g., reduced fecal matter or reduced public complaints) occur after population reductions or implementation of nonlethal management. Of the 20 field studies evaluating damage, all but four were in agricultural settings (habitat = 6, exclusion = 3, visual = 6, auditory = 4; Table 1, Figure 1, see Tables S2, S3, Appendix 1), whereas urban studies including damage often evaluated the ecological impact to other species.

Monk Parakeets

We found two studies that evaluated shooting to reduce monk parakeet populations, and these were to either mitigate damage to utilities from nest structures or reduce damage to crops within their native range (Table 1, Figure 1, see Table S1, Appendix 1). As found with rose-ringed parakeets, lab studies have been conducted on the efficacy of avicides and fertility control for monk parakeets, but methods to exclude nontarget species are needed (Table 1, Figure 1, see Table S1, Appendix 1). In South America, studies have tested avicides at the nest, but environmental concerns and the status of monk parakeets as native species requires alternative approaches. Of the 11 field studies evaluating damage, 10 were in agriculture (avicide = 2, falconry = 2, habitat = 4, crop variety = 2, visual = 2, bioacoustics = 1, chemical repellent = 2) and one was in an urban setting and assessed nest building behavior (Table 1, Figure 1, see Tables S1, S2, S3, Appendix 1). Most studies assessing monk parakeet damage have included nest destruction and its impact on subsequent bird behavior such as nest building or nest site selection. We found few reports that evaluated nonlethal damage management tools for monk parakeets in urban or agricultural settings, apart from modifying human structures (e.g., electrical towers) to minimize nests and thus damage (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Most studies evaluating surrounding habitat, and the resulting bird populations or crop damage, have been conducted in the native range of South America. Most invasive populations of monk parakeets in the United States are contained to periurban areas, but as populations increase and their distribution expands, we will likely see more studies evaluating tools to reduce agricultural damages, especially for periurban agriculture within expanding human development. Until then, we recommend more studies evaluating human dimensions to increase public support of invasive bird management.

Common Mynas

Distress call are the most common nonlethal damage management tool investigated for common mynas, although most studies were not explicitly testing such sounds as an auditory deterrent to avoid damages (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Common mynas are a popular test subject for behavioral studies due to their highly developed communication systems. Thus, studies evaluating response to distress calls or learning from observing conspecifics being trapped or attacked are common. We suggest future studies capitalize on the mynas' ability to learn and behavioral responses to auditory cues to effectively reduce damage to agriculture or native species. Due to common mynas' sociability, traps have been the most common and successful lethal tool. Fertility control, via understanding of nesting preferences and behaviors, is also prevalent in the literature to reduce impacts to native species. Additionally, evaluations of habitat use and food availability in urban to periurban sites have been investigated for mynas due to most negative impacts being directed at native species in or adjacent to human-modified environments. Lethal control by firearm is more common compared to European starlings because some eradication campaigns found the use of pesticides impractical or needed to target trap-shy individuals. Of the 11 field studies evaluating damage, seven were in agriculture (habitat = 1, netting = 4, visual = 4, bioacoustics = 1, chemical repellents = 2); whereas the other four studies evaluated damage in the form of ecological impact to other species (i.e., number of native birds or nest competition; Table 1, Figure 1, see Tables S2, S3, Appendix 1).

European Starlings

European starlings exploit a range of habitats from urban to rural. Their nesting behaviors negatively impact cavity nesting birds while their omnivorous diet makes it an invasive species that inflicts significant damage to agriculture as well as human health and safety. Thus, research on lethal techniques has a long history (Table 1; Figure 1, see Table S1, Appendix 1). Avicides were first used in the late 1960s and are well-studied in starlings due to their gregarious flocking and foraging behavior. When starlings form large roosts during winter, they focus their daily activities in relatively confined areas making lethal tools an effective option to reduce bird numbers at livestock facilities or urban sites. Lethal control by firearms is not as common, but future studies should evaluate culling via relatively quiet air rifles when pesticides or trapping are not options. Fertility control approaches are limited due to large population sizes and lack of bait dispensers that target breeding starlings and avoid nontargets. Nest boxes have been used to capture starlings when the birds are dispersed during the breeding season. Additionally, competition with cavity nesting birds has resulted in nest box designs to exclude starlings. Starlings are problematic for crop damage in the summer and fall requiring research to gauge the efficacy of exclusion tools, frightening devices, and chemical repellents with many techniques also being tested in urban areas. Although research in chemical repellents has a long history in the laboratory, difficulty in reaching the necessary residue levels on crops with current application methods limits field efficacy. Exclusion devices (e.g., nets) are often the best method to reduce damage to crops but cost, labor, and farm size constraints cause managers to look for alternatives capitalizing on antipredator behavior, especially bioacoustics. Ultimately, starlings can become habituated to tools even with integrated techniques that incorporate auditory, gustatory, and visual senses; granted if the damage period is short these tools can be effective. Modifying habitat effectively reduces bird density, but the ability of managers to affect change beyond their jurisdiction limits a landscape approach. Thus, apart from regional initiatives to organize against an invasive species, most studies evaluate tools that can be implemented on site (e.g., feed pellet size for livestock). Of the 24 field studies evaluating damage after tool implementation, all were in agriculture (avicides = 2, natural predators = 4, exclusion 6, cultural practices = 5, habitat = 1, visual = 8. bioacoustics = 1, chemical repellents = 6), highlighting the need of future studies to include damage reduction estimates in urban areas (e.g., public complaints, cost of cleaning). Most field studies on auditory repellents (distress calls = 8) focused on the behavior or number of birds and did not evaluate damage. Thus, we recommend that future research include damage reduction estimates in addition to bird behavior and numbers.

House Sparrows

Lethal campaigns against house sparrows have a long history, but most recent studies aim to understand declines in their native ranges. As far as lethal control, two eradication campaigns have been reported in the literature for house sparrows. Most studies use or evaluate trapping given house sparrows' propensity to enter traps and affinity for human development. The number of avicide (n = 13) and chemical repellent (n = 19) studies is a function of the past work to limit house sparrow populations or their damage to agriculture, which is not as common today. Fertility control in the form of nest destruction or nest box design is still prevalent given the species potential impact on native cavity nesters. Although opposite goals, studies evaluating declines can inform methods to reduce house sparrows in their invasive ranges. Hence, we included the 14 urban studies and 5 rural studies evaluating habitat or supplemental food (Table 1, Figure 1, see Tables S2, S3, Appendix 1). Of the 31 field studies evaluating damage after tool implementation, all but one was in agriculture (traps = 2, avicides = 2, nest destruction = 1, cultural practices = 9, habitat = 7, netting = 1, visual = 5, auditory = 3, chemical repellents = 8). Most of the nonlethal damage management tools (i.e., habitat modification, exclusions, visual deterrents, and auditory deterrents) investigated for house sparrows occurred in agricultural systems outside of the United States (Table 1, Figure 1, see Table S3, Appendix 1).

Management Implications

We recommend an integrated pest management strategy including lethal and nonlethal tools specific to the damage problem, species, and environment. The effects of nonlethal tools are temporary given birds are capable of learning and habituating to threats that do not pose a consequential negative stimulus. Thus, success with nonlethal tools requires combining and rotating multiple techniques and negative reinforcement (i.e., shooting). To achieve population reduction, a coordinated and sustained lethal campaign is required at broad scales. Primary management tools for culling invasive birds include shooting and, if feasible, trapping and toxicants at foraging sites and hand net capture at roosting sites. We recommend shotguns for birds in flight and air rifles for precise removal of perching birds. Research is needed on fertility control via contraceptives given functionality is limited by the difficulty in establishing feeding stations, especially when natural alternative food is available. The primary nonlethal management tools for reducing bird damage at agricultural sites include 1) modifying the crop and surrounding habitat, 2) exclusionary devices, and 3) frightening devices. For crop management, we recommend 1) growing sensitive crops away from flight lines, loafing sites, and night roosts, 2) eliminating early and late-maturing crops in the same locality to avoid establishment of feeding sites, 3) advancing harvest to shorten the damage period, 4) delaying destruction of unused crops to provide alternative forage, and 5) using large plots with limited space between plots to reduce damage at field edges. Habitat suitability can be reduced by altering the landscape by 1) removing loafing habitat near crops and 2) providing alternative forage via decoy crops where the birds are not harassed. Devices can exclude birds from entire crop fields and orchards (e.g., netting over trees and plots) or limit access to parts of the plant (e.g., bags, netting, or plastic over fruiting bodies). Promising tools for hazing and bird exclusion include lasers due to visual sensitivity in many bird species, drones due to the ability to access hard to reach areas, and playback of naturally occurring bioacoustics (e.g., distress calls) that reduce habituation. Primary nonlethal management tools at urban roosting sites include 1) modifying habitat (e.g., antiperch devices, alternative landscaping, or trimming roost trees) and 2) deploying frightening devices (e.g., lasers or water devices) that make the roost undesirable. The mobility and cognitive ability of pest birds along with temporal and spatial variation in damage patterns makes estimating damage difficult and costly (Sausse et al. 2021). Nevertheless, future research should include adaptive management plans for population suppression or eradication in addition to efficacy tests of nonlethal management tools that include animal numbers and behaviors with subsequent damages. Linking damage reduction with culling effort, pest densities, or tools in urban and agricultural areas will inform efficacy and thus tool adoption.

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Authors' contribution

PEK, WPB, ABS, SRS research conceptualization; PEK, WPB, ABS, BMK, SRS ethics approval; ABS, SRS funding administration; PEK writing original draft; PEK, WPB, ABS, BMK, CJA, SCH, EWR writing review and editing.

References

Abd El-Aal SM, Abd El-Aal A, Yosef A (2006) Efficacy of some integrated bird management on controlling house sparrow (*Passer domesticus niloticus*) birds and improving of Thompson seedless grapes. *Minia Journal of Agricultural Research & Development* 26: 391–403

Abd El-Gawad K, Metwally A, Mhmoud N, Omar M (2010) Effect of broad bean sowing distances on damage caused by house sparrow, *Passer domesticus niloticus* (L.). *Assiut Journal of Agricultural Science* 41: 216–221

Agüero DA, Johnson RJ, Eskridge KM (1991) Monofilament lines repel house sparrows from feeding sites. *Wildlife Society Bulletin* 19: 416–422

Albonetti P, Marletta A, Repetto I, Sasso E (2015) Efficacy of nicarbazin (Ovistop®) in the containment and reduction of the populations of feral pigeons (*Columba livia* var. *domestica*) in the city of Genoa, Italy: a retrospective evaluation. *Veterinaria Italiana* 51: 63–72

Ali M, Rao B, Rao M, Rao P (1981) Bird (*Psittacula krameri*) damage to maize. *Journal of the Bombay Natural History Society* 79: 201–204

Alizadeh E (2009) Effects of Sunflower Cultivars and Different Sowing Dates on the Damage Rate Caused by Birds, in Particular House Sparrow *Passer domesticus*. *Podoces* 4: 108–114

Andelt WF, Burnham KP (1993) Effectiveness of nylon lines for deterring rock doves from landing on ledges. *Wildlife Society Bulletin* 21: 451–456

Anderson CJ, Brennan LA, Bukoski WP, Hess SC, Hilton CD, Shiels AB, Siers SR, Kluever BM, Klug PE (2022a) Roost Culling as an Effective Management Strategy for Reducing Invasive Rose-Ringed Parakeets (*Psittacula krameri*) Populations. Unpublished Final Report QA-3185. USDA APHIS WS National Wildlife Research Center. Hilo, Hawaii, USA., 16 pp, https://doi.org/10.21203/rs.3.rs-1236333/v1

Anderson CJ, Tillman EA, Bukoski WP, Hess SC, Brennan LA, Shiels AB, Klug PE, Siers SR, Kluever BM (2022b) A novel selective feeder for control of invasive Psittacines. Unpublished Final Report QA-3187. USDA APHIS WS NWRC. Hilo, Hawaii, USA., 22 pp

Andres HGB, Misanes CAG, Vallejos DJR, Matillano EG (2020) Development of Modulated Audible Frequency and Electric Shock Repellent for Rock Dove and Pigeon with Monitoring System. 2020 IEEE 12th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management (HNICEM). IEEE, pp 1–5, https://doi.org/10.1109/HNICEM51456.2020.9400026

Avery JD, Lockwood J (2017) Introduction history, impacts, and management of house sparrows in North America. In: Pitt WC, Beasley JC, Witmer GW (eds), Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States. CRC Press, Boca Raton, Florida, USA, pp 359–384, https://doi.org/10.1201/9781315157078-17

Avery ML (2014) Feasibility of applying contraception for reducing crop damage by avian pest species in Uruguay-Final Report. USDA-APHIS-WS National Wildlife Research Center, 29 pp

Avery ML, Eisemann JD (2014) Invasive Myna Control in American Samoa. In: Timm RM, O'Brien JM (eds), Proceedings of the 26th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 140–144, https://doi.org/10.5070/V426110438

Avery ML, Feare CJ (2020) Control or eradication: problems in the management of invasive birds. In: Downs CT, Hart LA (eds), Invasive Birds: Global Trends and Impacts. CABI Publishing, Oxfordshire, United Kingdom and Bostson, Massachusettts, USA, pp 350, https://doi.org/10.1079/9781789242065.0350

Avery ML, Lindsay JR (2016) Monk Parakeets. Wildlife Damage Management Technical Series. USDA-APHIS-WS National Wildlife Research Center, Fort Collins, Colorado, USA, 11 pp

Avery ML, Shiels AB (2018) Monk and rose-ringed parakeets. In: Pitt W, Beasley J, Witmer G (eds), Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States. CRC Press, Taylor and Francis Group, New York, USA, pp 333–357, https://doi.org/10.1201/9781315157078-16

Avery ML, Werner SJ (2017) Frightening Devices. In: Linz GM, Avery ML, Dolbeer RA (eds), Ecology and Management of Blackbirds (Icteridae) in North America. CRC Press/Taylor & Francis, Boca Raton, Florida, USA, pp 159–174, https://doi.org/10.4324/9781315156439-9

Avery ML, Primus TM, Defrancesco J, Cummings JL, Decker DG, Humphrey JS, Davis JE, Deacon R (1996) Field evaluation of methyl anthranilate for deterring birds eating blueberries. *Journal of Wildlife Management* 60: 929–934, https://doi.org/10.2307/3802395

Avery ML, Greiner EC, Lindsay JR, Newman JR, Pruett-Jones S (2002a) Monk parakeet management at electric utility facilities in south Florida. In: Timm RM, Schmidt RH (eds), Proceedings

of the 20th Vertebrate Pest Conference University of California, Davis, California, USA, pp 140–145, https://doi.org/10.5070/V420110236
Avery ML, Humphrey JS, Tillman EA, Phares KO, Hatcher JE (2002b) Dispersing vulture roosts on communication towers. *Journal of Raptor Research* 36: 45–50
Avery M, Lindsay J, Newman J, Pruett-Jones S, Tillman E (2006) Reducing monk parakeet impacts to electric utility facilities in south Florida. *Advances in Vertebrate Pest Management* 4: 125–136
Avery ML, Keacher KL, Tillman EA (2008a) Nicarbazin bait reduces reproduction by pigeons (*Columba livia*). *Wildlife Research* 35: 80–85, https://doi.org/10.1071/WR07017
Avery ML, Tillman EA, Humphrey JS (2008b) Effigies for dispersing urban crow roosts. In: Timm RM, Schmidt RH (eds), Proceedings of the 20th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 123–128, https://doi.org/10.5070/V423110599
Avery ML, Yoder CA, Tillman EA (2008c) Diazacon inhibits reproduction in invasive monk parakeet populations. *Journal of Wildlife Management* 72: 1449–1452, https://doi.org/10.2193/2007-391
Baker J, Harvey KJ, French K (2014) Threats from introduced birds to native birds. *Emu* 114: 1–12, https://doi.org/10.1071/MU12122
Barzen JA, Ballinger Jr KE (2018) Effective and sustainable prevention of avian damage to planted seeds through seed treatment. *Proceedings of the North American Crane Workshop* 14: 89–100
Basappa H (2004) Integrated pest management in sunflower: an Indian scenario. Proceedings of the 16th International Sunflower Conference. Fargo, North Dakota, USA, pp 853–859
Bashir EA (1979) A new "PAROTRAP" adapted from the MAC trap for capturing live parakeets in the field. In: Jackson WB, Jackson SS, Jackson BA (eds) Proceeding of the 8th Bird Control Seminars. Bowling Green State University, Bowling Green, Ohio, USA, pp 167–171
Baxter AT, Allan JR (2008) Use of lethal control to reduce habituation to blank rounds by scavenging birds. *Journal of Wildlife Management* 72: 1653–1657
Beason RC (2004) What Can Birds Hear? In: Timm RM, Gorenzel WP (eds), Proceedings of the 21st Vertebrate Pest Confernece. University of California, Davis, California, USA, pp 92–96
Bednarczuk E, Feare CJ, Lovibond S, Tatayah V, Jones CG (2010) Attempted eradication of house sparrows *Passer domesticus* from Round Island (Mauritius), Indian Ocean. *Conservation Evidence* 7: 75–86
Belaire JA, Westphal LM, Whelan CJ, Minor ES (2015) Urban residents' perceptions of birds in the neighborhood: Biodiversity, cultural ecosystem services, and disservices. *Condor* 117: 192–202, https://doi.org/10.1650/CONDOR-14-128.1
Belant JL, Ickes SK (1997) Mylar flags as gull deterrents. In: Lee CD, Hygnstrom SE (eds), Proceedings of the 13th Great Plains Wildlife Damage Control Workshop. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, Manhattan, Kansas, USA, pp 73–80
Belant JL, Seamans TW (1999) Alpha-chloralose immobilization of rock doves in Ohio. *Journal of Wildlife Diseases* 35: 239–242, https://doi.org/10.7589/0090-3558-35.2.239
Bendjoudi D, Chenchouni H, Doumandji S, Voisin J-F (2013) Bird species diversity of the Mitidja Plain (Northern Algeria) with emphasis on the dynamics of invasive and expanding species. *Acrocephalus* 34: 13–26, https://doi.org/10.2478/acro-2013-0002
Benras H, Guezoul O, Benghedier A, Korichi A (2019) First assessment of hybrid sparrow (*Passer domesticus* x *P. hispaniolensis*) damage on cereal crops in Ouargla (Algeria). *Lebanese Science Journal* 20: 380, https://doi.org/10.22453/LSJ-020.3.380-390
Berge A, Delwiche M, Gorenzel W, Salmon T (2007) Sonic broadcast unit for bird control in vineyards. *Applied Engineering in Agriculture* 23: 819–825, https://doi.org/10.13031/2013.24049
Bergman DL, Washburn BE (2018) Is Razor-wire an Effective Deterrent for Birds Perching on Security Fences at Airports? In: Morin DJ, Cherry MJ (eds), Proceedings of the 17th Wildlife Damage Management Conference. Orange Beach, Alabama, USA, pp 13–19
Bernat-Ponce E, Gil-Delgado JA, Guijarro D (2018) Factors affecting the abundance of House Sparrows *Passer domesticus* in urban areas of southeast of Spain. *Bird Study* 65: 404–416, https://doi.org/10.1080/00063657.2018.1518403
Bernat-Ponce E, Ferrer D, Gil-Delgado JA, López-Iborra GM (2022) Effect of replacing surface with underground rubbish containers on urban House Sparrows *Passer domesticus*. *Urban Ecosystems* 25: 121–132, https://doi.org/10.1007/s11252-021-01138-y
Besser JF, Royall Jr WC, De Grazio JW (1967) Baiting starlings with DRC-1339 at a cattle feedlot. *Journal of Wildlife Management* 31: 48–51, https://doi.org/10.2307/3798359
Bhargava M, Kumawat K (2010) Pests of stored grains and their management, 2nd edn. New India Publishing Agency, India, 264 pp
Bishop J, McKay H, Parrott D, Allan J (2003) Review of international research literature regarding the effectiveness of auditory bird scaring techniques and potential alternatives. Produced by Central Science Laboratories for the Department for Environmental Food and Rural Affairs. London, United Kingdom, 52 pp

Blackburn T, Pettorelli N, Katzner T, Gompper M, Mock K, Garner T, Altwegg R, Redpath S, Gordon I (2010) Dying for conservation: eradicating invasive alien species in the face of opposition. *Animal Conservation* 13: 227–228, https://doi.org/10.1111/j.1469-1795.2010.00372.x

Blackwell BF, Bernhardt GE, Dolbeer RA (2002) Lasers as nonlethal avian repellents. *Journal of Wildlife Management* 66: 250–258, https://doi.org/10.2307/3802891

Blanvillain C, Ghestemme T, Saavedra S, Yan L, Michoud-Schmidt J, Beaune D, O'Brien M (2020) Rat and invasive birds control to save the Tahiti monarch (*Pomarea nigra*), a critically endangered island bird. *Journal for Nature Conservation* 55: 125820, https://doi.org/10.1016/j.jnc.2020.125820

Blumstein DT (2016) Habituation and sensitization: new thoughts about old ideas. *Animal Behaviour* 120: 255–262, https://doi.org/10.1016/j.anbehav.2016.05.012

Bomford M, O'Brien PH (1990) Sonic deterrents in animal damage control: A review of device tests and effectiveness. *Wildlife Society Bulletin* 18: 411–422, https://doi.org/10.1016/0196-6553(90)90264-S

Bomford M, O'Brien PH (1995) Eradication or control for vertebrate pests? *Wildlife Society Bulletin* 23: 249–255

Borray-Escalante N, Mazzoni D, Ortega-Segalerva A, Arroyo L, Morera-Pujol V, González-Solís J, Senar JC (2020) Diet assessments as a tool to control invasive species: comparison between monk and rose-ringed parakeets with stable isotopes. *Journal of Urban Ecology* 6: juaa005, https://doi.org/10.1093/jue/juaa005

Braun M, Buyer R, Randler C (2010) Cognitive and Emotional Evaluation of Two Educational Outdoor Programs Dealing with Non-Native Bird Species. *International Journal of Environmental and Science Education* 5: 151–168

Braysher M (2017) Managing Australia's pest animals: a guide to strategic planning and effective management. CSIRO Publishing, Canberra, Australia, 200 pp, https://doi.org/10.1071/9781486304448

Brown RN, Brown DH (2021) Robotic laser scarecrows: A tool for controlling bird damage in sweet corn. *Crop Protection*: 105652, https://doi.org/10.1016/j.cropro.2021.105652

Bruggers R, Brooks J, Dolbeer R, Woronecki P, Pandit R, Tarimo T, All-India Co-Ordinated Research Project on Economic Ornithology, Hoque M (1986) Responses of pest birds to reflecting tape in agriculture. *Wildlife Society Bulletin* 14: 161–170

Bunbury N, Haverson P, Page N, Agricole J, Angell G, Banville P, Constance A, Friedlander J, Leite L, Mahoune T, Melton-Durup E, Moumou J, Raines K, van de Crommenacker J, Fleischer-Dogley F (2019) Five eradications, three species, three islands: overview, insights and recommendations from invasive bird eradications in the Seychelles. In: Veitch C, Clout M, Martin A, Russell J, West C (eds), Proceedings of the International Conference on Island Invasives 2017. Occasional Paper of the IUCN Species Survival Commission, University of Dundee, Scotland, pp 282–288

Burger J, Gochfeld M (2009) Exotic monk parakeets (*Myiopsitta monachus*) in New Jersey: nest site selection, rebuilding following removal, and their urban wildlife appeal. *Urban Ecosystems* 12: 185–196, https://doi.org/10.1007/s11252-009-0094-y

Burgio KR, Rubega MA, Sustaita D (2014) Nest-building behavior of Monk Parakeets and insights into potential mechanisms for reducing damage to utility poles. *PeerJ* 2: e601, https://doi.org/10.7717/peerj.601

Butler CJ (2003) Population biology of the introduced Rose-ringed Parakeet *Psittacula krameri* in the UK. PhD Thesis, Zoology, University of Oxford, Oxford, United Kingdom, 313 pp

Byrd R, Cummings J, Tupper S, Eisemann J (2009) Evaluation of sodium lauryl sulfate as a blackbird wetting agent. In: Boulanger JR (eds), Proceedings of the 13th Wildlife Damage Management Conference. Saratoga Springs, New York, USA, pp 191–196

Campbell S, Cook S, Mortimer L, Palmer G, Sinclair R, Woolnough A (2012a) To catch a starling: testing the effectiveness of different trap and lure types. *Wildlife Research* 39: 183–191, https://doi.org/10.1071/WR11115

Campbell S, Powell C, Parr R, Rose K, Martin G, Woolnough A (2012b) Can artificial nest-cavities be used as a management tool to assist the control of Common Starlings (*Sturnus vulgaris*)? *Emu-Austral Ornithology* 112: 255–260, https://doi.org/10.1071/MU11050

Campbell S, Roberts E, Craemer R, Pacioni C, Rollins L, Woolnough AP (2016) Assessing the economic benefits of starling detection and control to Western Australia. *Australasian Journal of Environmental Management* 23: 81–99, https://doi.org/10.1080/14486563.2015.1028486

Canavelli SB, Swisher ME, Branch LC (2013) Factors related to farmers' preferences to decrease monk parakeet damage to crops. *Human Dimensions of Wildlife* 18: 124–137, https://doi.org/10.1080/10871209.2013.745102

Canavelli SB, Branch LC, Cavallero P, González C, Zaccagnini ME (2014) Multi-level analysis of bird abundance and damage to crop fields. *Agriculture, Ecosystems & Environment* 197: 128–136, https://doi.org/10.1016/j.agee.2014.07.024

Canning G (2011) Eradication of the invasive common myna, *Acridotheres tristis*, from Fregate Island, Seychelles. *Phelsuma* 19: 43–53

Cardinell H, Hayne D (1945) Corn injury by red-wings in Michigan. Michigan State University. Agricultural Experiment Station, Sections of Horticulture and Zoology. Technical Bulletin 198, East Lansing, Michigan, USA, 59 pp

Carlson JC, Clark L, Antolin MF, Salman MD (2011a) Rock Pigeon Use Of Livestock Facilities In Northern Colorado: Implications For Improving Farm Bio-Security. *Human-Wildlife Conflicts* 5: 112–122

Carlson JC, Franklin AB, Hyatt DR, Pettit SE, Linz GM (2011b) The role of starlings in the spread of *Salmonella* within concentrated animal feeding operations. *Journal of Applied Ecology* 48: 479–486, https://doi.org/10.1111/j.1365-2664.2010.01935.x

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

Castro J, Sáez C, Molina-Morales M (2022) The monk parakeet (*Myiopsitta monachus*) as a potential pest for agriculture in the Mediterranean basin. *Biological Invasions* 24: 895–903, https://doi.org/10.1007/s10530-021-02702-5

Chakravarthy A (2004) Role of vertebrates in inflicting diseases in fruit orchards and their management. In: Mukerji KG (ed), Fruit and Vegetable Diseases. Springer, Netherlands, pp 95–142, https://doi.org/10.1007/0-306-48575-3_4

Chandler JC, Anders JE, Blouin NA, Carlson JC, LeJeune JT, Goodridge LD, Wang B, Day LA, Mangan AM, Reid DA (2020) The Role of European Starlings (*Sturnus vulgaris*) in the Dissemination of Multidrug-Resistant *Escherichia coli* among Concentrated Animal Feeding Operations. *Scientific Reports* 10: 1–11, https://doi.org/10.1038/s41598-020-64544-w

Charter M, Izhaki I, Mocha YB, Kark S (2016) Nest-site competition between invasive and native cavity nesting birds and its implication for conservation. *Journal of Environmental Management* 181: 129–134, https://doi.org/10.1016/j.jenvman.2016.06.021

Christiansen P, Steen KA, Jørgensen RN, Karstoft H (2014) Automated detection and recognition of wildlife using thermal cameras. *Sensors* 14: 13778–13793, https://doi.org/10.3390/s140813778

Clapperton BK, Porter RER, Day TD, Waas JR, Matthews LR (2012) Designer repellents: combining olfactory, visual or taste cues with a secondary repellent to deter free-ranging house sparrows from feeding. *Pest Management Science* 68: 870–877, https://doi.org/10.1002/ps.3244

Clark BA, Klug PE, Stepanian PM, Kelly JF (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

Clergeau P, Vergnes A (2011) Bird feeders may sustain feral rose-ringed parakeets *Psittacula krameri* in temperate Europe. *Wildlife Biology* 17: 248–252, https://doi.org/10.2981/09-092

Conover MR (1983) Pole-bound hawk-kites failed to protect maturing cornfields from blackbird damage. In: Jackson WB, Jackson Dodd B (eds), Bird Control Seminars Proceedings, Bowling Green State University, Bowling Green, Ohio, USA, pp 85–90

Conover MR (1984) Comparative effectiveness of avitrol, exploders, and hawk-kites in reducing blackbird damage to corn. *Journal of Wildlife Management* 48: 109–116, https://doi.org/10.2307/3808458

Conover MR (1987) Reducing raccoon and bird damage to small corn plots. *Wildlife Society Bulletin* 15: 268–272

Conover MR (1994) How birds interpret distress calls: implications for applied uses of distress call playbacks. In: Halverson WS, Crabb AC (eds), Proceedings of the 16th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 233–234

Conover MR (2002) Resolving Human-Wildlife Conflicts: The Science of Wildlife Damage Management. CRC Press, Boca Raton, FL, USA, 440 pp

Conover MR, Dolbeer RA (1989) Reflecting tapes fail to reduce blackbird damage to ripening cornfields. *Wildlife Society Bulletin* 17: 441–443

Conover MR, Dolbeer RA (2007) Use of decoy traps to protect blueberries from juvenile European starlings. *Human-Wildlife Interactions* 1: 265–270

Conover MR, Perito JJ (1981) Response of starlings to distress calls and predator models holding conspecific prey. *Zeitschrift für Tierpsychologie* 57: 163–172, https://doi.org/10.1111/j.1439-0310.1981.tb01320.x

Conroy MJ, Senar JC (2009) Integration of demographic analyses and decision modeling in support of management of invasive Monk Parakeets, an urban and agricultural pest. In: Thomson DL, Cooch EG, Conroy MJ (eds), Modeling Demographic Processes in Marked Populations. Ecological Statistics vol 3. Springer, Boston, MA, pp 491–510, https://doi.org/10.1007/978-0-387-78151-8_21

Cook A, Rushton S, Allan J, Baxter A (2008) An evaluation of techniques to control problem bird species on landfill sites. *Environmental Management* 41: 834–843, https://doi.org/10.1007/s00267-008-9077-7

Coombs C, Isaacson A, Murton R, Thearle R, Westwood N (1981) Collared doves (*Streptopelia decaocto*) in urban habitats. *Journal of Applied Ecology* 18: 41–62, https://doi.org/10.2307/2402478

Copsey J, Parkes J (2013) Institutional Capacity Building for Invasive Bird Management in the Pacific. Biodiversity Conservation Lessons Learned Technical Series. Critical Ecosystem Partnership Fund (CEPF) and Conservation International Pacific Islands Program (CI-Pacific), 78 pp

Crick HQ, Robinson RA, Appleton GF, Clark NA, Rickard AD (2002) Investigation into the causes of the decline of starlings and house sparrows in Great Britain. *BTO Research Report* 290: 1–305

Crocker DR, Perry SM, Wilson M, Bishop JD, Scanlon CB (1993) Repellency of cinnamic acid derivatives to captive rock doves. *Journal of Wildlife Management* 57: 113–122, https://doi.org/10.2307/3809007

Crowley SL, Hinchliffe S, McDonald RA (2019) The parakeet protectors: understanding opposition to introduced species management. *Journal of Environmental Management* 229: 120–132, https://doi.org/10.1016/j.jenvman.2017.11.036

Cummings JL, Knittle CE, Guarino JL (1986) Evaluating a pop-up scarecrow coupled with a propane exploder for reducing blackbird damage to ripening sunflower. In: Salmon TP (eds), Proceedings of the 12th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 286–291

Curtis PD, Merwin IA, Pritts MP, Peterson DV (1994) Chemical repellents and plastic netting for reducing bird damage to sweet cherries, blueberries, and grapes. *HortScience* 29: 1151–1155, https://doi.org/10.21273/HORTSCI.29.10.1151

D'Amico M, Rouco C, Russell JC, Román J, Revilla E (2013) Invaders on the road: synanthopic bird foraging along highways. *Oecologia Australis* 17: 86–95, https://doi.org/10.4257/oeco.2013.1701.08

Daugovish O, Yamomoto M (2006) Bird Control in Production Strawberries with Falconry. *HortScience* 41: 1047, https://doi.org/10.21273/HORTSCI.41.4.1047C

Day TD, Clapperton BK, Porter RE, Waas JR, Matthews LR (2012) Responses of free-ranging house sparrows to feed containing primary and secondary repellents. *New Zealand Journal of Crop and Horticultural Science* 40: 127–138, https://doi.org/10.1080/01140671.2011.630738

DeLiberto ST, Werner SJ (2016) Review of anthraquinone applications for pest management and agricultural crop protection. *Pest Management Science* 72: 1813–1825, https://doi.org/10.1002/ps.4330

DeLiberto ST, Carlson JC, McLean HE, Olson CS, Werner SJ (2020) Repellent Surface Applications for Pest Birds. *Human-Wildlife Interactions* 14: 409–418

Delwiche M, Houk A, Gorenzel W, Salmon T (2007) Control of crows in almonds by broadcast distress calls. *Transactions of the ASABE* 50: 675–682, https://doi.org/10.13031/2013.22656

Depenbusch B, Drouillard J, Lee C (2011) Feed depredation by European starlings in a Kansas feedlot. *Human-Wildlife Interactions* 5: 58–65

DeVault TL, Blackwell BF, Seamans TW, Begier MJ, Kougher JD, Washburn JE, Miller PR, Dolbeer RA (2018) Estimating interspecific economic risk of bird strikes with aircraft. *Wildlife Society Bulletin* 42: 94–101, https://doi.org/10.1002/wsb.859

Dhindsa MS, Saini HK, Toor H (1992) Wrapping leaves around cobs to protect ripening maize from rose-ringed parakeets. *International Journal of Pest Management* 38: 98–102, https://doi.org/10.1080/09670879209371657

Diquelou MC, Griffin AS (2019) It's a trap! Invasive common mynas learn socially about control-related cues. *Behavioral Ecology* 30: 1314–1323, https://doi.org/10.1093/beheco/arz079

Dodaro G, Battisti C (2014) Rose-ringed parakeet (*Psittacula krameri*) and starling (*Sturnus vulgaris*) syntopics in a Mediterranean urban park: evidence for competition in nest-site selection? *Belgian Journal of Zoology* 144: 5–14, https://doi.org/10.26496/bjz.2014.61

Dolbeer RA, Linz GM (2016) Blackbirds. Wildlife Damage Management Technical Series. Fort Collins, Colorado, USA, pp 16

Dolbeer RA, Woronecki PP, Bruggers RL (1986) Reflecting tapes repel blackbirds from millet, sunflowers, and sweet corn. *Wildlife Society Bulletin* 14: 418–425

Downs CT, Hart LA (2020) Invasive birds: Global trends and impacts. CABI Publishing, Oxfordshire, United Kingdom and Boston, Massachusetts, USA, 384 pp, https://doi.org/10.1079/9781789242065.0000

Dyer EE, Redding DW, Blackburn TM (2017) The global avian invasions atlas, a database of alien bird distributions worldwide. *Scientific Data* 4: 1–12, https://doi.org/10.1038/sdata.2017.41

Eaton-Robb P (2005) Bird lovers cry foul over nest destruction. Sarasota Herald-Tribune. Gannett Co., Inc., Sarasota, FL, USA 34236, https://www.heraldtribune.com/news/20051206/bird-lovers-cry-foul-over-nest-destruction (accessed 20 October 2021)

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

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

Eisemann JD, Pipas PA, Cummings JL (2003) Acute and chronic toxicity of compound DRC-1339 (3-chloro-4-methylaniline hydrochloride) to birds. In: Linz GM (ed), Management of

North American Blackbirds, Proceedings of a special symposium of The Wildlife Society, 9th Annual Conference. USDA-APHIS-Wildlife Services National Wildlife Research Center, Fort Collins, Colorado, USA, pp 24–28

Eisemann JD, Werner SJ, O'hare JR (2011) Registration considerations for chemical bird repellents in fruit crops. *Outlooks on Pest Management* 22: 87–91, https://doi.org/10.1564/22apr12

Ejaz-ul-Hassan S, Mehdi S, Ahmad N (1994) Interrelationship studies on bird damage resistance in 38 S1 families of sunflower [rose-ringed parakeet, house crows, house sparrows, weaver bird and woodpecker]. *Journal of Agricultural Research* 32: 231–243

Engeman RM, Peterla J, Constantin B (2002) Methyl anthranilate aerosol for dispersing birds from the flight lines at Homestead Air Reserve Station. *International Biodeterioration & Biodegradation* 49: 175–178, https://doi.org/10.1016/S0964-8305(01)00119-6

Enos JK, Ward MP, Hauber ME (2021) A review of the scientific evidence on the impact of biologically salient frightening devices to protect crops from avian pests. *Crop Protection* 148: 105734, https://doi.org/10.1016/j.cropro.2021.105734

Erickson WA, Marsh RE, Salmon TP (1990) A review of falconry as a bird-hazing technique. In: Davis LR, Marsh RE (eds), Proceedings of the 14^{th} Vertebrate Pest Conference. University of California, Davis, California, USA, pp 314–316

Esther A, Tilcher R, Jacob J (2013) Assessing the effects of three potential chemical repellents to prevent bird damage to corn seeds and seedlings. *Pest Management Science* 69: 425–430, https://doi.org/10.1002/ps.3288

Evans T, Kumschick S, Şekercioğlu ÇH, Blackburn TM (2018) Identifying the factors that determine the severity and type of alien bird impacts. *Diversity and Distributions* 24: 800–810, https://doi.org/10.1111/ddi.12721

Fagerstone K, Coffey M, Curtis P, Dolbeer R, Killian G, Miller L, Wilmont L (2002) Wildlife Fertility Control. Wildlife Society Technical Review 02-2, 29 pp

Fagerstone KA, Miller LA, Killian G, Yoder CA (2010) Review of issues concerning the use of reproductive inhibitors, with particular emphasis on resolving human-wildlife conflicts in North America. *Integrative Zoology* 5: 15–30, https://doi.org/10.1111/j.1749-4877.2010.00185.x

Farfán MÁ, Díaz-Ruiz F, Duarte J, Real R (2019) Feral pigeon (*Columba livia* var. *domestica*) management in low-density urban areas: prevention is better than cure. *Urban Ecosystems* 22: 1027–1035, https://doi.org/10.1007/s11252-019-00879-1

Feare CJ (2010) The use of Starlicide® in preliminary trials to control invasive common myna *Acridotheres tristis* populations on St Helena and Ascension islands, Atlantic Ocean. *Conservation Evidence* 7: 52–61

Feare C, Swannack K (1978) Starling damage and its prevention at an openfronted calf yard. *Animal Science* 26: 259–265, https://doi.org/10.1017/S000335610004085X

Feare C, Wadsworth J (1981) Starling damage on farms using the complete diet system of feeding dairy cows. *Animal Science* 32: 179–183, https://doi.org/10.1017/S0003356100024983

Feare CJ, van der Woude J, Greenwell P, Edwards HA, Taylor JA, Larose CS, Ahlen PA, West J, Chadwick W, Pandey S (2017) Eradication of common mynas *Acridotheres tristis* from Denis Island, Seychelles. *Pest Management Science* 73: 295–304, https://doi.org/10.1002/ps.4263

Feare C, Waters J, Fenn S, Larose C, Retief T, Havemann C, Ahlen P, Waters C, Little M, Atkinson S (2021a) Eradication of invasive common mynas *Acridotheres tristis* from North Island, Seychelles, with recommendations for planning eradication attempts elsewhere. *Management of Biological Invasions* 12: 700–715, https://doi.org/10.3391/mbi.2021.12.3.12

Feare CJ, Bristol RM, Van de Crommenacker J (2021b) Eradication of a highly invasive bird, the Common Myna *Acridotheres tristis*, facilitates the establishment of insurance populations of island endemic birds. *Bird Conservation International* 32: 439–459, https://doi.org/10.1017/S0959270921000435

Fernandez-Duque F, Bailey R, Bonter D (2019) Egg oiling as an effective management technique for limiting reproduction in an invasive passerine. *Avian Conservation and Ecology* 14: 20, https://doi.org/10.5751/ACE-01491-140220

Firake D, Behere G, Chandra S (2016) An environmentally benign and cost-effective technique for reducing bird damage to sprouting soybean seeds. *Field Crops Research* 188: 74–81, https://doi.org/10.1016/j.fcr.2016.01.008

Fisher P, Booth L, Campion M (2012) Review of avicides for use in eradication of introduced sparrows and pigeons from the Juan Fernandez Islands, Chile. Contract Report: LC910. Landcare Research, Lincoln, New Zealand, 28 pp

Fukuda Y, Frampton C, Hickling G (2008) Evaluation of two visual birdscarers, the Peaceful Pyramid® and an eye-spot balloon, in two vineyards. *New Zealand Journal of Zoology* 35: 217–224, https://doi.org/10.1080/03014220809510117

Furlan L, Contiero B, Chiarini F, Bottazzo M, Milosavljević I (2021) Risk factors and strategies for integrated pest management of bird pests affecting maize establishment. *Crop Protection* 148: 105744, https://doi.org/10.1016/j.cropro.2021.105744

Gagliardo A, Pollonara E, Vanni L, Giunchi D (2020) An experimental study on the effectiveness of a gel repellent on feral pigeons. *European Journal of Wildlife Research* 66: 1–8, https://doi.org/10.1007/s10344-020-1365-4

Galbraith JA, Beggs JR, Jones DN, Stanley MC (2015) Supplementary feeding restructures urban bird communities. *Proceedings of the National Academy of Sciences* 112: E2648–E2657, https://doi.org/10.1073/pnas.1501489112
Gaudioso JM, Shiels AB, Pitt WC, Bukowski WP (2012) Rose-ringed parakeet impacts on Hawaii's seed crops on the island of Kauai: Population estimate and monitoring of movements using radio telemetry. Unpublished Final Report QA-1874. USDA APHIS WS National Wildlife Research Center, Hilo, Hawaii, USA, 34 pp
Gill EL, Watkins RW, Cowan DP, Bishop JD, Gurney JE (1998) Cinnamamide, an avian repellent, reduces woodpigeon damage to oilseed rape. *Pesticide Science* 52: 159–164, https://doi.org/10.1002/(SICI)1096-9063(199802)52:2<159::AID-PS691>3.0.CO;2-S
Gilsdorf JM, Hygnstrom SE, VerCauteren KC (2002) Use of frightening devices in wildlife damage management. *Integrated Pest Management Reviews* 7: 29–45, https://doi.org/10.1023/A:1025760032566
Gippet JM, Bertelsmeier C (2021) Invasiveness is linked to greater commercial success in the global pet trade. *Proceedings of the National Academy of Sciences* 118: e2016337118, https://doi.org/10.1073/pnas.2016337118
Giunchi D, Baldaccini NE, Sbragia G, Soldatini C (2007) On the use of pharmacological sterilisation to control feral pigeon populations. *Wildlife Research* 34: 306–318, https://doi.org/10.1071/WR06153
Glahn JF, Otis DL (1986) Factors influencing blackbird and European starling damage at livestock feeding operations. *Journal of Wildlife Management* 50: 15–19, https://doi.org/10.2307/3801481
Gorenzel P, Salmon T (2008) Bird hazing manual: Techniques and strategies for dispersing birds from spill sites. Univeristy of California Agriculture and Natural Resources Communication Services Oakland, California, USA, 102 pp
Gorenzel WP, Salmon TP (1992) Urban crow roosts in California. In: Borrecco JE, Marsh RE (eds), Proceedings of the 15th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 97–102
Grant S, Young J, Riley S (2011) Assessment of Human-Coyote Conflicts: City and County of Broomfield, Colorado. *Wildland Resources Faculty Publications* Paper 1677
Grarock K, Tidemann CR, Wood JT, Lindenmayer DB (2014) Understanding basic species population dynamics for effective control: a case study on community-led culling of the common myna (*Acridotheres tristis*). *Biological Invasions* 16: 1427–1440, https://doi.org/10.1007/s10530-013-0580-2
Greer R, O'Connor D (1994) Waterbird Deterrent Techniques. Exxon, Biomedical Sciences, Inc. Marine Spill Response Corporation, Washington. DC MSRC Technical Report Series 94-003, 38 pp
Griffin AS, Boyce HM (2009) Indian mynahs, *Acridotheres tristis*, learn about dangerous places by observing the fate of others. *Animal Behaviour* 78: 79–84, https://doi.org/10.1016/j.anbehav.2009.03.012
Haag-Wackernagel D (2000) Behavioural responses of the feral pigeon (Columbidae) to deterring systems. *Folia Zoologica* 49: 101–114
Haag-Wackernagel D, Geigenfeind I (2008) Protecting buildings against feral pigeons. *European Journal of Wildlife Research* 54: 715–721, https://doi.org/10.1007/s10344-008-0201-z
Hagen E, Bonham J, Campbell K (2019) House sparrow eradication attempt on Robinson Crusoe Island, Juan Fernández Archipelago, Chile. In: Veitch C, Clout M, Martin A, Russell J, West C (eds), Proceedings of the International Conference on Island Invasives 2017. Occasional Paper of the IUCN Species Survival Commission, University of Dundee, Scotland, pp 289–294
Hagy HM, Linz GM, Bleier WJ (2008) Optimizing the use of decoy plots for blackbird control in commercial sunflower. *Crop Protection* 27: 1442–1447, https://doi.org/10.1016/j.cropro.2008.07.006
Harris E, De Crom EP, Labuschagne J, Wilson A (2016) Visual deterrents and physical barriers as non-lethal pigeon control on University of South Africa's Muckleneuk campus. *SpringerPlus* 5: 1–16, https://doi.org/10.1186/s40064-016-3559-5
Harris E, de Crom EP, Fouche J, Wilson A (2018) Comparative study on the short-term effects of audio and visual raptor presence on a pigeon population, with a view towards pest control. *International Journal of Pest Management* 6: 31–39, https://doi.org/10.1080/09670874.2018.1542185
Ryzhov S, Mursejev M (2010) Trained Goshawks Against Pigeons. *Raptors Conservation* 20: 25–34
Heck N, Schwartze S (2020) Use of falconry and shooting as Rock Pigeon abatement techniques at an electrical converter station in Alberta, Canada. *Journal of Raptor Research* 54: 193–197, https://doi.org/10.3356/0892-1016-54.2.193
Heidenreich C (2007) Bye birdie-Bird management strategies for small fruit. Cornell Cooperative Extension, 13 pp
Heiderich E, Schildger B, Lierz M (2015) Endoscopic vasectomy of male feral pigeons (*Columba livia*) as a possible method of population control. *Journal of Avian Medicine and Surgery* 29: 9–17, https://doi.org/10.1647/2013-063

Hernández-Brito D, Carrete M, Ibáñez C, Juste J, Tella JL (2018) Nest-site competition and killing by invasive parakeets cause the decline of a threatened bat population. *Royal Society Open Science* 5: 172477, https://doi.org/10.1098/rsos.172477

Hernández-Brito D, Blanco G, Tella JL, Carrete M (2020) A protective nesting association with native species counteracts biotic resistance for the spread of an invasive parakeet from urban into rural habitats. *Frontiers in Zoology* 17: 1–13, https://doi.org/10.1186/s12983-020-00360-2

Herrnstadt Z, Howard PH, Oh C-O, Lindell CA (2015) Consumer preferences for 'natural' agricultural practices: Assessing methods to manage bird pests. *Renewable Agriculture and Food Systems* 31: 516–523, https://doi.org/10.1017/S1742170515000447

Hetmański T, Bocheński M, Tryjanowski P, Skórka P (2011) The effect of habitat and number of inhabitants on the population sizes of feral pigeons around towns in northern Poland. *European Journal of Wildlife Research* 57: 421–428, https://doi.org/10.1007/s10344-010-0448-z

Hile AG, Shan Z, Zhang S-Z, Block E (2004) Aversion of European starlings (*Sturnus vulgaris*) to garlic oil treated granules: garlic oil as an avian repellent. Garlic analysis by nuclear magnetic resonance spectroscopy. *Journal of Agricultural and Food Chemistry* 52: 2192–2196, https://doi.org/10.1021/jf035181d

Holevinski RA, Curtis PD, Malecki RA (2007) Hazing of Canada geese is unlikely to reduce nuisance populations in urban and suburban communities. *Human-Wildlife Conflicts* 1: 257–264

Hothem RL, DeHaven RW (1982) Raptor-mimicking kites for reducing bird damage to wine grapes. In: Marsh RE (eds), Proceedings of the 10th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 171–178

Hyman J, Pruett-Jones S (1995) Natural history of the monk parakeet in Hyde Park, Chicago. *Wilson Bulletin* 107: 510–517

Iannone III BV, Bell EC, Carnevale S, Hill JE, McConnell J, Main M, Enloe SF, Johnson SA, Cuda JP, Baker SM (2021) Standardized invasive species terminology for effective outreach education. FOR730/FR439, 8/2021. *EDIS* 2021: 8–8, https://doi.org/10.32473/edis-fr439-2021

Invasive Species Compendium (2021) *Psittacula krameri* (Rose-Ringed Parakeet). CABI Publishing, Wallingford, Oxfordshire, United Kingdom, https://www.cabi.org/isc/datasheet/45158 (accessed 8 August 2022)

Iqbal M, Khan H, Ahmad M (2001) Feeding regimens of the rose-ringed parakeet on a brassica and sunflower in an agroecosystems in Central Punjab, Pakistan. *Pakistan Veterinary Journal* 4: 111–115

Jacob G, Prévot-Julliard A-C, Baudry E (2015) The geographic scale of genetic differentiation in the feral pigeon (*Columba livia*): implications for management. *Biological Invasions* 17: 23–29, https://doi.org/10.1007/s10530-014-0713-2

Jacquin L, Cazelles B, Prevot-Julliard A-C, Leboucher G, Gasparini J (2010) Reproduction management affects breeding ecology and reproduction costs in feral urban pigeons (*Columba livia*). *Canadian Journal of Zoology* 88: 781–787, https://doi.org/10.1139/Z10-044

Jenni-Eiermann S, Heynen D, Schaub M (2014) Effect of an ultrasonic device on the behaviour and the stress hormone corticosterone in feral pigeons. *Journal of Pest Science* 87: 315–322, https://doi.org/10.1007/s10340-014-0553-y

Johnson SA, Donaldson-Fortier G (2009) Florida's introduced birds: Eurasian collared-dove (*Streptopelia decaocto*). University of Florida, Department of Wildlife Ecology and Conservation, IFAS Extension, WEC 256. https://edis.ifas.ufl.edu/entity/topic/series_floridas_introduced_birds (accessed 24 January 2022)

Kaiser BA, Ostlie MH, Johnson BL, Werner SJ, Klug PE (2021) Inefficiency of anthraquinone-based avian repellents when applied to sunflower: the importance of crop vegetative and floral characteristics in field applications. *Pest Management Science* 77: 1502–1511, https://doi.org/10.1002/ps.6171

Kennedy TF, Connery J (2008) An investigation of seed treatments for the control of crow damage to newly-sown wheat. *Irish Journal of Agricultural and Food Research* 47: 79–91

Khaleghizadeh A (2011) Effect of morphological traits of plant, head and seed of sunflower hybrids on house sparrow damage rate. *Crop Protection* 30: 360–367, https://doi.org/10.1016/j.cropro.2010.12.023

Khan AA, Ahmad S (1983) Parakeet damage to sunflower in Pakistan. In: Jackson WB, Jackson Dodd B (eds), Proceedings 9th Bird Control Seminar. Bowling Green State University, Bowling Green, Ohio, USA, pp 191–195

Khan HA (1999) Effect of tree species and size on the availability of nest cavities of Rose-Ringed Parakeet (*Psittacula krameri*) in Central Punjab, Pakistan. *Pakistan Veterinary Journal* 19: 145–148

Khan HA (2002) Diurnal Rhythms of the Rose-Ringed Parakeet (*Psittacula krameri*) in Daylight Hours in its Communal Roost. *Online Journal of Biological Sciences* 2: 551–553, https://doi.org/10.3923/jbs.2002.551.553

Khan HA (2003) Movement Models of the Rose-ringed Parakeet (*Psittacula krameri*) in Daylight Hours in its Communal Roost. *Pakistan Journal of Biological Sciences* 6: 184–187, https://doi.org/10.3923/pjbs.2003.184.187

Khan HA, Hassan B, Mehmood I (2006) A comparison of population abundance of the rose-ringed parakeet, *Psittacula krameri*, in the two roosts of central Punjab, Pakistan. *Journal of Agriculture and Social Sciences (Pakistan)* 2: 136–141

Khan HA, Ahmad S, Javed M, Ahmad K, Ishaque M (2011) Comparative effectiveness of some mechanical repellents for management of rose ringed parakeet (*Psittacula krameri*) in citrus, guava and mango orchards. *International Journal of Agriculture & Biology* 13: 396–400

Khatri-Chhetri U, Woods JG, Walker IR, Curtis PJ (2020) Origin identification of migratory pests (European Starling) using geochemical fingerprinting. *PeerJ* 8: e8962, https://doi.org/10.7717/peerj.8962

Klug PE (2017) The Future of Blackbird Management Research. In: Linz GM, Avery ML, Dolbeer RA (eds), Ecology and Management of Blackbirds (Icteridae) in North America. CRC Press/Taylor & Francis, Boca Raton, Florida, USA, pp 217–234, https://doi.org/10.4324/9781315156439-13

Klug PE, Homan HJ (2020) Movement Behavior of Radio-Tagged European Starlings in Urban, Rural, and Exurban Landscapes. *Human-Wildlife Interactions* 14: 398–408

Klug PE, Bukoski WP, Shiels AB, Kleuver BM, Siers SR (2019) Critical review of potential control tools for reducing damage by the invasive Rose-ringed Parakeet (*Psittacula krameri*) on the Hawaiian Islands. Unpublished Final Report QA-2836. USDA APHIS WS NWRC, Fort Collins, Colorado, USA, 52 pp

Klug PE, Yackel Adams AA, Siers SR, Brindock KM, Mosher SM, Mazurek MJ, Pitt WC, Reed RN (2021) Locally abundant, endangered Mariana swiftlets impact the abundance, behavior, and body condition of an invasive predator. *Oecologia* 195: 1083–1097, https://doi.org/10.1007/s00442-021-04876-0

Koopman ME, Pitt WC (2007) Crop diversification leads to diverse bird problems in Hawaiian agriculture. *Human-Wildlife Conflicts* 1: 235–243

Kotagama S, Dunnet G (2007) Behavioral activities of the Rose-ringed Parakeet *Psittacula krameri* in the wild. *Siyoth* 2: 51–57

Kotten EA, Hennessy I, Brym Z, Kluever BM, Blackwell BF, Humberg LA, Klug PE (2022) Industrial Hemp as a Resource for Birds in Agroecosystems: Human-Wildlife Conflict or Conservation Opportunity? *Human-Wildlife Interactions* (*in press*)

Kross SM, Tylianakis JM, Nelson XJ (2012) Effects of introducing threatened falcons into vineyards on abundance of passeriformes and bird damage to grapes. *Conservation Biology* 26: 142–149, https://doi.org/10.1111/j.1523-1739.2011.01756.x

Kubasiewicz L, Bunnefeld N, Tulloch A, Quine C, Park K (2016) Diversionary feeding: an effective management strategy for conservation conflict? *Biodiversity and Conservation* 25: 1–22, https://doi.org/10.1007/s10531-015-1026-1

Kumschick S, Nentwig W (2010) Some alien birds have as severe an impact as the most effectual alien mammals in Europe. *Biological Conservation* 143: 2757–2762, https://doi.org/10.1016/j.biocon.2010.07.023

Lambert MS, Massei G, Bell J, Berry L, Haigh C, Cowan DP (2009) Reproductive success of rose-ringed parakeets *Psittacula krameri* in a captive UK population. *Pest Management Science* 65: 1215–1218, https://doi.org/10.1002/ps.1812

Lambert MS, Massei G, Yoder CA, Cowan DP (2010) An evaluation of Diazacon as a potential contraceptive in non-native rose-ringed parakeets. *Journal of Wildlife Management* 74: 573–581, https://doi.org/10.2193/2008-531

Laundré JW, Hernández L, Altendorf KB (2001) Wolves, elk, bison: reestablishing the "landscape of fear" in Yellowstone National Park, U.S.A. Canadian Journal of Zoology 79: 1401–1409, https://doi.org/10.1139/z01-094

Lawson H (1979) Feral pigeon damage to field beans. *Annals of Applied Biology* 92: 153–157, https://doi.org/10.1111/j.1744-7348.1979.tb02968.x

Le Roux DS, Ikin K, Lindenmayer DB, Bistricer G, Manning AD, Gibbons P (2016) Effects of entrance size, tree size and landscape context on nest box occupancy: Considerations for management and biodiversity offsets. *Forest Ecology and Management* 366: 135–142, https://doi.org/10.1016/j.foreco.2016.02.017

Lindell CA (2020) Supporting Farmer Adoption of Sustainable Bird Management Strategies. *Human-Wildlife Interactions* 14: 442–450

Lindell C, Eaton RA, Howard PH, Roels SM, Shave M (2018a) Enhancing agricultural landscapes to increase crop pest reduction by vertebrates. Agriculture, *Ecosystems & Environment* 257: 1–11, https://doi.org/10.1016/j.agee.2018.01.028

Lindell CA, Hannay MB, Hawes BC (2018b) Bird Management in Blueberries and Grapes. *Agronomy* 8: 295, https://doi.org/10.3390/agronomy8120295

Linley GD, Paton DC, Weston MA (2017) A citizen-trapper effort to control Common Myna: Trap success, specificity and preferred bait type. *Ecological Management & Restoration* 18: 249–252, https://doi.org/10.1111/emr.12269

Linz GM, Bergman DL (1996) DRC-1339 avicide fails to protect ripening sunflowers. *Crop Protection* 15: 307–310, https://doi.org/10.1016/0261-2194(95)00154-9

Linz GM, Homan HJ (2011) Use of glyphosate for managing invasive cattail (*Typha* spp.) to disperse blackbird (Icteridae) roosts. *Crop Protection* 30: 98–104, https://doi.org/10.1016/j.cropro.2010.10.003

Linz GM, Homan HJ, Werner SJ, Hagy HM, Bleier WJ (2011) Assessment of bird-management strategies to protect sunflowers. *BioScience* 61: 960–970, https://doi.org/10.1525/bio.2011.61.12.6

Linz GM, Bucher EH, Canavelli SB, Rodríguez E, Avery ML (2015) Limitations of population suppression for protecting crops from bird depredation: A review. *Crop Protection* 76: 46–52, https://doi.org/10.1016/j.cropro.2015.06.005

Linz G, Johnson R, Thiele J (2018) European starlings. In: Pitt W, Beasley J, Witmer G (eds), Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States. CRC Press, Taylor and Francis Group, New York, USA, pp 333–357, https://doi.org/10.1201/9781315157078-15

Lowe S, Browne M, Boudjelas S, De Poorter M (2004) 100 of the world's worst invasive alien species: a selection from the global invasive species database. Published by The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12 pp

Luna Á, Franz D, Strubbe D, Shwartz A, Braun MP, Hernández-Brito D, Malihi Y, Kaplan A, Mori E, Menchetti M (2017) Reproductive timing as a constraint on invasion success in the ring-necked parakeet (*Psittacula krameri*). *Biological Invasions* 19: 2247–2259, https://doi.org/10.1007/s10530-017-1436-y

Lyon LA, Caccamise DF (1981) Habitat selection by roosting blackbirds and starlings: management implications. *Journal of Wildlife Management* 45: 435–443, https://doi.org/10.2307/3807925

Mabb KT (1997) Roosting behavior of naturalized parrots in the San Gabriel Valley, California. *Western Birds* 28: 202–208

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout MN, Bazzaz F (2000) Biotic invasions: causes, epidemiology, global consequences and control. *Ecological Applications* 10: 689–710, https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2

Mahesh S, Rao VV, Surender G, Swamy K (2017) Distress feeding of depredatory birds in sunflower and sorghum protected by bioacoustics. *bioRxiv*: 200097, https://doi.org/10.1101/200097

Mahli C (2000) Timings of operations to control damage by rose-ringed parakeets to maturing sunflower crops and their relationship with sowing times. International *Pest Control* 42: 86–88

Mahjoub G, Hinders MK, Swaddle JP (2015) Using a "sonic net" to deter pest bird species: Excluding European starlings from food sources by disrupting their acoustic communication. *Wildlife Society Bulletin* 39: 326–333, https://doi.org/10.1002/wsb.529

Manikowski S, Billiet F (1984) Coloured flags protect ripening rice against *Quelea quelea*. *International Journal of Pest Management* 30: 148–150, https://doi.org/10.1080/09670878409370868

Marateo JSG, Grilli PG, Bouzas N, Ferretti V, Juárez MCNS, Soave GE (2015) Habitat use by birds in airports: A case study and its implications for bird management in South American airports. *Applied Ecology and Environmental Research* 13: 799–808, https://doi.org/10.15666/aeer/1303_799808

Marsh RE, Erickson WA, Salmon TP (1992) Scarecrows and predator models for frightening birds from specific areas. In: Borrecco JE, Marsh RE (eds), Proceedings of the 15th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 112–114

Martin-Albarracin VL, Amico GC, Simberloff D, Nuñez MA (2015) Impact of non-native birds on native ecosystems: a global analysis. *PLoS ONE* 10: e0143070, https://doi.org/10.1371/journal.pone.0143070

Mason JR, Adams MA, Clark L (1989) Anthranilate repellency to starlings: chemical correlates and sensory perception. *Journal of Wildlife Management* 53: 55–64, https://doi.org/10.2307/3801306

Mason JR, Clark L, Bean NJ (1993) White plastic flags repel snow geese (*Chen caerulescens*). *Crop Protection* 12: 497–500, https://doi.org/10.1016/0261-2194(93)90089-2

Matsyura A (2018) Efficiency of bird laser repellents (the case of Rooks and Pigeons). *Ukrainian Journal of Ecology* 8: 320–321, https://doi.org/10.15421/2018_346

McLellan BA, Walker KA (2021) Efficacy of motion-activated sprinklers as a humane deterrent for urban coyotes. *Human Dimensions of Wildlife* 26: 76–83, https://doi.org/10.1080/10871209.2020.1781985

McLennan J, Langham N, Porter R (1995) Deterrent effect of eye-spot balls on birds. *New Zealand Journal of Crop and Horticultural Science* 23: 139–144, https://doi.org/10.1080/01140671.1995.9513880

Medhanie GA, Pearl DL, McEwen SA, Guerin MT, Jardine CM, LeJeune JT (2015) Dairy cattle management factors that influence on-farm density of European starlings in Ohio, 2007-2009. *Preventive Veterinary Medicine* 120: 162–168, https://doi.org/10.1016/j.prevetmed.2015.04.016

Menchetti M, Mori E (2014) Worldwide impact of alien parrots (Aves Psittaciformes) on native biodiversity and environment: a review. *Ethology Ecology & Evolution* 26: 172–194, https://doi.org/10.1080/03949370.2014.905981

Menchetti M, Mori E, Angelici FM (2016) Effects of the recent world invasion by ring-necked parakeets *Psittacula krameri*. In: Angelici FM (ed), Problematic Wildlife. Springer, Switzerland, pp 253–266, https://doi.org/10.1007/978-3-319-22246-2_12

Millett J, Climo G, Shah NJ (2004) Eradication of common mynah *Acridotheres tristis* populations in the granitic Seychelles: successes, failures and lessons learned. *Advances in Vertebrate Pest Management* 3: 169–183

Mitchell CJ, Hayes RO, Hughes Jr. T (1979) Effects of the chemosterilant Ornitrol on house sparrow reproduction. *American Midland Naturalist* 101: 443–446, https://doi.org/10.2307/2424610

Mitchell RT (1963) The floodlight trap: a device for capturing large numbers of blackbirds and starlings at roosts. United States Department of the Interior, Bureau of Sport Fisheries and Wildlife, 26 pp

Montplaisir LM, Linz GM, Tomanek D, Penry LB, Bergman DL, Homan HJ (2006) Movements of house sparrows captured at an experimental grain station in Fargo, North Dakota. In: Springer JT, Springer EC (eds), Prairie Invaders: Proceedings of the 20th North American Prairie Conference. University of Nebraska, Kearney, Nebraska, USA, pp 69–72

Moran S (2001) Aversion of the feral pigeon and the house sparrow to pellets and sprouts treated with commercial formulations of methyl anthranilate. *Pest Management Science: formerly Pesticide Science* 57: 248–252, https://doi.org/10.1002/ps.271

Mori E, Meini S, Strubbe D, Ancillotto L, Sposimo P, Menchetti M (2018) Do alien free-ranging birds affect human health? A global summary of known zoonoses. In: Mazza G, Tricarcio E (eds), Invasive Species and Human Health, CABI Editions, Boston, Massachusetts, USA pp 120–129, https://doi.org/10.1079/9781786390981.0120

Mori E, Onorati G, Giuntini S (2020) Loud callings limit human tolerance towards invasive parakeets in urban areas. *Urban Ecosystems* 23: 755–760, https://doi.org/10.1007/s11252-020-00954-y

Morrison SA, DeNicola AJ, Walker K, Dewey D, Laughrin L, Wolstenholme R, Macdonald N (2016) An irruption interrupted: eradication of wild turkeys *Meleagris gallopavo* from Santa Cruz Island, California. *Oryx* 50: 121–127, https://doi.org/10.1017/S0030605314000428

Mukherjee A, Borad C, Parasharya B (2000) Damage of rose-ringed parakeet, *Psittacula krameri* Bordeat, to safflower, *Carthamus tinctorius* L. *Pavo* 38: 15–18

Nasu H, Matsuda L (1976) The damage to soybean by pigeons and doves and its control methods. *Biological Agriculture and Horticulture* 51: 563–566

Nelson PC (1994) Bird control in New Zealand using alpha-chloralose and DRC1339. In: Halverson WS, Crabb AC (eds), Proceedings of the 16th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 259–264

O'Connor R (1986) Biological characteristics of invaders among bird species in Britain. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences* 314: 583–598, https://doi.org/10.1098/rstb.1986.0074

O'Hare JR, Eisemann JD, Fagerstone KA, Koch LL, Seamans TW (2007) Use of alpha-chloralose by USDA Wildlife Services to immobilize birds. In: Nolte DL, Arjo WM, Stalman DH (eds), Proceedings of the 12th Wildlife Damage Management Conference. Corpus Christi, Texas, USA, pp 103–113

Olivera L, Pereyra S, Banchero G, Tellechea G, Sawchik J, Avery ML, Rodríguez E (2021) Nicarbazin as an oral contraceptive in eared doves. *Crop Protection* 146: 105643, https://doi.org/10.1016/j.cropro.2021.105643

Olsen P (1998) Australia's Pest Animals: New Solutions to Old Problems. Bureau of Resource Sciences and Kangaroo Press. Canberra, Australia, 160 pp

Opar A (2017) Lasers, Drones, and Air Cannons: Inside the Effort to Save Migrating Waterfowl From a Toxic Death. Audubon. https://www.audubon.org/news/lasers-drones-and-air-cannons-inside-effort-save-migrating-waterfowl-toxic-death (accessed 25 August 2021)

Paini DR, Sheppard AW, Cook DC, De Barro PJ, Worner SP, Thomas MB (2016) Global threat to agriculture from invasive species. *Proceedings of the National Academy of Sciences* 113: 7575–7579, https://doi.org/10.1073/pnas.1602205113

Papworth S, Rist J, Coad L, Milner-Gulland E (2009) Evidence for shifting baseline syndrome in conservation. *Conservation Letters* 2: 93–100, https://doi.org/10.1111/j.1755-263X.2009.00049.x

Patel J, Patel M, Parasharya B, Patel A (2002) Management of fruit damage by parakeets (*Psittacula krameri*) in pomegranate (*Punica granatum* L.). *Annals of Arid Zone* 41: 207–209

Peck HL, Pringle HE, Marshall HH, Owens IP, Lord AM (2014) Experimental evidence of impacts of an invasive parakeet on foraging behavior of native birds. *Behavioral Ecology* 25: 582–590, https://doi.org/10.1093/beheco/aru025

Peisley RK (2017) Bird control: Bird perches: A simple method to reduce bird damage to grapes. *Wine & Viticulture Journal* 32: 50

Pellizzari M (2017) Control of pigeon numbers through contraception. *International Pest Control* 59: 20–22

Perry G, Perry D (2008) Improving interactions between animal rights groups and conservation biologists. *Conservation Biology* 22: 27–35, https://doi.org/10.1111/j.1523-1739.2007.00845.x

Phillips RB, Cooke BD, Carrión V, Snell HL (2012) Eradication of rock pigeons, *Columba livia*, from the Galápagos Islands. *Biological Conservation* 147: 264–269, https://doi.org/10.1016/j.biocon.2012.01.013

Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of non-indigenous species in the United States. *BioScience* 50: 53–65, https://doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2

Pitt WC, Beasley J, Witmer GW (2017) Ecology and management of terrestrial vertebrate invasive species in the United States. CRC Press, Boca Raton, Florida, USA, 415 pp, https://doi.org/10.1201/9781315157078

Pochop PA, Johnson RJ, Aguero DA, Eskridge KM (1990) The status of lines in bird damage control-a review. In: Davis LR, Marsh RE (eds), Proceedings of the 14th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 317–324

Pruett-Jones S (2021) Naturalized Parrots of the World: Distribution, Ecology, and Impacts of the World's Most Colorful Colonizers. Princeton University Press, Princeton, New Jersey, USA, 304 pp, https://doi.org/10.1515/9780691220710

Pruett-Jones S, Newman JR, Newman CM, Avery ML, Lindsay JR (2007) Population viability analysis of monk parakeets in the United States and examination of alternative management strategies. *Human-Wildlife Conflicts* 1: 35–44

Radford A, Penniman T (2014) Mitred Conure Control on Maui. In: Timm RM, O''Brien JM (eds), Proceedings of the 26th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 61–66, https://doi.org/10.5070/V426110411

Reddy V, Gurumurthy P (2003) Reducing bird and animal pest damage in two sunflower fields with nylon nets and bird scarers. *Pavo* 40–41: 79–82

Ribeiro J, Carneiro I, Nuno A, Porto M, Edelaar P, Luna Á, Reino L (2021) Investigating people's perceptions of alien parakeets in urban environments. *European Journal of Wildlife Research* 67: 1–9, https://doi.org/10.1007/s10344-021-01487-1

Ribot RF, Berg ML, Buchanan KL, Bennett AT (2011) Fruitful use of bioacoustic alarm stimuli as a deterrent for Crimson Rosellas (*Platycercus elegans*). *Emu* 111: 360–367, https://doi.org/10.1071/MU10080

Ridgway MS, Middel TA, Pollard JB (2012) Response of double-crested cormorants to a large-scale egg oiling experiment on Lake Huron. *Journal of Wildlife Management* 76: 740–749, https://doi.org/10.1002/jwmg.308

Rodríguez E, Tiscornia G (2002) Evaluation of control alternatives for the parrot (*Myiopsitta monachus*) [Evaluación de alternativas de control de la cotorra (*Myiopsitta monachus*)]. Instituto Nacional de Investigación Agropecuaria, Montevideo, Uruguay, 50 pp

Rodríguez E, Tiscornia G (2005) Evaluation of falconry as a method of bird repellency in sunflower plots [Evaluación de la cetrería como método de repelencia de aves en parcelas de girasol]. http://chasque.net/dgsa/lab_biol/cetreria_informe_final.pdf (accessed 8 August 2022)

Rollins LA, Woolnough AP, Wilton AN, Sinclair R, Sherwin WB (2009) Invasive species can't cover their tracks: using microsatellites to assist management of starling (*Sturnus vulgaris*) populations in Western Australia. *Molecular Ecology* 18: 1560–1573, https://doi.org/10.1111/j.1365-294X.2009.04132.x

Rollins LA, Woolnough AP, Sinclair R, Mooney NJ, Sherwin WB (2011) Mitochondrial DNA offers unique insights into invasion history of the common starling. *Molecular Ecology* 20: 2307–2317, https://doi.org/10.1111/j.1365-294X.2011.05101.x

Ruelle P, Bruggers R (1982) Traditional approaches for protecting cereal crops from birds in Africa. In: Marsh RE (ed), Proceedings of the 10th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 80–86

Saavedra S (2010) Eradication of Invasive Mynas from islands. Is it possible? *Aliens Newsletter* 29: 40–47

Saavedra S, Medina FM (2020) Control of invasive ring-necked parakeet (*Psittacula krameri*) in an island Biosphere Reserve (La Palma, Canary Islands): combining methods and social engagement. *Biological Invasions* 22: 3653–3667, https://doi.org/10.1007/s10530-020-02351-0

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

Schäckermann J, Weiss N, von Wehrden H, Klein A-M (2014) High trees increase sunflower seed predation by birds in an agricultural landscape of Israel. *Frontiers in Ecology and Evolution* 2: 35, https://doi.org/10.3389/fevo.2014.00035

Schiano F, Natter D, Zambrano D, Floreano D (2021) Autonomous Detection and Deterrence of Pigeons on Buildings by Drones. *IEEE Access* 10: 1745–1755, https://doi.org/10.1109/ACCESS.2021.3137031

Seamans TW, Blackwell BF (2011) Electric shock strips as bird deterrents: does experience count? *International Journal of Pest Management* 57: 357–362, https://doi.org/10.1080/09670874.2011.621983

Seamans TW, Barras SC, Bernhardt GE (2007) Evaluation of two perch deterrents for starlings, blackbirds and pigeons. *International Journal of Pest Management* 53: 45–51, https://doi.org/10.1080/09670870601058890

Sebastián-González E, Hiraldo F, Blanco G, Hernandez-Brito D, Romero-Vidal P, Carrete M, Gomez-Llanos E, Pacifico EC, Diaz-Luque JA, Denes FV (2019) The extent, frequency and ecological functions of food wasting by parrots. *Scientific Reports* 9: 1–11, https://doi.org/10.1038/s41598-019-51430-3

Seiler GJ, Rogers CE (1987) Influence of sunflower morphological characteristics on achene depredation by birds. *Agriculture, Ecosystems & Environment* 20: 59–70, https://doi.org/10.1016/0167-8809(87)90028-4

Senar JC, Montalvo T, Pascual J, Peracho V (2017) Reducing the availability of food to control feral pigeons: changes in population size and composition. *Pest Management Science* 73: 313–317, https://doi.org/10.1002/ps.4272

Senar JC, Navalpotro H, Pascual J, Montalvo T (2021) Nicarbazin has no effect on reducing feral pigeon populations in Barcelona. *Pest Management Science* 77: 131–137, https://doi.org/10.1002/ps.6000

Shafi M, Khan A, Hussain I (1986) Parakeet damage to citrus fruit in Punjab. *Journal of the Bombay Natural History Society* 83: 439–444

Shapiro L, Aylett P, Arthur D, Eason C (2017) Primary poisoning risk for encapsulated sodium nitrite, a new tool for pest control. *New Zealand Journal of Zoology* 44: 108–121, https://doi.org/10.1080/03014223.2016.1264979

Shiels AB, Kalodimos NP (2019) Biology and impacts of Pacific Island invasive species. *Psittacula krameri*, the rose-ringed parakeet (Psittaciformes: Psittacidae). *Pacific Science* 73: 421–449, https://doi.org/10.2984/73.4.1

Shiels AB, Bukoski WP, Siers SR (2018) Diets of Kauai's invasive rose-ringed parakeet (*Psittacula krameri*): evidence of seed predation and dispersal in a human-altered landscape. *Biological Invasions* 20: 1449–1457, https://doi.org/10.1007/s10530-017-1636-5

Shiels AB, Klug PE, Kluever BM, Siers SR (2020) Rose-ringed Parakeets in California: Established Populations and Potentially a Serious Agricultural Threat. In: Woods D (eds), Proceedings of the 29th Vertebrate Pest Conference. Paper No. 43. University of California, Davis, California, USA, 5 pp

Shirley SM, Kark S (2009) The role of species traits and taxonomic patterns in alien bird impacts. *Global Ecology and Biogeography* 18: 450–459, https://doi.org/10.1111/j.1466-8238.2009.00452.x

Shirota Y, Sanada M, Masaki S (1983) Eyespotted Balloons as a Device to Scare Gray Starlings. *Applied Entomology and Zoology* 18: 545–549, https://doi.org/10.1303/aez.18.545

Shivambu TC, Shivambu N, Downs CT (2020) Impact assessment of seven alien invasive bird species already introduced to South Africa. *Biological Invasions* 22: 1829–1847, https://doi.org/10.1007/s10530-020-02221-9

Shivashankar T, Subramanya S (2008) Prevention of Rose-ringed Parakeet *Psittacula krameri* damage to sunflower *Helianthus annus* - a new approach. *Indian Birds* 4: 62–65

Soh MC, Pang RY, Ng BX, Lee BP-H, Loo AH, Kenneth B (2021) Restricted human activities shift the foraging strategies of feral pigeons (*Columba livia*) and three other commensal bird species. *Biological Conservation* 253: 108927, https://doi.org/10.1016/j.biocon.2020.108927

Sol D, Senar JC (1995) Urban pigeon populations: stability, home range, and the effect of removing individuals. *Canadian Journal of Zoology* 73: 1154–1160, https://doi.org/10.1139/z95-137

Sol D, González-Lagos C, Lapiedra O, Díaz M (2017) Why are exotic birds so successful in urbanized environments? In: Murgui E, Hedblom M (eds), Ecology and Conservation of Birds in Urban Environments. Springer International Publishing AG, Berlin, Germany, pp 75–89, https://doi.org/10.1007/978-3-319-43314-1_5

Spencer AW, De Grazio JW (1962) Capturing blackbirds and starlings in marsh roosts with dip nets. *Bird-Banding* 33: 42–43, https://doi.org/10.2307/4510913

Spennemann DH, Pike M, Watson MJ (2017) Effects of acid pigeon excreta on building conservation. *International Journal of Building Pathology and Adaptation* 35: 2–15, https://doi.org/10.1108/IJBPA-09-2016-0023

Steensma K, Lindell C, Leigh D, Burrows C, Wieferich S, Zwamborn E (2016) Bird damage to fruit crops: A comparison of several deterrent techniques. In: Timm RM, Baldwin RA (eds), Proceedings of the 27th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 196–203, https://doi.org/10.5070/V427110693

Stevens GR, Clark L (1998) Bird repellents: development of avian-specific tear gases for resolution of human-wildlife conflicts. *International Biodeterioration & Biodegradation* 42: 153–160, https://doi.org/10.1016/S0964-8305(98)00056-0

Stock B, Haag-Wackernagel D (2014) Effectiveness of gel repellents on feral pigeons. *Animals* 4: 1–15, https://doi.org/10.3390/ani4010001

Strubbe D, Matthysen E (2009) Experimental evidence for nest-site competition between invasive ring-necked parakeets (*Psittacula krameri*) and native nuthatches (*Sitta europaea*). *Biological Conservation* 142: 1588–1594, https://doi.org/10.1016/j.biocon.2009.02.026

Strubbe D, Matthysen E (2011) A radiotelemetry study of habitat use by the exotic Ring-necked Parakeet *Psittacula krameri* in Belgium. *Ibis* 153: 180–184, https://doi.org/10.1111/j.1474-919X.2010.01074.x

Subramanya S (1994) Non-random foraging in certain bird pests of field crops. *Journal of Biosciences* 19: 369–380, https://doi.org/10.1007/BF02703174

Suliman AS, Meier GG, Haverson PJ (2010) Eradication of invasive House Crow (*Corvus splendens*) from Socotra Island, Republic of Yemen-Lessons learned from 15 years of facing a bird invasion. In: Timm RM, Fagerstone KA (eds), Proceedings of the 24th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 257–262, https://doi.org/10.5070/V424110552

Suliman A, Meier G, Haverson P (2011) Eradication of the house crow from Socotra Island, Yemen. In: Veitch CR, Clout MN, Towns DR (eds), Island invasives: Eradication and management. Proceedings of the International Conference on Island Invasives, International Union for Conservation of Nature (IUCN), Gland, Switzerland and The Centre for Biodiversity and Biosecurity (CBB), Auckland, New Zealand, pp 361–363

Swaddle J, Moseley D, Hinders M, Smith EP (2015) A sonic net excludes birds from an airfield: implications for reducing bird strike and crop losses. *Ecological Applications* 26: 339–345, https://doi.org/10.1890/15-0829

Taber MR (2002) Netting applications for agricultural bird control. In: Timm RM, Schmidt RH (eds), Proceedings of the 20th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 117–122, https://doi.org/10.5070/V420110192

Thiele JR (2020) One Step Closer to a Better Starling Trap. *Human-Wildlife Interactions* 14: 419–426

Tidemann C (2005) Indian mynas - can the problems be controlled. In: Hayward M (ed), Proceedings of the 15th National Urban Animal Management Conference. Australian Veterinary Association, Canberra, Australia, pp 55–57

Tidemann C (2010) Investigation into the potential for broadscale control of mynas by trapping at communal roosts. Final Report to the Hermon Slade Foundation, the Australian Rainforest Foundation and the NSW Department of Environment, Climate Change and Water. Australian National University, Canberra, Australia, 32 pp

Tidemann CR, Grarock K, King DH (2011) Euthanasia of pest sturnids in nestboxes. *Corella* 35: 49–51

Tillman EA (2016) Development of a feeder selective for Monk parakeets (*Myiopsitta monachus*). Unpublished Report QA-1488. USDA APHIS WS National Wildlife Research Center, Fort Collins, Colorado, USA, 51 pp

Tillman EA, Van Doom A, Avery ML (2000) Bird damage to tropical fruit in south Florida. In: Brittingham MC, Kays J, McPeake R (eds), Proceedings of the 9th Wildlife Damage Management Conference. State College, Pennslyvania, USA, pp 47–59

Tipton KW, Floyd EH, Marshall JG, McDevitt JB (1970) Resistance of Certain Grain Sorghum Hybrids to Bird Damage in Louisiana. *Agronomy Journal* 62: 211–213, https://doi.org/10.2134/agronj1970.00021962006200020010x

Tipton AR, Rappole JH, Kane AH, Flores RH, Johnson D, Hobbs J, Schulz P, Beasom S, Palacios J (1989) Use of monofilament line, reflective tape, beach-balls, and pyrotechnics for controlling grackle damage to citrus. Great Plains Wildlife Damage Control Workshop Proceedings, 413

Tracey J, Bomford M, Hart Q, Saunders G, Sinclair R (2006) Managing bird damage to fruit and other horticultural crops. Bureau of Rural Sciences, Canberra, Australia, 268 pp

Tobin M, Woronecki P, Dolbeer R, Bruggers R (1988) Reflecting tape fails to protect ripening blueberries from bird damage. *Wildlife Society Bulletin* 16: 300–303

Toor H, Ramzan M (1974) Extent of losses to sunflower due to rose-ringed parakeet, *Psittacula krameri*, (Scopoli) at Ludhiana (Punjab). *Journal of Research, Punjab Agricultural University* 11: 197–199

USDA-APHIS-WS (2001a) United States Department of Agriculture Animal Plant and Health Inspection Service Wildlife Services. Tech Note: DRC-1339 (Starlicide). https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1735&context=icwdm_usdanwrc (accessed 25 August 2021)

USDA-APHIS-WS (2001b) United States Department of Agriculture Animal Plant and Health Inspection Service Wildlife Services. Tech Note: Egg Oil: An Avian Population Control Tool. https://www.aphis.usda.gov/wildlife_damage/nwrc/publications/Tech_Notes/TN_EggOil.pdf (accessed 25 August 2021)

USDA-APHIS-WS (2012) United States Department of Agriculture Animal Plant and Health Inspection Service Wildlife Services. Tech Note: Sodium Lauryl Sulfate: European Starling and Blackbird Wetting Agent. https://www.aphis.usda.gov/wildlife_damage/nwrc/publications/Tech_Notes/TN_SodiumLaurylSulfate.pdf (accessed 25 August 2021)

USEPA (2022) United States Environmental Protection Agency. Pesticide Product and Label System. https://iaspub.epa.gov/apex/pesticides/f?p=113:1::::RP,17,1 (accessed 2 June 2022)

VerCauteren KC, Seward N, Hirchert D, Jones M, Beckerman SF (2005) Dogs for reducing wildlife damage to organic crops: a case study. In: Nolte DL, Fagerstone KA (eds), Proceedings of the 11th Wildlife Damage Mangement Conference, pp 286–293

Wandrie LJ, Klug PE, Clark ME (2019) Evaluation of two unmanned aircraft systems as tools for protecting crops from blackbird damage. *Crop Protection* 117: 15–19, https://doi.org/10.1016/j.cropro.2018.11.008

Wang Z, Griffin AS, Lucas A, Wong K (2019) Psychological warfare in vineyard: Using drones and bird psychology to control bird damage to wine grapes. *Crop Protection* 120: 163–170, https://doi.org/10.1016/j.cropro.2019.02.025

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

Werner SJ, DeLiberto ST, McLean HE, Horak KE, VerCauteren KC (2021) Toxicity of sodium nitrite-based vertebrate pesticides for European starlings (*Sturnus vulgaris*). *PLoS ONE* 16: e0246277, https://doi.org/10.1371/journal.pone.0246277

Werrell AK, Klug PE, Lipcius RN, Swaddle JP (2021) A Sonic Net reduces damage to sunflower by blackbirds (Icteridae): implications for broad-scale agriculture and crop establishment. *Crop Protection* 144: 105579, https://doi.org/10.1016/j.cropro.2021.105579

White MG (2021) An evaluation of the social perceptions and biological efficacy of unmanned aircraft systems for avian-agriculture conflict. MS Thesis, Biology, Environmental and Conservation Sciences (Biological Sciences), North Dakota State University, Fargo, North Dakota, USA, 83 pp

Woods, RD, Swaddle JP, Bearhop S, Colhoun K, Gaze WH, Kay SM, McDonal RA (2022) A Sonic Net deters European starlings *Sturnus vulgaris* from maize silage stores. *Wildlife Society Bulletin* e1340: 1–12, https://doi.org/10.1002/wsb.1340

Woolnough AP, Massam M, Payne R, Pickles G (2005) Out on the border: keeping starlings out of Western Australia. Proceedings of the 13th Australasian Vertebrate Pest Conference. Landcare Research, Wellington, New Zealand, pp 183–189

Woolnough AP, Lowe TJ, Rose K (2006) Can the Judas technique be applied to pest birds? *Wildlife Research* 33: 449–455, https://doi.org/10.1071/WR06009

Woronecki PP (1988) Effect of ultrasonic, visual, and sonic devices on pigeon numbers in a vacant building. In: Crabb AC, Marsh RE (eds), Proceedings of the 13th Vertebrate Pest Conference. University of California, Davis, California, USA, pp 266–272

Woronecki PP, Dolbeer RA, Otis DL (1988) Evaluating corn varieties for resistance to damage by blackbirds and starlings. Vertebrate Pest Control and Management Materials: 5th Volume 974: 26, https://doi.org/10.1520/STP26168S

Yap CA-M, Sodhi NS, Brook BW (2002) Roost characteristics of invasive mynas in Singapore. *Journal of Wildlife Management* 66: 1118–1127, https://doi.org/10.2307/3802943

Yoder CA, Avery ML, Keacher KL, Tillman EA (2007) Use of DiazaCon™ as a reproductive inhibitor for monk parakeets (*Myiopsitta monachus*). *Wildlife Research* 34: 8–13, https://doi.org/10.1071/WR06069

Supplementary material

The following supplementary material is available for this article:

Table S1. References listed chronoligcally for studies evaluating population control tools at nesting, foraging, loafing, and roosting sites for the seven small-bodied, invasive birds inhabiting periurban habitats (* = field studies; D = field studies where damage was recorded).

Table S2. References listed chronoligcally for studies evaluating nonlethal damage management at urban nesting, foraging, loafing, and roosting sites for the seven small-bodied, invasive birds inhabiting periurban habitats (* = field studies; D = field studies where damage was recorded).

Table S3. References listed chronoligcally for studies evaluating nonlethal damage management at agricultural foraging sites for the seven small-bodied, invasive birds inhabiting periurban habitats (* = field studies; D = field studies where damage was recorded).

Appendix 1. References for studies evaluating lethal and nonlethal damage management tools for the seven small-bodied, invasive birds inhabiting periurban habitats.

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