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ACRP

SYNTHESIS 23

AIRPORT
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Bird Harassment, Repellent, and Deterrent Techniques for Use on and Near Airports

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A Synthesis of Airport Practice

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AIRPORT COOPERATIVE RESEARCH PROGRAM

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Bird Harassment, Repellent, and Deterrent Techniques for Use on and Near Airports

A Synthesis of Airport Practice

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principle means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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Cover figure: Bird dispersal at Seattle-Tacoma International Airport (*courtesy*: Seattle-Tacoma International Airport).

FOREWORD

Airport administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to the airport industry. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire airport community, the Airport Cooperative Research Program authorized the Transportation Research Board to undertake a continuing project. This project, ACRP Project 11-03, "Synthesis of Information Related to Airport Practices," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an ACRP report series, *Synthesis of Airport Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Gail R. Staba
Senior Program Officer
Transportation Research Board

This synthesis provides airport managers and biologists with a document that reviews techniques for reducing bird collisions with aircraft and their relative effectiveness.

Information used in this study was acquired through a review of the literature and interviews with airport operators and industry experts.

Jerrold L. Belant and James A. Martin, Mississippi State University, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

BIRD HARASSMENT, REPELLENT, AND DETERRENT TECHNIQUES FOR USE ON AND NEAR AIRPORTS

SUMMARY

Birds and airplanes are a dangerous combination. Airport managers and other transportation safety and security officials have spent significant financial and personnel resources in an effort to prevent or mitigate the possibility of aircraft collisions with wildlife, including birds. These collisions pose substantial risks to human safety: wildlife strikes have resulted in the loss of more than 200 human lives and more than 200 military and civil aircraft since 1988. Economic considerations of wildlife collisions are also a concern for the aviation industry, as annual economic losses from wildlife-related damage to civil aircraft are conservatively estimated by Allan in 2002 to exceed $1.2 billion worldwide and by Dolbeer et al. in 2010 to reach $600 million in the United States alone. Following the highly publicized bird strike that forced US Airways Flight 1549 to make an emergency landing in the Hudson River in January 2009, public awareness of wildlife collisions with aircraft is presently at an all-time high. Nonetheless, research-backed information on current approaches to bird deterrent techniques at airports is often scattered across different disciplines and fields of research, and few attempts have been made to develop a comprehensive assessment of these techniques.

The objective of this synthesis is to provide airport managers and biologists with a document that reviews techniques for reducing bird collisions with aircraft and their relative effectiveness. To gather relevant research and information on current practices, primary and grey literature were reviewed using multiple data sources, and six airports surveyed as case studies from which to obtain qualitative information on existing bird management strategies and their perceived effectiveness. From this information, an overview of various types of techniques (e.g., exclusion and effigies) and their relative effectiveness was developed. Concepts of avian ecology were also summarized and these concepts related to the degree of attractiveness, or site fidelity, to areas containing bird-specific resources (e.g., food, roosting, or loafing areas) found at or near airports. Site fidelity was then examined in the context of control techniques most likely to be successful in dispersing birds. As expected, control techniques varied markedly across species of birds and depend on factors such as seasonality, fidelity, and physiological characteristics of target species. Similar to other control programs, integrated damage management, which includes harassment, repellent, and exclusion techniques as well as other practices such as habitat management and potentially lethal control, appears to be more effective than single techniques.

Because many of these control methods do not have sufficient empirical evidence to support or refute the effectiveness of the techniques being employed under different circumstances, further assessment of these techniques is necessary, either through directed, rigorous scientific study or initially through quantification of existing techniques used at airports to help refine priorities for research. Additionally, reviews of other aspects of bird management techniques at airports, including habitat and population management, are warranted. This synthesis is intended to provide a baseline assessment of information from which to approach further research into wildlife control techniques for the aviation industry.

CHAPTER ONE

INTRODUCTION

The impetus for this synthesis is to provide airport managers and biologists with a document that reviews the tools, methods, techniques, and procedures for reducing bird collisions with aircraft (i.e., bird strikes) and their relative effectiveness into a single treatise. The management of wildlife in the context of aviation, specifically the reduction of wildlife strikes to aircraft, is a unique application of wildlife damage management. Wildlife damage management typically involves overabundant species and their effect on human property (Conover 2002; Cleary and Dolbeer 2005). However, wildlife damage to aircraft may have immediate implications for human safety. Consequently, airport managers must frequently take immediate action to mitigate risk. Wildlife species involved with aviation hazard may not be overabundant; populations may be within biological and cultural carrying capacity outside of airspace, but their presence within airspace is hazardous and unwanted.

Control techniques should be implemented in the context of an airport hazard management plan or program. Airport personnel are inherently and legally responsible to reduce aviation risk using a myriad of methods given the constraints of resources and time. Biologists face considerable uncertainty regarding the effectiveness of specific techniques under given conditions and circumstances. Furthermore, animals adapt and change behavior in response to techniques—what worked last time may not work similarly when reapplied. Biologists should be equipped with the most current information on the effectiveness of harassment, deterrent, and repellent techniques, and adequate empirical data should be readily available. For these methods to be meaningful, they must be integrated with principles of avian ecology. Techniques must be founded on ecological principles to be effective, and both managers and biologists should understand and appreciate that relationship.

BIRDS AND AIRCRAFT: UNDERSTANDING THE INTERACTION

Aircraft collisions with birds and other wildlife (wildlife strikes) pose increasing safety and financial concerns to the aviation industry worldwide. Recent events such as the forced landing of US Airways Flight 1549 in the Hudson River have renewed public interest in risks to aircraft posed by wildlife (Marra et al. 2009). However, wildlife biologists and aviation personnel have been aware of these issues for decades (Solman 1973; Blokpoel 1976). Since the inception of the FAA National Wildlife Strike Database in 1990, 99,411 reported wildlife strikes to airplanes have resulted in at least $1.2 billion annually in losses (damage to aircraft and associated costs) to civil aviation worldwide and more than $625 million annually in the United States, in addition to more than 200 human lives lost (Allan 2002; Dolbeer et al. 2010). The vast majority (97.4%) of all wildlife strikes involve birds.

Before the jet age of air travel, bird strikes were less common because piston-powered aircraft were noisy and relatively slow, and the number of aircraft was comparatively low. Birds could often avoid collisions, and in the event of a strike, damage was minimal. Modern jet aircraft are much faster and relatively quiet compared with their piston-powered predecessors; this changes the dynamics of bird and aircraft interactions dramatically.

The skies are becoming increasingly crowded with aircraft and hazardous bird species (Dolbeer 2009). Aircraft movements increased about 3% per year between 1985 and 2004 (Dolbeer 2009). Many species of wildlife also have increased in the last half-century, including those species that pose the most risk to aviation (Dolbeer et al. 2000). Many of these species exceed the airframe and engine certification standards for wildlife strikes [e.g., Canada geese (*Branta canadensis*)]. These parallel factors create a considerable need to employ risk mitigation measures that effectively reduce bird strikes.

Dolbeer (2006) noted that 66% of wildlife strikes resulting in substantial damage to aircraft occurred less than 500 ft above ground level (AGL), effectively 10,000 ft from the airfield based on a 3° glideslope (Foundation 2000; Blackwell et al. 2009). About 95% of bird strikes occur less than 3,500 ft AGL (Dolbeer 2006). At that altitude, aircraft would be within about 5 miles of the airfield for the busiest airports (Federal Aviation Administration 2008). Dolbeer (2011) reported that bird-strike rates above 500 ft AGL have increased since 1990, whereas strike rates below 500 ft AGL have decreased during that period. These empirical data suggest that recent wildlife management on airports has reduced strike rates and damaging strikes (Dolbeer 2011); however, airport sponsors and managers are legally obligated [Title 14 Code of Federal Regulations, part 139 (14

CFR, part 139)] to make certain the airport environment, including areas near the airport, is safe.

Airport managers can use five basic strategies to manage hazardous wildlife at or near the airport (from Cleary and Dickey 2010):

1. Repelling techniques: Use of various audio, visual, or chemical repellents to harass and repel problem wildlife.

2. Habitat modification: Elimination or reduction of food, water, or shelter attractive to wildlife at or near the airport.

3. Exclusion: Use of physical barriers to stop wildlife from gaining access to food, water, or shelter at or near the airport.

4. Population management: Reduction or elimination of wildlife populations that are posing a hazard to aircraft at or near the airport by either capturing (live capture and relocation) or killing the problem animals.

5. Notices to Airmen (NOTAM) of potential wildlife hazards.

This synthesis emphasizes numbers 1 and 3; however, the repellent techniques cannot be considered in isolation and typically are applied in conjunction with one or more of the other strategies.

METHODOLOGY FOR SYNTHESIS

Literature Search

We reviewed the literature for papers that included information regarding bird deterrents, repellents, harassment, and/or hazing. We did not limit our review to studies conducted within the airport environment because much of the research in this arena has involved captive studies and field studies in agriculture settings. We used numerous databases to find primary and secondary literature, including Google Scholar, DigitalCommons at University of Nebraska–Lincoln, Scopus™, and numerous conference proceedings databases (e.g., Vertebrate Pest Conference). We searched for the following terms in article abstracts and keywords: deterrents, hazing, harassment, repellents, damage management, airports, aviation, frightening devices, and numerous combinations of the aforementioned. We supplemented searches by examining bibliographies of articles for additional references. Much of the published literature on the subjects was found in the secondary literature.

Guiding Principles of Bird Damage Management

Bird management at airports is best considered an adaptive process of deterrence where species composition and behavior can be expected to change during the day, between seasons, and across years, even when techniques in this synthesis are actively employed. Many bird species habituate to deterrent techniques and will return to the area, particularly if the area is attractive to them. Consequently, two critical questions to ask are “Why are they present?” and “Are they occasional or habitual users of areas on and near the airport?” Figure 1 depicts a gradient of bird activities along a continuum of fidelity or attractiveness to a particular site. Essentially, as site fidelity increases, difficulty in moving the birds will similarly increase. Matching the type of control technique with the type of bird activity will improve chances of success. Additionally, the more frequently a bird occupies an airport without negative consequences such as control methods, irrespective of degree of site fidelity, the more difficult it will be to disperse the bird. Consequently, effective management is management highly responsive to dispersing birds from airports as soon as they are detected.

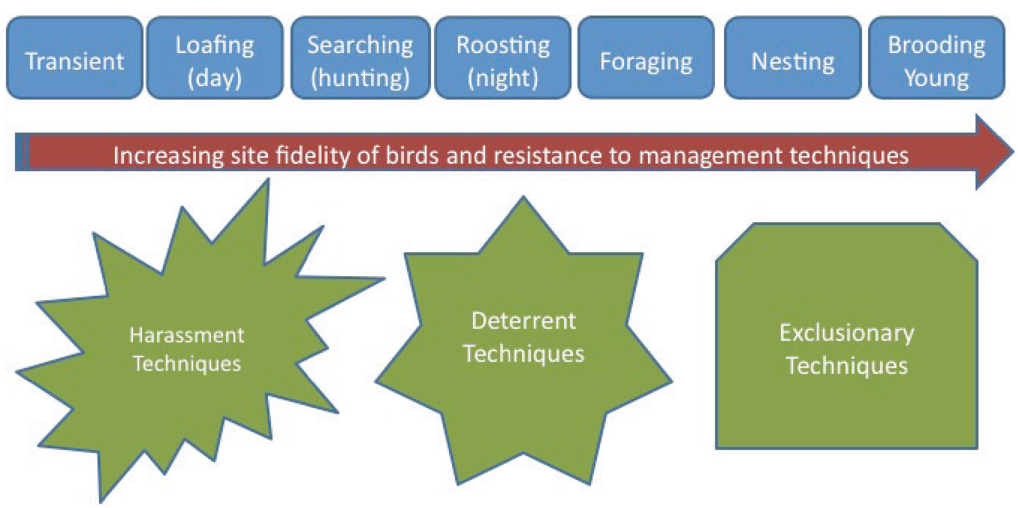

FIGURE 1 Gradient of bird activities in increasing order of site fidelity and resistance to control techniques (*Source*: Adapted from Steve Osmek, SEA Airport).

CHAPTER TWO

INTEGRATIVE DAMAGE MANAGEMENT

To maximize reduction of bird use of airports or other areas, integrated approaches employing multiple techniques are generally more successful and more widely used than individual techniques (Conover 2002). In addition to harassment, deterrent, and exclusion techniques, other categories of bird damage management including habitat management and lethal control must be implemented when appropriate. There are several examples (e.g., Montoney and Boggs 1995; Belant 1997; Tobin 1998) of integrated approaches having improved effectiveness over single techniques. Mott and Timbrook (1988) demonstrated greater reductions in goose abundance at campgrounds when incorporating goose alarm and distress calls with pyrotechnics. Waterfowl use of ponds was reduced when motion-activated frightening devices were integrated with a chemical repellent (Stevens et al. 2000). An integrated approach including harassment techniques and public education was effective in reducing goose abundance and the number of nuisance complaints (Preusser et al. 2008). Use of multiple hazing techniques, particularly those that included the use of border collies, was most successful in dispersing Canada geese in urban and suburban communities (Holevinski et al. 2007). A combination of lasers, distress calls, and pyrotechnics was 98% effective in reducing crow abundance at urban roosts (Chipman et al. 2008). Lethal control can also enhance the efficacy of harassment and deterrent techniques at airports (Dolbeer et al. 1993).

Although integration of multiple deterrent, harassment, and repellent techniques can likely reduce bird use of airports more than any single technique, habitat within the airport and surrounding landscape must also be considered. Following distribution theory, as habitat suitability on and adjacent to the airport increases, use of this habitat by birds and other wildlife at the individual and population level will also increase. In turn, reductions in habitat suitability would be expected to result in reduced bird and other wildlife use. As habitat becomes less suitable, the potential for enhanced effectiveness of deterrent, harassment, and repellent techniques should increase.

CHAPTER THREE

PRINCIPLES OF AVIAN ECOLOGY AND BIOLOGY

BIRD MOVEMENTS AND SPACE USE

The airport environment comprises a relatively small land area in the context of bird movements and space use; thus it is likely only a small proportion of areas used for most species. Furthermore, birds likely spend only a small percentage of time in the airport environment foraging, loafing, or raising young. Also, considering the patchiness of the typical landscapes in and surrounding airports, bird likely use only portions of airports. There is also temporal variation in bird use of areas including airports. For migrant species, use may be restricted to fall and spring migration periods. Alternatively, birds may be present only during winter or summer to nest and raise young. Finally, resident species may use habitat on airports year-round. The mechanisms driving bird distributions in the context of habitat are important to consider because they can influence the timing of use and effectiveness of deterrents, hazing, and repellents.

Dispersal

Several models have been proposed to explain how individuals within groups or subpopulations disperse from one location to another. Slatkin (1985) postulated that dispersal may simply be a random walk in space with few, if any, factors driving species dispersal. However, it is not likely that most species perceive the environment in this manner, and this model is not well supported in the ecological literature. The ideal free distribution model (Fretwell and Lucas 1970), or balanced dispersal model (Doncaster et al. 1997), states that dispersal patterns are contingent on the fitness (e.g., increased survival or reproductive success) of the individual in a given habitat type, and dispersal is not constrained by population density in the other habitat patches. Source-sink dynamics is another type of model used to describe how variation in habitat quality can influence use and distribution of animals. In source-sink models, the source is an area of higher quality habitat that on average can support more individuals and allows populations to increase. In contrast, a sink is an area of low-quality habitat that cannot sustain a population and generally supports low numbers of individuals. For general source-sink models (Holt 1985; Pulliam 1988), dispersal is constrained between patches, density-independent or dependent dispersal are both possible, and habitat quality may vary greatly among patches. Also, as the name implies, the presence of a sink is assumed under source-sink models. Finally, Senar et al. (2002) proposed a model based on work with Citril finches (*Serinus citronella*), whereby animals may disperse from low- to high-quality sites because the high-quality sites act as pools of genetic variability and are sources of higher-quality food. Given the assumptions of each model, predictions may vary greatly regarding dispersal. Further, the response of individual populations to human and environmental disturbances, as well as land management actions and deterrent techniques, will depend on which model of dispersal is applicable in a given system and circumstances.

Flocking Behavior

Birds may form flocks of individuals of single or multiple species. Flock formation is a balance between costs and benefits to individuals within a flock by reducing the risk of predation and enabling cooperative foraging (Emlen 1952; Powell 1974; Caraco et al. 1980a,b; Caraco 1981; Tinbergen 1981; Pulliam et al. 1982; Fernández-Juricic et al. 2004). Unstable and indefensible areas (e.g., food sources or loafing sites) promote flocking behavior (Verbeek 1972; Gill 1995). Verbeek (1972) found that corvids abandoned territories and developed flocks when food supplies became less stable and more widely and unevenly distributed. Flocking behavior has also been demonstrated to be a function of breeding activity in starlings (Davis 1970). Feeding in flocks can increase competition for food, but has been demonstrated to collectively increase foraging efficiency (Caraco 1981; Sullivan 1984). Cooperative feeding is common in species such as pelicans, cormorants, and mergansers (Bartholomew 1942; Emlen 1952). Flock members can also benefit from prey that is flushed by a flock-mate. For example, Cezilly et al. (1990) found that forage striking and number of captures per minute improved as flock size increased for little egrets (*Egretta garzetta*).

Individual fitness of a bird can also be increased in flocks through reduced predation risk (Charnov and Krebs 1975; Sirot 2006). Predators can be confused by flock movements that make it more difficult to single out one individual (Landeau and Terborgh 1986). Page and Whitacre (1975) reported that merlin (*Falco columbarius*) hunting success varied according to prey flock size. Kenward (1978) found that goshawk (*Accipiter gentilis*) predation was also disparately lower when pigeon flock sizes were large. Another possible hypothesis for reduced predation rates in flocks relates to increased vigilance for predator detection. Flock members can warn other birds of the presence of the predator using alarm calls or visual cues (Charnov and Krebs 1975).

We use an example to place the aforementioned ecological concepts and flocking behavior into an airport management context. Merlins may use airport properties as a consequence of songbirds foraging in grasslands. These songbirds may prefer to forage in taller grass because of more abundant prey; thus under ideal free distribution we would expect higher abundance of songbirds in tall grass areas. Mowing areas of high grass closer to runways for aircraft safety would leave fewer areas of tall grass, further concentrating songbirds. These flocks may reduce foraging efficiency for merlins, thus reducing overall merlin use of airports and associated risk to aircraft. However, the larger flocks of songbirds would pose a greater risk to aircraft. As individual songbirds pose little risk to aircraft, management actions would not likely be directed toward these individuals. However, larger flocks of these birds may well trigger implementation of control measures. As Figure 2 shows, understanding ecological relationships within and between species, and how these species interact with their environment, is critical for maximizing efficiency and effectiveness of control measures.

HARASSMENT, REPELLENT, AND DETERRENT TECHNIQUES

Harassment, repellents, and deterrents encompass a wide range of techniques and methods used to manipulate behavior of birds to shift use away from an area or resource (Werner and Clark 2003). The use of a method or device must be coupled with an understanding the mode of behavior response; simply stated, the tool must of match the task, as shown in Figure 3. Essentially, two types of repellents exist—primary and secondary (Clark 1998). Primary repellents cause involuntary withdrawal or escape behavior in an animal usually through taste, odor, or irritation (Clark 1998). Secondary repellents induce an undesirable physiological effect for the animal, such as gastric malaise. The goal of airport biologists is to create avoidance behavior such that the animal will discontinue occupying an area or to reduce ease of foraging for food in a given patch (Werner and Clark 2003). The periodicity of repellents is also an important determinant of their effectiveness. Devices used to repel, haze, and generally frighten animals can be periodic, random, or motion activated (Gilsdorf et al. 2002). The timing of the stimuli has a direct impact on effectiveness. Random or animal-activated devices may reduce habituation and increase the time of protection over nonrandom (i.e., systematic) devices (Koehler et al. 1990).

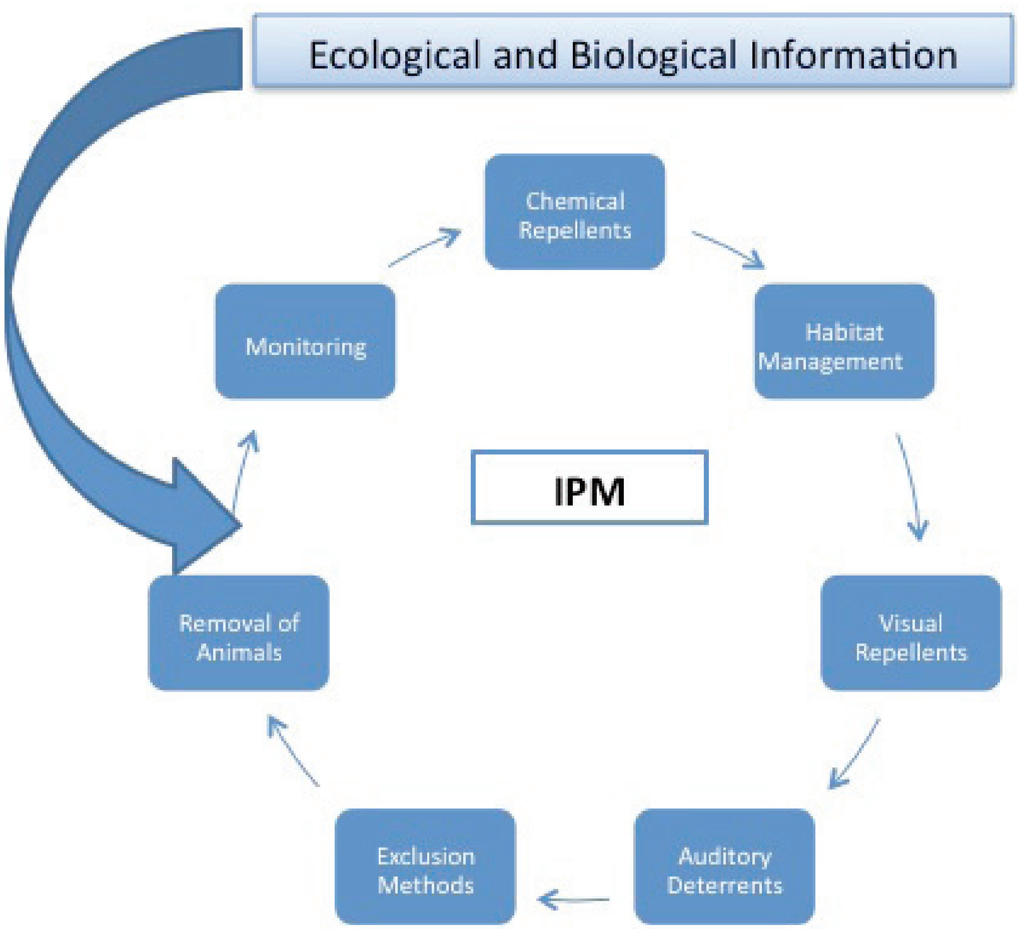

FIGURE 2 Integrated pest management (*Source*: Werner and Clark 2003).

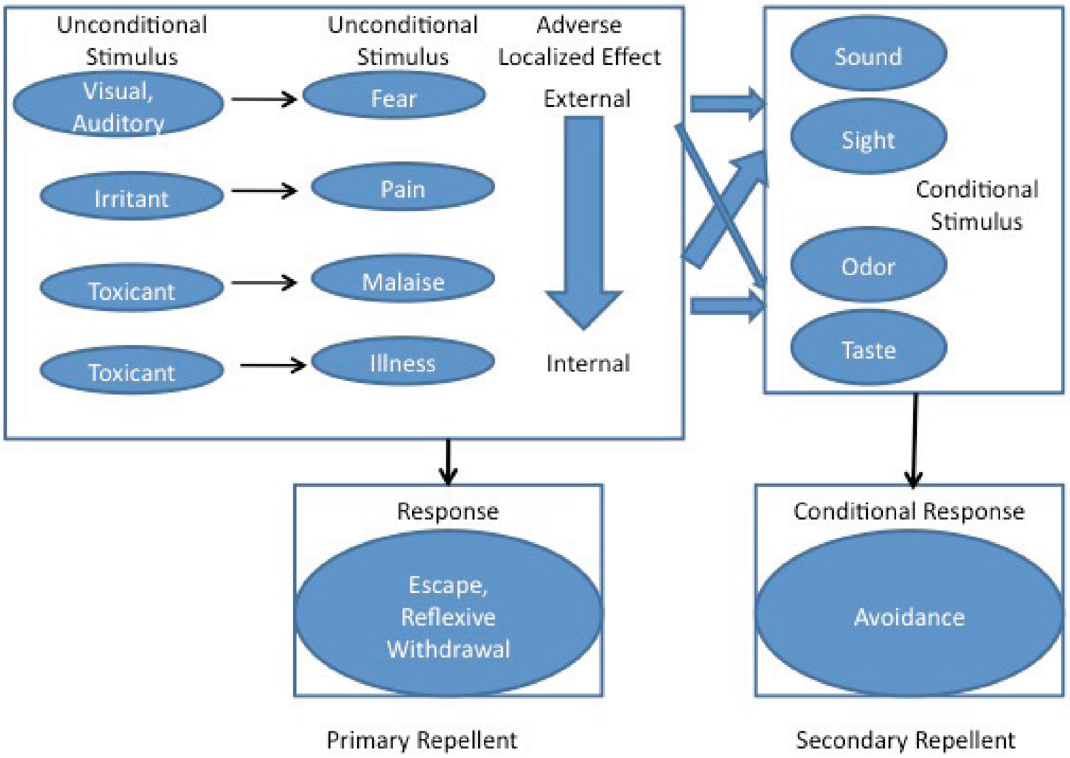

FIGURE 3 Conceptual model depicting the different modes of repellents and behavior responses to the stimuli. Arrow width represents relative likelihood of response-stimulus association among birds (*Source*: Werner and Clark 2003).

SENSES

The primary senses of birds targeted by repellent applications include the chemical senses, vision (sight), audition (hearing), and touch (e.g., tactile). If the chemical senses are treated as one, the likelihood that a chemical repellent will fail is high because it will be designed and delivered in a contextually inappropriate manner. The chemical senses of an animal are composed of olfactory (smell), gustatory (taste), and chemesthetic (irritation and pain) systems (Mason and Clark 2000). In terms of chemical signals, the integrated perception of all three chemosensory inputs is called flavor. Unlike hearing and sight, where the signals are distinctly different in nature, the chemical senses involve similar stimuli mediated through different sensory systems, which in turn provide the context of the message.

Smell and Taste

Birds can taste and smell, but little is known regarding the level of specificity of avian tasting and smelling ability (Strong 1911; Duncan 1960; Wenzel 1967, 2007; Mason and Clark 2000). However, research indicates that some species of birds have a moderate to excellent sense of smell (Strong 1911; Duncan 1960; Waldvogel 1989; Wallraff et al. 1995; Roper 1999; Mason and Clark 2000; Wenzel 2007). Thus, the extent of olfactory development in birds is comparable to that in mammals (Mason and Clark 2000). Olfactory cues may serve as conditional stimuli to which learned aversions can be formed when paired in the presence of toxicants or irritants (Waldvogel 1989; Clark and Smeraski 1990; Raguso and Willis 2002). The most effective avian repellents will likely be those that produce condition aversions (i.e., avoidance rather than escape behavior) in the target species (Rogers 1974; Mason and Clark 2000; Werner et al. 2008). Deterrents based merely on offensive flavors or altered flavors associated with a familiar food are not likely to be effective in the absence of aversive, post-consumptive effects such as gastric malaise (Provenza 1997). The coupling of novel odors associated with chemicals such as pyrazine or methypyrazine is more effective in reducing bird use of resources because of the intestinal malaise that creates a primary response (Avery and Nelms 1990; Avery and Mason 1997; Nelms and Avery 1997). Gustation requires a more intimate contact between the source of the chemical signal and the receptors (Mason and Clark 2000). Gustatory receptors are located in taste buds located throughout the oral cavity of birds (Berkhoudt 1985; Ganchrow and Ganchrow 1985). Bird taste receptor sensitivity is similar to that of mammals and is species specific in their response to various chemicals (Moore and Elliott 1946; Duncan 1960; Berkhoudt 1985; Ganchrow and Ganchrow 1985; Mastrota and Mench 1995).

Sound

Sound is one form of communication used for territorial defense, mate choice, navigation, song learning of individuals, and predator avoidance (Gill 1995). In the context of repelling birds with sound, predator avoidance and territorial defense are the two mechanisms targeted. However, few empirical data are available regarding conspecific avoidance behavior elicited through sound in wildlife damage research (Muller et al. 1997).

Auditory Reception

The auditory capability of animals is important when considering acoustic frightening devices. The frequency of sound is measured in Hertz (Hz), and sound pressure (volume) is measured in decibels at sound pressure level (dB SPL). Humans can detect sounds from approximately 20–20,000 Hz (Bomford and O'Brien 1990) with an absolute sensitivity of 0 dB SPL (Durrant and Lovrinic 1984). Ultrasonic frequencies are those above 20,000 Hz and infrasonic frequencies those below 20 Hz.

Birds appear to be most receptive to sounds from 1,000–3,000 Hz, with an absolute sensitivity of −10 to 10 dB SPL (Dooling 1978; Stebbins 1983; Fay and Wilber 1989; Dooling et al. 2000). However, the range of sounds detected among species varies markedly. For example, barn owls (*Tyto alba*) hear best at 6,000–7,000 Hz with volumes as low as −18 dB SPL (Fay 1988). In contrast, pigeons can detect frequencies as low as 0.05 Hz (i.e., infrasound), but it is unclear how the birds use this capability (Fay and Wilber 1989; Fay and Popper 2000).

Reception of high frequencies (>10,000 Hz) is very poor in birds (Dooling 1978). Nocturnal predatory species (e.g., owls) generally hear better than other bird species, while songbirds hear low frequencies better than nonsongbirds (Dooling et al. 2000).

Bioacoustics

The use of bird alarm and distress calls to disperse birds is based on sound biological principles. Alarm and distress calls warn other birds in the area that danger is present, typically causing the other birds to flee. Birds are less likely to habituate to alarm and distress calls than to other sounds because they are related to evolutionary signals of danger (Thompson et al. 1968; Johnson et al. 1985; Bomford and O'Brien 1990).

Avian Vision

The primary sensory pathway in birds is vision (Sillman 1973; Zeigler and Bischof 1993). However, it is evident that there are species-specific vision characteristics (Sillman 1973; Zeigler and Bischof 1993; Blackwell 2002). To effectively use light in managing bird conflicts with aviation, an understanding of avian vision is critical. Color and type of light used to frighten birds have shown species-specific reactions ranging from indifference to flight (Belton 1976; Blackwell 2002; Gorenzel et al. 2002). Many birds discriminate the color of light at wavelengths between 400 and 700 nm, comparable to humans (Pearson 1972).

In addition, some species, including pigeons, mallards (*Anas platyrhynchos*), belted kingfishers (*Megaceryle alcyon*), and some passerines (Bowmaker and Martin 1985; Martin 1986; Cuthill et al. 2000) also perceive ultraviolet light (<390 nm). Rock doves (*Columba livia*) and some songbirds have also exhibited sensitivity to the plane of polarization of light (Able 1982; Young and Martin 1984), to which humans have very limited sensitivity. The avian retina, consisting of high cone densities, deep foveae, near-ultraviolet receptors, and colored oil droplets, is likely the most capable daylight retina of any animal (Gill 1995). Furthermore, because birds can apparently detect color, it could be an important consideration during the construction and development of devices used to deter and disperse birds.

CHAPTER FOUR

HARASSMENT, REPELLENT, AND DETERRENT TECHNIQUES

We begin this section with a tabular summary of relative efficacy of harassment, repellent, and deterrent techniques for birds at airports. Table 1 is a synthesized literature review providing examples of relative efficacy of each technique.

AUDITORY DETERRENTS

Ultrasonic

Ultrasonic devices likely will not be a viable option as a deterrent for birds. Erickson et al. (1992) surmised that high-frequency sound (>20,000 Hz or cycles per second) devices generally were not effective in repelling birds. Griffiths (1987) tested a commercial ultrasonic unit against numerous bird species in the mid-Atlantic United States and found no apparent effect on bird activity. Martin and Martin (1984) found another ultrasonic device to be ineffective. Woronecki (1988) reported that an ultrasonic device (Ultrason UET-360) was not effective in reducing rock dove activity during a 20-day treatment period. However, he reported that a combination of a visual device (tested as Deva-Spinning Eyes) and a sonic device (tested as Deva-Megastress II) did temporarily alter rock dove behavior during a 10-day treat-

TABLE 1
RELATIVE EFFECTIVENESS OF AVIAN REPELLENT TECHNIQUES

	Deterrent								Harassment							Exclusion	
	4-AP	Methyl anthranilate	Anthraquinone	Tactiles	Effigies	Reflecting Tape, Flags	Lights and Mirrors	Predator models	Gas Exploders	Pyrotechnics	Biosonics	Ultrasonic	Lasers	Falconry	Dogs	Overhead wires	Anti-perching devices
Crows/Jays/Magpies		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Blackbirds	G	G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Starlings	G	G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Cormorants/Anhingas		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Ducks	F	G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Geese	F	G	G	F/G	G	P	F	F	F/G	G	G	N	P	F	G	G	G
Swans	F	G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Gulls	F	G	G	F/G	G	F	F	F	F/G	G	F	N	P	F	G	F	G
Herons		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	F	G
Egrets		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	F	G
Cranes		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	F	G
Pigeons/Doves	F	G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Vultures		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Hawks		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Falcons		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Eagles		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Osprey/Kites		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Owls		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Gallinaceous Birds		G	G	F/G	G	P	F	F	F/G	G	P	N	P	F	G	F	G
Shorebirds		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G		G
Thrushes		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G
Sparrows		G	G	F/G	G	P	F	F	F/G	G		N	P	F	G	G	G

Source: Adapted from Cleary and Dickey (2010).
Effectiveness: G = Good; F = Fair; P = Poor; N = Not Recommended.

ment period and reduced the rock dove population present during the onset of treatment. However, this study was not conducted in an airport environment but in a vacant building. Also, the study was not replicated, nor were paired non-treated sites used for comparisons.

Gas Exploders

Gas-operated exploders, sometimes referred to as gas or propane cannons, offer temporary efficacy for deterring birds from airfields. They have been commonly used to repel pest birds in agriculture and around airports since the late 1940s (Gilsdorf et al. 2002). These devices produce extremely loud, intermittent explosions, usually at fixed 1- to 10-minute intervals as desired, that exceed the blast of a 12-gauge shotgun. Present-day exploders consist of a bottled gas supply, separate pressure and combustion chambers, an igniting mechanism, and a barrel to direct and intensify the noise of the explosion. To alleviate habituation, exploders should be moved periodically (e.g., every 1 to 3 days) within the area needing protection (Littauer et al. 1997; Reinhold and Sloan 1997).

Washburn et al. (2006) conducted an experiment with propane exploders at John F. Kennedy International Airport. These authors did not find a significant difference in bird behavior in response to the exploder. Furthermore, the addition of lethal removal did not enhance effectiveness. Conover (1984a) reported a 77% reduction in bird damage within cornfields in response to exploders. Propane exploders were more cost-effective compared with a chemical technique (tested as Avitrol FC-99) and a visual technique (tested as hawk-kites). In the Mississippi alluvial plain, Mott et al. (1998) described that harassing double-crested cormorants roosting at night was successful in dispersing cormorants and reducing depredation rates at nearby catfish farms, suggesting that it may work on stormwater ponds around airports. Also, Cummings et al. (1986) described that a combination of a gas exploder and a CO2 driven pop-up scarecrow was effective sporadically in a row crop agriculture setting; however, habituation was likely occurring in later tests.

Biosonics: Alarm and Distress Calls

Biosonic calls, including alarm and distress calls, appear to have some efficacy for deterring birds. However, additional research involving rigorous experimental design is necessary to understand efficacy more fully. Biosonics as a repelling technique is based on acoustical signals emitted by birds and other animals to convey information to other individuals of the same species (Boudreau 1968; Conover and Perito 1981; Bomford and O'Brien 1990). Two audible bird-warning stimuli, distress and alarm calls, have been explored or used for acoustically repelling birds from urban and rural roosts (Pearson et al. 1967; Brough 1969), fish-rearing ponds (Spanier 1980; Andelt et al. 1997), airport runways (Blokpoel 1976), agricultural settings, and other locations (Baxter 2000).

From the Field…Golden Triangle Airport (GTR)

The Golden Triangle Regional Airport Authority was established in 1971 through a partnership with the cities of Columbus, Starkville, and West Point, and the counties of Lowndes and Oktibbeha, Mississippi. The airport property consists of 1,000 acres and has approximately 40,000 airplane movements a year. Bird harassment is conducted by the airport firemen, who dedicate approximately 10% of their time to wildlife management. Seasonal influxes of geese in the winter and raptors in the summer are the main problems that arise with wildlife. The staff uses pyrotechnics to move birds from problem areas. Additionally, in the fall, flocks of sparrows and other small flocking birds can create potential hazards. In these instances, personnel have used fire trucks to apply high volume and pressure of water to disperse birds with good success. Mike Hainsey, airport executive director, noted, "Habitat management is a primary line of defense."

Mott and Timbrook (1988) examined the effect of alarm and distress calls on Canada geese. They found a 71% decrease in goose numbers in response to the calls. Additionally, they found a 96% reduction in goose observations when the distress calls were coupled with pyrotechnics (tested as racket bombs, a noise-making pyrotechnic shot from a pistol launcher). Unfortunately, recolonization of the study area occurred shortly after the treatments stopped. In an urban setting, Gorenzel and Salmon (1993) experimented with distress and alarm calls in an effort to deter crows. Initially, crows from nearby roosts were attracted to the calls, but after 30 seconds the crows left the immediate vicinity.

Cook et al. (2008) used a modeling approach to assess the effectiveness of nine techniques, including pyrotechnics, handheld distress calls, static distress calls, blank ammunition, a combination of blank and lethal use of ammunition, falcons (*Falco* spp.), hawks (*Accipiter* spp.), wailers, and kites. These techniques were employed on three species of gulls at landfill sites. Distress calls were among the most effective; however, when habituation was considered, distress calls were not as effective as other techniques with lethal consequences. Conklin et al. (2009) tested bioacoustic deterrents for nesting cliff swallows (*Petrochelidon pyrrhonota*). Eight unique recordings of alarm and distress calls were used together in a mix played through an acoustical broadcast unit. Random playback order was used to delay or reduce habitation by swallows. The presence of calls reduced nesting activity by more than 50%. Coates et al. (2010) evaluated bioacoustics as a deterrent to wild turkeys in California vineyards. Broadcast calls of three different types were used independently: wild turkey alarm call, domestic turkey alarm, and crow distress call. No differences in damage rates were found in treated versus untreated plots.

Pyrotechnics

Pyrotechnics have long been used as deterrents to birds in a variety of settings (Neff and Mitchell 1955; Zajanc 1962; Mott 1980; Tipton et al. 1989; Mott and Boyd 1995; Andelt et al. 1997; Littauer et al. 1997; Mott and Brunson 1997) and can be effective in deterring birds. These devices rely on an explosion or other type of loud noise to deter birds from an area (Mott 1980) and can produce visual stimuli such as a flash of light or burst of smoke. Devices include rifles and shotguns firing live ammunition or blanks and 12-gauge shotguns and flare pistols that shoot exploding or noisy projectiles, including shell crackers, bird bombs, bird whistles, whistle bombs, or racket bombs (Booth 1994; Harris and Davis 1998). Signal flares also have been used at some airports but are more expensive than the other devices (Lefebvre and Mott 1987). An example of these devices is shown in Figure 4.

From the field…Sacramento International Airport (FAA code--SMF)

Approximately 152,000 operations occur annually at Sacramento International Airport, including commercial, cargo, general aviation, and military operations. Sacramento International Airport is located within the Natomas basin of California, situated in the Pacific migratory flyway for numerous waterfowl and other bird species. Greg Rowe, senior environmental analyst, described their style of wildlife management as a holistic approach that integrates harassment techniques and animal removal, but most important, working with land use and habitat management to reduce use of the airport landscape by hazardous birds. The airport employs two full-time biologists, and two other employees spend approximately half of their time to reduce hazardous wildlife. Waterfowl are by far the most common problem species, but other birds such as vultures, ibis species, and swallows are also problematic. Additionally, raptors are a growing problem. The most commonly employed deterrent technique is pyrotechnics and electronic sound emission devices. These are typically used to scare birds from ponds located near the runway. Greg notes, "Our biologists typically have to apply these techniques to the same group of birds on a daily basis in order to be effective." Greg also stressed that land management is key and other techniques are secondary in the mission to reduce hazards.

FIGURE 4 Pyrotechnics (*Source*: USDA/APHIS/WS Ohio Field Station).

Aguilera et al. (1991) reported that screamer shells were effective in dispersing flocks of Canada geese; also, no habituation was reported after treatment. Mott (1980) tested scare cartridges and noise bombs simultaneously to disperse roosting red-winged blackbirds and European starlings in Kentucky and Tennessee. Roosting bird populations of about 1 million birds in five roosts were reduced 96% to 100% during 3 to 8 evenings of harassment. Mott et al. (1992) tested the effectiveness of pyrotechnics as a dispersant for roosting double-crested cormorants (*Phalacrocorax auritis*) in the Delta region of Mississippi. Bird-bangers and screamer-sirens were fired from single-shot pistol launchers on 4 consecutive evenings. Cormorant numbers were decreased from approximately 8,000 birds to 6 during the harassment period. However, Mott et al. (1992) stated that this technique would be less effective if multiple roost sites were available to birds in an immediate area. Logistically and financially, harassing birds in this fashion may not be efficacious. Most bird species become habituated to noises produced by pyrotechnics if used repeatedly over time (Littauer et al. 1997; Reinhold and Sloan 1997; Stevens et al. 2000; Ronconi et al. 2004; Ronconi and Clair 2006; Cook et al. 2008).

VISUAL REPELLENTS

Vision-based deterrents present a visual stimulus that is novel, startling, or that the birds associate with danger. The danger can be a predator, a simulated predator, the result of a predator attack, or some unusual object that birds avoid because it is unfamiliar. Lights, scarecrows, dyes, reflecting tape, predator decoys, kites, balloons, smoke, and dead or live birds are visual stimuli that may disperse birds.

Effigies

Effigies have been demonstrated to reduce bird use of target areas; however, their efficacy varies markedly depending on type of effigy used, species being deterred, and resource (nest site, loafing site, foraging area) from which birds are being deterred. Effigies include devices such as scarecrows, scary-eyes, and predator-mimicking devices (e.g., hawk or owl) (Harris and Davis 1998). Scarecrows are one of the oldest devices that have been used to control birds (Frings and Frings 1967). Most scarecrows are human-shaped effigies constructed from various inexpensive materials, including grain sacks or old clothes stuffed with straw. The more realistic the facial features and the human shape, the more effective scarecrows are likely to be (Gilsdorf et al. 2002). Painting scarecrows a bright color can increase their detectability (Littauer 1990).

Stickley et al. (1995) demonstrated that a pop-up human effigy reduced double-crested cormorant use of catfish ponds; however, the device was only tried for 7 days. It is unclear if habituation would have occurred later. Nomsen (1989) reported that a humanlike scarecrow that popped up from a double propane cannon when fired was highly successful in keeping blackbirds from feeding over 4 to 6 acres of sunflowers. Ducks and geese were observed to be much easier to frighten from the site than blackbirds. Coniff (1991) reported that this kind of scarecrow placed near a catfish pond effectively frightened cormorants. Numbers of great blue herons (*Ardea herodias*) and black-crowned night-herons (*Nycticorax nycticorax*) initially decreased at a fish hatchery following implementation of two human effigies (tested as Scary Man Fall Guy), but the herons quickly habituated to the devices and numbers increased after the first 4 nights (Andelt et al. 1997). Boag and Lewin (1980) found that a human effigy was effective in deterring dabbling and diving ducks from small natural ponds. When the effigy was present, the number of ducks on the ponds declined by 95%. Over the same interval there was only a 20% decline on adjacent control ponds, indicating that the effigy was quite effective.

Cummings et al. (1986) used a propane cannon and a CO_2 pop-up scarecrow to deter blackbirds from sunflowers. They found that most birds were frightened away by the scarecrows; fewer birds returned during the treatment period than were observed during the control period. Cummings et al. (1986) speculated that the birds that returned had become habituated to the scarecrow in some cases, and in other cases, that feeding patterns were too well established to allow effective deterrence of the birds.

Seamans (2004) reported the effective use of a vulture effigy to deter vultures from a tower in northern Ohio. However, the author reported seasonal differences in effectiveness; in the summer there was no difference in vulture use of the tower during pre-and posttreatment periods. Seamans and Bernhardt (2004) conducted field evaluations of Canada goose effigies. They found an initial decrease in goose abundance; however, during a second treatment period no difference was detected. Geese were likely habituated to the effigies after a short time. Figure 5 shows an example of a visual repellent in the form of a dead Canada goose.

FIGURE 5 Dead goose effigy (*Source*: USDA/APHIS/WS Ohio Field Station).

Ball (2009) described in an anecdotal note that effigies appeared to be effective in reducing vulture use of the airfield at Cherry Point Air Force Base in North Carolina. Similarly, Tillman et al. (2002) reported that effigies were effective in dispersing vultures from roost sites near livestock production facilities. Additionally, the authors tested waterfowl decoys painted to resemble dead vultures. They report a continued effectiveness upon switching from the taxidermy effigies to the mock-up decoys. Avery et al. (2002) corroborated Tillman et al. (2002) in the context of vulture [black vulture (*Coragyps atratus*) and turkey vulture (*Cathartes aura*)] use of communication towers. They found a 93% to 100% decline in vulture numbers immediately following installation of the effigies. The authors also noted that effectiveness was independent of species composition of the vulture flock or the vulture species used for the effigy. Most important, Avery et al. (2002) found that the effectiveness was maintained 5 months posttreatment. Effigies appear to be an effective tool to reduce use of an area by both species of vultures.

Predator Models

Decoys or models have been used to repel birds for decades in agricultural crops, and should be similar in the airport environment (Conover, 1979, 1982a, 1984a, 1985a; Hothem and DeHaven 1982) (Table 1). Conover (1979, 1982a) found that stationary, mounted hawks and hawk-kites deterred birds from feeding stations and cornfields but that their effectiveness was short-term. Conover (1984a) elucidated that hawk-kites reduced red-winged blackbird (*Aegaeileus phonecius*) damage by 83% in an agriculture setting. Belant et al. (1998) found plastic, hand-painted effigies of great horned owls (*Bubo virginianus*) and merlins (*Falco columbarius*) ineffective in reducing starling use of nest boxes. There was no significant difference in starling activity among nest boxes with or without the effigies. Conover (1983) found that blackbirds and crows often mob owls or owl models, increasing use of an area by hazardous birds. However, Conover (1982b, 1985b) found that an animated plastic owl model clutching a plastic crow in its talons repelled crows from gardens and small fields, while a stationary version of the same model was not effective.

Seamans and Helon (2006) tested a lightweight plastic device that forms a spiral when suspended and contains pigments that allow the device to change color depending on viewing angle (tested as the ChormaFlair™ Crow Buster) to repel starlings at nest sites. There was no difference in the presence of nest material between treated and control nest boxes. Also, clutch size was similar between treated and controls, but a slight delay in egg laying was observed in the treated boxes.

Balloons or modified balloons have been tested on numerous occasions as a deterrent for birds in various settings (Conover 1982a; Avery et al. 1988; McLennan et al. 1995; Nakamura et al. 1995; Mott et al. 1998). Seamans et al. (2002) tested a balloon with a kite and stabilizer attached to deter gulls near a landfill in New York. Under various circumstances the device was effective in decreasing gull use. However, Seamans et al. (2002) reported high maintenance costs and time requirements to deploy such devices. They maintained that devices such as these should be used as a part of an integrated management program for gulls. Figure 6 shows an example of a visual repellent in the form of a balloon.

FIGURE 6 Helikites in action (*Source*: USDA/APHIS/WS Ohio Field Station).

Lasers

Lasers (such as the device shown in Figure 7) have been demonstrated to deter birds; however, efficacy varies across species and with wavelength (i.e., color) of transmitted light. Relative efficacy increases with decreasing ambient light. The use of lasers to disperse birds is relatively new (Lustick 1973; Gilsdorf et al. 2002). Glahn et al. (2000) tested the efficacy of lasers to disperse double-crested cormorants from night roosts in the Mississippi Alluvial Valley during winter. Two types of lasers were tested: the Desman™ laser [red (632.8 nm) helium-neon laser] and a Dissuader™ laser security device that is also a red beam (650 nm) but is a diode laser (Glahn et al. 2000). The authors pretested the lasers on wild-trapped cormorants, but results of that study were inconclusive. However, the field trial portion demonstrated significant reductions in cormorant populations by ≥90%. No difference was found between laser types.

FIGURE 7 Laser used for dispersing birds (*Source*: USDA/APHIS/WS Ohio Field Station).

Blackwell et al. (2002) tested the efficacy of a 10-mW continuous-wave, 633-nm laser to repel brown-headed cowbirds and European starlings while perching. They tested a 68-mW, continuous-wave, 650-nm laser in dispersing starlings and rock doves from perches; also, they tested this laser on Canada geese and mallards in grass plots. There were mixed results; brown-head cowbirds or European starlings were not repelled from their perch, whereas rock doves demonstrated avoidance during the first 5 min of the 80-min dispersal periods, suggesting weak efficacy. Geese demonstrated the strongest avoidance behavior, 96% of birds dispersed from the laser-treated plots. Mallards were dispersed initially but habituated to the beam after 20 min.

Gorenzel et al. (2002) found similar results with American crows. Most crows were dispersed from roosts by the laser, but returned within 15 min. Lasers are a relatively unobtrusive device to humans and show promise as a repellent for birds, but results are species specific (Blackwell et al.

2002; Gilsdorf et al. 2002; Gorenzel et al. 2002). Although green and blue lasers were ineffective at deterring white-tailed deer (*Odocoileus virginianus*) (VerCauteren et al. 2006), they have not yet been tested for efficacy in repelling birds. However, qualitative evidence at some airports suggests green lasers can be highly effective at dispersing birds such as rock doves and European starlings.

Reflecting Tape, Reflectors, and Flags

Reflecting tape and similar devices appear to have limited efficacy in most circumstances. Summers and Hillman (1990) tested a red fluorescent tape (20 mm wide) in fields of winter wheat in the United Kingdom to deter brant. The tape proved more successful than the cannon and scarecrows in repelling brant. Compared with control fields, a 1% reduction in grain yield in the taped field was found compared with a 6% reduction in the untaped field. Belant and Ickes (1997) tested mylar flags (reflective material) for their effectiveness as gull deterrents. Flags were tested at two nesting colonies and two loafing sites at a landfill near Lake Erie. The authors concluded that the reflecting tape was unsuccessful in deterring herring gulls from nesting colonies but can reduce herring and ring-billed gull use of loafing areas. Reflecting tape was ineffective in deterring birds from ripening blueberries (Tobin et al. 1988). In this study habituation was considered likely, and reportedly not enough tape was used to elicit a response. Conover and Dolbeer (1989) found similar results with red-winged blackbirds in cornfields. Fields treated with reflector tape had similar damage rates to untreated fields. These results contrasted with those of Dolbeer (1981), Bruggers et al. (1986), and Dolbeer et al. (1986), who found reflective tapes to be effective in grain fields. Conover and Dolbeer (1989) attributed the possible differences to variation in row spacing of tape. Gilsdorf et al. (2002) further suggest that closer spacing of ribbons of tape may be more effective, but likely not cost-effective.

Lights and Mirrors

Lights and mirrors appear to have application for dispersing birds from airport environments, but additional research is necessary before specific recommendations can be made. Few studies have evaluated the effectiveness of mirrors to deter birds. Seamans et al. (2001) evaluated mirrors to deter nesting starlings in northern Ohio. Various combinations of mirror types and the addition of lights (green and red flashing) were tested. Fewer nests were found in treated nest boxes in the first year of study. During the second year lower occupancy rates of nest boxes were also found, specifically in the mirror and light combination treatment. The authors concluded that even though slight reduction in starling use was found, mirrors were not a practical repellent. Seamans et al. (2003) followed up the previous study with a similar experiment testing rotating mirrors as a deterrent for decoy traps. Capture rates did not differ between treated (rotating mirror) and untreated traps for blackbirds. However, red mirrors reduced the capture rate compared with the control. Furthermore, more brown-headed cowbirds (*Molothrus ater*) and common grackles (*Quiscalus quiscula*) were captured more often in control traps versus treated traps with mirrors.

Numerous types of lights have been used to deter birds at feeding, roosting, and loafing sites (Koski et al. 1993; Seamans et al. 2001). Larkin et al. (1975) observed that migrating birds reacted to searchlight beams at distances of 200–300 m. In the same study, birds took evasive action to approaching small aircraft with landing lights. Blackwell and Bernhardt (2004) tested the efficacy of pulsing white and wavelength-specific aircraft-mounted light during daylight hours. Their experiments involved captive brown-head cowbirds, Canada geese, European starlings, herring gulls, and mourning doves. Cowbirds were the only species that exhibited a response to the landing lights, but responses were sporadic. Blackwell and Bernhardt (2004) contended that more research was needed on specific light wavelengths and pulse frequencies. Specifically, understanding object lighting in the context of avian antipredator responses, and how antipredator behavior varies among bird species, may improve efficacy of lighting as a control technique (Blackwell et al. 2009).

Dogs and Falconry

The use of dogs to deter and haze birds is promising and generally appears effective, but more experimental research is needed. The use of dogs has received attention and research as a tool to deter birds from airports (Carter 2000a,b; Castelli and Sleggs 2000; Patterson 2000). Castelli and Sleggs (2000) reported a retrospective analysis of the efficacy of a border collie program to repel and haze geese. At the local scale of the airport, the program was effective at reducing geese overabundance, but at the larger regional scale it did not contribute to the solution. Carter (2000b) reported several case studies on the use of border collies. Most strikingly, in Delaware the use of dogs reduced bird numbers by 99.9%, and damage was reduced from $600,000/year to $24,000/year. Figure 8 shows an example of a dog on bird-deterrent duty at an airport.

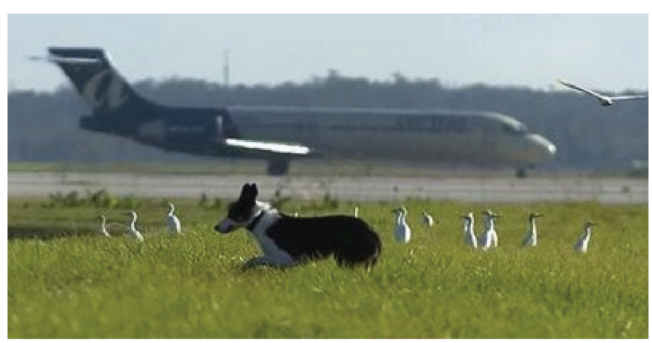

FIGURE 8 Border collie at work in Florida [*Source*: Marc Beaudin, The *News-Press* (Ft. Myers, Fla.)].

The use of falconry has received some attention as a bird deterrent and appears to have limited efficacy. Some falconry is employed in the United States, but it has mostly occurred in the United Kingdom (Blokpoel 1976; Hild 1984; Erickson et al. 1990; Dolbeer 1998; Walker 2003; Bryant 2005; Kitowski et al. 2010;). Peregrine falcons (*Falco pereqrinus*), gyrfalcons (*Falco rusticolus*), and goshawks (*Accipiter gentilis*) are the species most frequently used (Blokpoel 1976). At John F. Kennedy International Airport, Dolbeer (1998) tested the use of falconry to reduce laughing gull use and strikes to aircraft. Falconry in this case did not provide additional efficacy to a shooting program, but did provide increased public acceptance of the management program at the airport.

CHEMICAL REPELLENTS

Chemical aversion agents have been used to control birds in a wide range of settings (Guarino 1972; Rogers 1974; Crase and Dehaven 1976; Conover 1984b; Greig-Smith and Rowney 1987; Bomford and O'Brien 1990; Clark and Shah 1991, 1993; Clark et al. 1991; Avery and Decker 1994). Their efficacy is highly variable and depends on chemical use, mode of action, species being deterred, and resource (e.g., loafing site, feeding area) being protected.

4-aminopyridine and 3,5-dimethyl-4-(methylthio)phenyl methylcarbamate

Chemical frightening agents and repellents such as 4-aminopyridine (4-AP) (e.g., tested as Avitrol) and 3,5-dimethyl-4-(methylthio)phenyl methylcarbamate (e.g., tested as methiocarb) are poisons that, in sublethal doses, may cause disorientation and erratic behavior. They are usually added to bait. Typically only a portion of a bait presentation (e.g., 10% of corn kernels) is treated with the chemical so that only a small number of the birds to be dispersed are affected. When the treated bait is ingested, a distress response occurs (DeFusco and Nagy 1983; White and Weintraub 1983). Distress calls from affected birds can start 15 min after ingestion, and can last up to 30 min after first effect. Besides emitting distress calls, affected birds may become disoriented and exhibit erratic behavior, often flopping about on the ground. This behavior often alarms other birds and causes them to fly away. If too high a dose is ingested, the bird will die. Tremors and convulsions occur before death if birds receive an overdose of the aversion agent, and these may induce other birds to leave the area.

Dolbeer et al. (1976) and Woronecki et al. (1989) tested the effectiveness of 2 aminopyridine (chemically similar to 4-AP) in sweet corn fields. Overall, no reduction in damage was observed. However, Avitrol has been proven useful in dispersing birds (Goodhue and Baumgartner 1965; Woronecki et al. 1989; Gadd 1992; Swindle 2002). 4-AP, tested as Avitrol, has been effective against gulls, starlings, crows, rock doves, and house sparrows (*Passer domesticus*) (Seamans 1970). Avitrol also has been used successfully on loafing gulls and pigeons (Blokpoel 1976). Sweeney and McLaren (1987) demonstrated its effectiveness on gulls at landfills. However, Dolbeer (1981) found Avitrol not to be cost-effective in grain crops. Knittle et al. (1988) found 4-AP to be effective for reducing blackbird damage to sunflowers, but it was mostly ineffective in fields greater than 2 miles from a roost. Avitrol is toxic and can be difficult to administer in a dose sufficient to cause the desired effect but not to kill the bird immediately (Harris and Davis 1998). Death may be delayed and affected individuals may be able to fly away before dying elsewhere (Holler and Schafer 1982).

Methyl Anthranilate

Methyl anthranilate (MA) has been tested on numerous occasions as a deterrent for birds in a variety of settings (Avery 1992; Cummings et al. 1992, 1995; Dolbeer et al. 1992; Vogt 1994; Avery et al. 1995; Belant et al. 1995, 1996, 1997). Both dimethyl and MA were strongly avoided by captive mallards and Canada geese when birds were offered both treated and untreated grain (Cummings et al. 1992). When offered only treated grain, both ducks and geese reduced their food intake, but mallards, and to a lesser extent, Canada geese, gradually increased consumption during the 2 to 4 days of the experiment. Cummings et al. (1992) assumed that the birds were habituating to the chemical, but they were not given an alternative food source, and the increased consumption may have been caused by increased hunger. Cummings et al. (1995) tested another formulation of MA, REJEX-IT AG-36, as a grazing repellent for Canada geese. In the pen trial, 59 kg/ha of the chemical applied reduced goose activity on treated grass plots for less than 4 days. Similarly, Cummings et al. (1995) evaluated the effectiveness of MA, tested as ReJex-iT AG-36, as a deterrent for blueberries. In Michigan, MA applied at 16.1 kg/ha did not reduce overall damage by birds, but did offer ephemeral control for 7 days. In the same study, Cummings et al. (1995) tested MA at a rate of 32 kg/ha in Florida to caged cedar waxwings (*Bombycilla cedrorum*). Results were similar for waxwings in Florida to those in Michigan—berry consumption did not differ. Belant et al. (1995) tested two formulations of MA (tested as AP-50 and TP-40) to repel gulls and mallards from water. Overall, gull activity was reduced in pools treated with the MA (tested as AP-50, a free-flowing powder) formulation compared with untreated pools. The MA formulation tested as TP-40 (containing a surfactant), with 1.6-3.0 times greater concentration of MA at the water surface, was slightly more effective in reducing bird activity. Conversely, Belant et al. (1996) found MA in a 14.5% vol/vol formulation was ineffective in reducing geese foraging activity. Also, Belant (1997) found MA ineffective in reducing woodpecker activity on wood siding of residential buildings. Dolbeer et al. (1992) investigated MA (tested as ReJeX-iT) at two different concentrations. Both concentrations were effective in repelling mallards and ring-billed gulls. Stevens and Clark (1998) tested MA in an aerosol form as an irritant for captive starlings. The MA aerosol was effective as an irritant and starlings did not habituate to repeated exposure. Aerosols may hold promise as a hazing technique for some species of birds; however, more research is needed on their effectiveness and proper application concentrations.

Anthraquinone

Dolbeer et al. (1998) evaluated an anthraquinone formulation [tested as Flight Control™ (FC)] as a feeding repellent for Canada geese and brown-headed cowbirds. The formulation was applied to turf within small pens housing captive geese. They found 2.5 times more bill contacts/min observed on untreated plots compared with treated plots during a 7-day trial. Presented with untreated millet or millet treated with FC, caged cowbirds avoided the treated seed and lost body mass during the 3- to 4-day trials. Cummings et al. (2002) conducted a field evaluation of anthraquinone (tested as FC) in newly planted rice fields. Seed was treated with FC at a 2% (g/g) concentration at day of planting. Blackbird abundance and seed damage were significantly lower in treated fields compared with untreated fields. Blackwell et al. (1999) tested the possible enhancement of anthraquinone (tested as FC) with the addition of a plant growth regulator [tested as Stronghold™ (SH)]. The plant growth regulator alone was not effective in reducing herbivory of grass by geese. However, a combination of anthraquinone and the plant growth regulator reduced geese presence by 62% and reduced foraging activity by 88%. Blackwell et al. (1999) also reported a continued effect of the treatments 22 days after initiation. The plant growth regulator (tested as SH) greatly enhanced anthraquinone (tested as FC) as a repellent for geese on turf grass. Blackwell et al. (2001) again used anthraquinone (tested as FC) and methyl anthranilate (tested as ReJeX-iT AG-36), but in this instance sandhill cranes (*Grus canadensis*) were used in pen trials with corn. Both chemicals were effective in reducing corn consumption by cranes. Cranes consumed 8.6 times more corn in the untreated pens compared with corn treated with MA (tested as FC) and consumed 9.8 times more untreated corn compared with corn treated with MA (tested as ReJex-iT AG-36). Methyl anthranilate applied with a plant regulator appears to provide repellency against birds at food sources for up to several weeks (Blackwell et al. 1999).

Miscellaneous Chemicals

Dolbeer et al. (1988) tested the effectiveness of naphthalene as a repellent for starlings around structures. No differential use was found in treated or untreated nest boxes. No recent investigations of napthalene as a repellent have been conducted.

Belant et al. (1997a) compared the effectiveness of d-pulegone and mangone, both taste aversives, on captive brown-headed cowbirds. The 0.01% d-pulegone lowered cowbird feeding activity, but at lower rates did not. Mangone was slightly more effective at lower concentrations, but consumption of mangone-treated millet was similar among one-choice tests.

Dolomitic limestone has been hypothesized as a taste aversive for birds (Clark and Belant 1998). Belant et al. (1997) tested if adding limestone in the form of a dry substance or slurry reduced consumption of grain. Results were mixed, as reductions of total food intake decreased for both cowbirds and geese during one-choice tests with lime and grain. However, body mass was not affected during two-choice tests. In treated grass plots, goose feeding was reduced for 2 to 3 days after application of lime in both forms. Similarly, tests of dolomitic lime, activated charcoal, a silica-based compound (tested as Nutra-lite), and white quartz sand as taste aversives on cowbirds and Canada geese revealed that lime and charcoal showed potential as repellents (Belant et al. 1997b). However, Belant et al. (1997b) reported short-lived efficacy of the silica-based compound for geese.

Chemical-based Tactile Deterrents

Tactile deterrents are perhaps the least studied bird deterrent approach. Most tactile repellents are sticky substances that deter birds from sitting on perches, such as building ledges, antennas, and airfield lights and signs. Reidinger and Libay (1979) tested glue applied on perches to deter birds near ricefields. The authors found the glue to be effective during the short treatment period (5 to 8 days). Clark (1997) tested several dermal contact repellents to deter starlings from using structures. In theory, these repellents cause irritation to the bird through contact with the dermis on the foot and birds avoid such areas subsequently. Starlings demonstrated agitation in response to 5% oil extracts of cumin, rosemary, and thyme (Clark 1997). Furthermore, starlings avoid perches treated with R-limonene, S-limonene, or ß-pinene.

Conklin et al. (2009) tested surface modifications in an effort to deter cliff-swallows from nesting on highway structures. Polyethylene sheeting proved to be effective in reducing nesting activity; however, swallows were still able to build nests.

EXCLUSION METHODS

Various devices and materials have been used to provide perceived or actual barriers to exclude birds from unwanted areas to prevent loafing, nesting, foraging, and other activities. Exclusion methods used include razor wire, overhead wires, netting, covers (floating and other), and floating balls such as those shown in Figure 9 (Harris and Davis 1998). Total exclusion measures for birds are generally impractical and cost prohibitive; therefore, other partial exclusory techniques and “virtual” barriers are more typically employed.

FIGURE 9 Bird balls at Heathrow (*Source*: USDA/APHIS/WS Ohio Field Station).

Overhead Wires

Overhead wires, such as those shown in Figure 10, are likely the most researched and used exclusion method for birds (Amling 1980; Blokpoel and Tessier 1984; Laidlaw et al. 1984; Lefebvre and Mott 1987; Agüero et al. 1991; Belant and Ickes 1996) and can be highly effective. The use of overhead wires is typically effective at deterring use of an area by birds; however, most tests have been conducted on small water bodies or rooftops. The logistics and costs associated with using this technique on larger areas will likely limit its application at airports. McAtee and Piper (1936) produced the initial work on excluding birds from water resources in the early part of the last century; subsequently, several other authors have published material on overhead wires (McLaren et al. 1984; Pochop et al. 1990; Agüero et al. 1991; Clark et al. 2004); in many cases wires proved to be effective. Belant and Ickes (1996) evaluated the effectiveness of overhead wires to reduce roof-nesting by ring-billed (*Larus delawarensis*) and herring gulls (*Larus argentatus*). In this instance, wires were configured in a spoke-like pattern at a maximum of 16 m spacing on a food warehouse roof. Nesting by ring-billed and herring gulls was reduced by 76% and 100% in the first year and 99% and 100% in the second year, respectively, compared with pretreatment data.

FIGURE 10 Overhead wires on water source (*Source*: USDA/APHIS/WS Mississippi Field Station).

Clark et al. (2004) experimentally tested how overhead lines affected red-winged blackbird nest survival. Collectively, the presence of overhead wires decreased daily nest survival probabilities, but inferences on line spacing could not be elucidated. Lowney (1993) tested overhead wires as a deterrent to Canada geese around water sources. An 8.3 m grid was placed over small ponds on multiple sites. This system was successful in deterring geese from water sources.

Antiperching Wire or Metal

Antiperching devices, such as that shown in Figure 11, appear to be effective for large birds, but less so for smaller species. As larger birds are generally more hazardous to aircraft (Dolbeer et al. 2000), use of antiperching devices

Netted/Bottom-Lined Ponds Mitigate Attractiveness of Stormwater Ponds to Hazardous Birds at Seattle-Tacoma Airport

The Seattle–Tacoma International Airport (SEA) uses netted/bottom-lined stormwater detention ponds to minimize vegetation growth, reduce attracting hazardous waterfowl, and lower long-term maintenance costs. The use of netting and pond liners is preferred to use of a floating ball or blanket cover because unrestricted access to the ponds was an important design criterion for these facilities. Research was needed to ensure that this practice did not compromise aircraft safety by causing birds to repeatedly fly over ponds when attempting to get below the netting. During fall 2008, 1,000 hours of sampling effort was archived from three avian radars and postprocessed to compare the average time (seconds) targets spent over each of three netted/bottom-lined ponds compared with a paired control site. Paired sites were located an equal distance from the radar antenna. Radar data collected from altitudes 0–450 ft above runway level suggested bird use of netted/bottom-lined ponds was similar or less than control sites.

An 80 mil HDPE liner system was used along the sides of stormwater detention ponds at SEA to prevent aquatic plant growth and waterfowl habitat created by the presence of open-water and emergent/submergent vegetation. In larger ponds, the stainless steel cables that support the nets are attached to a collar that can slide down the pre-corroded steel pipe, when needed to reduce the damaging effects of snow and ice buildup on the netting. Once melted, the counter weights inside the pipe pull the collars and net back to their original position. Each pipe is capped with a daddy long leg type deterrent device to prevent use by perching birds above the net.

is common. Birds perching on fences, signposts, light fixtures, ledges, or any structure in the airport environment can lead to problems with aircraft (Federal Aviation Administration 2007, 2008). Avery and Genchi (2004) tested antiperching devices in an effort to deter birds from perching on the FAA's Low Level Wind-shear System (LLWAS). Six different antiperch devices were tested on five bird species. No single device proved effective for all species involved in tests. Categorically, larger birds such as owls and vultures require different devices than do smaller species [e.g., cowbirds and fish crows (*Corvus ossifragus*)]. The combination device (Figure 11) provided the best protection for all species; however, 100% deterrence was not achieved. Seamans et al. (2007) tested an antiperching device to deter brown-headed cowbirds, European starlings, red-winged blackbirds, rock pigeons, and common grackles. In this case a commercial antiperching device (tested as Birdwire™) was tested in an aviary setting. The device was effective in reducing perch use by all species. Blackbirds and starlings were, however, capable of using the perches, but only for a short time.

Miscellaneous Techniques

A wide variety of control techniques have been employed to reduce bird use of airports but not formally evaluated. Examples include use of remote-controlled vehicles such as radio-operated model aircraft and boats, in addition to many varieties of nonlethal projectiles, including rubber slugs and paint balls. Also, lasers emitting green beams, personnel in vehicles, and various forms of netting have been used. Although several of these techniques may actually be effective in reducing bird use, the lack of quantitative and rigorous assessments precludes categorizing their utility and application to wildlife damage application.

FIGURE 11 Antiperching devices used to deter birds from a low level windshear alert system (*Source*: Steve Osmek).

CHAPTER FIVE

CONCLUSIONS AND INFORMATION NEEDS

The use of harassment, repellent, and deterrent techniques is an important component of integrated wildlife damage management programs at airports. Nonlethal techniques to reduce human-wildlife conflicts, including bird collisions with aircraft, are generally more acceptable to the public than lethal techniques (e.g., population control). However, it must be recognized that most harassment, repellent, and deterrent techniques have only limited effectiveness in reducing bird use of specific areas. The limited efficacy is inherently grounded in ecological principles including predation, risk, foraging, and distribution theories, as well as territorial and neophobic behavior, among others. These techniques and principles must be considered in the context of an integrated management program that should include aspects of resource (e.g., food and habitat) distribution at large spatial scales, as well as monitoring program efficacy.

Considerable time and financial effort is expended on reducing bird and other wildlife presence on airports. However, these efforts often are not quantified or only partially quantified. Spending additional time to collect and summarize data in a systematic fashion on effort and resources expended and bird response to control efforts would allow airports to conduct bird control programs in an adaptive resource management framework. This approach would help airport managers and biologists to make informed decisions on the effectiveness of techniques and to conduct basic economic analysis that supports program operations most likely to achieve airport goals. Additionally, there is need to develop criteria for data collection to assess the efficacy of tools and techniques to reduce bird use of airports. Models from these data could be developed to inform airport biologists and used as guidance for conduct of more rigorous scientific experiments.

Interpretation and inference of a majority of research conducted on avian harassment, repellent, and deterrent techniques were limited by experimental design, notably lack of replication and inclusion of reference sites or populations. A number of other studies were conducted in captive situations that may not reflect bird responses in free-ranging situations. It is evident that advances in our understanding of the effectiveness of these techniques for reducing bird use of airports and other areas will require more rigorous experimental designs at spatial scales relevant to ultimate airport applications. Once efficacies of individual techniques are established, a second suite of experiments that integrates multiple techniques to assess their efficacy in combination will be required. Finally, and most important, greater emphasis needs to be placed on the underlying ecological principles that are associated with the desired avian responses to deterrent techniques. Once understood, the ecological principles that have previously resulted in the limited effectiveness of harassment, deterrent, and repellent techniques can be used to modify these techniques and maximize their effectiveness to further reduce bird collisions with aircraft.

Many of these techniques are currently being employed by airport biologists and personnel but have not been evaluated using rigorous experimental designs. Based on qualitative assessments, several of these techniques appear to be effective in dispersing birds. To better understand the potential efficacy of these techniques, a survey of select airports could be performed that requests information on specific techniques employed, characteristics of these techniques, and estimated efficacy. This survey could be analyzed to provide a rank order list of potentially viable techniques and methods. This list could be used to help prioritize future research and maximize effectiveness of limited research funds.

In addition, a comprehensive management program to minimize bird use of airports will require improved understanding of other aspects of management, including effects of habitat alterations on bird use and viability of lethal control alone or in combination with other techniques. Future syntheses or reports of these areas of management, integrated with this synthesis, will provide airport wildlife biologists and personnel performing control measures a more thorough and comprehensive framework to improve the effectiveness of management programs.

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APPENDIX A

Species List

American crow (*Corvus brachyrhynchos*)

barn owl (*Tyto alba*)

belted kingfisher (*Megaceryle alcyon*)

black-crowned night-heron (*Nycticorax nycticorax*)

black vulture (*Coragyps atratus*)

brown-headed cowbird (*Molothrus ater*)

Canada goose (*Branta canadensis*)

Citril finch (*Serinus citronella*)

cliff swallow (*Petrochelidon pyrrhonota*)

cedar waxwing (*Bombycilla cedrorum*)

common grackle (*Quiscalus quiscula*)

double-crested cormorant (*Phalacrocorax auritus*)

European starling (*Sturnus vulgaris*)

fish crow (*Corvus ossifragus*)

great blue heron (*Ardea herodias*)

great horned owl (*Bubo virginianus*)

herring gull (*Larus argentatus*)

little egret (*Egretta garzetta*)

mallard (*Anas platyrhynchos*)

merlin (*Falco columbarius*)

northern goshawk (*Accipiter gentilis*)

ring-billed gull (*Larus delawarensis*)

red-winged blackbird (*Aegaeileus phonecius*)

rock dove (*Columba livia*)

turkey vulture (*Cathartes aura*)

white-tailed deer (*Odocoileus virginianus*)

APPENDIX B

Ranking of Bird Species or Groups as to Relative Hazard to Aircraft in Airport Environments Based on a Composite Rank

RANKING OF 66 BIRD SPECIES OR GROUPS (1 = MOST HAZARDOUS) AS TO RELATIVE HAZARD TO AIRCRAFT IN AIRPORT ENVIRONMENTS [≤ 500 FT (152 M) ABOVE GROUND LEVEL) BASED ON A COMPOSITE RANK

Species[1]	Total Strikes Reported	Composite Rank	Relative Hazard Score
Other geese	20	1	100
Other ducks	77	2	78
Canada goose (*Branta canadensis*)	776	2	76
Turkey vulture (*Cathartes aura*)	159	2	73
Great horned owl (*Bubo virginianus*)	29	5	72
Double-crested cormorant (*Phalacrorax auritis*)	24	5	71
Brown pelican (*Pelecanus erythrorhynchos*)	31	7	66
Sandhill crane (*Grus canadensis*)	66	8	61
Wild turkey (*Melagris gallopavo*)	38	9	65
Glaucous-winged gull (*Larus glaucescens*)	27	9	64
Bald eagle (*Haliaeetus leucocephalus*)	74	11	59
Great black-backed gull (*L. marinus*)	20	12	53
Osprey (*Pandion haliaetus*)	77	13	53
Great blue heron (*Ardea herodius*)	132	14	51
Ring-necked pheasant (*Phasianus colchicus*)	45	15	47
Herring gull (*L. argentatus*)	291	16	47
Snowy owl (*Bubo scandiacus*)	28	17	46
Mallard (*Anas platyrhynchos*)	221	18	47
Great egret (*Ardea alba*)	24	19	45
Red-tailed hawk (*Buteo jamaicensis*)	534	20	42
California gull (*L. californicus*)	23	21	37
Cattle egret (*Bubulcus ibis*)	112	22	37
Ring-billed gull (*L. delawarensis*)	362	23	37
Franklin’s gull (*Leucophaeus pipixcani*)	26	23	31
Rock dove (*Columba livia*)	1,035	25	33
Swainson’s hawk (*Buteo swainsoni*)	24	26	32
Other hawks	34	27	30
Laughing gull (*L. atricilla*)	106	28	29
Mew gull (*L. canus*)	21	29	31
Peregrine falcon (*Falco peregrinus*)	44	29	23
Laysan albatross (*Phoebastria immutabilis*)	29	31	30
Upland sandpiper (*Bartramia longicauda*)	32	31	21
Short-eared owl (*Asio flammeus*)	58	33	19
American crow (*Corvus brachyrhynchos*)	141	34	19
Black-bellied plover (*Pluvialis squatarola*)	20	35	25
Spotted dove (*Streptopelia chinensis*)	46	35	16
Barn owl (*Tyto alba*)	174	37	18
Mourning dove (*Zenaida macroura*)	1,313	38	17
Blackbirds	976	39	14
European starling (*Sturnus vulgaris*)	1,408	40	14

Continued on p. 32

Continued from p. 31

Species[1]	Total Strikes Reported	Composite Rank	Relative Hazard Score
Killdeer (*Charadrius vociferous*)	553	41	11
American kestrel (*Falco sparverius*)	536	42	9
Zebra dove (*Geopelia striata*)	54	42	9
Common myna (*Acridotheres tristis*)	21	44	9
Snow bunting (*Plectrophenax nivalis*)	84	45	16
Bank swallow (*Riparia riparia*)	49	45	10
Meadowlarks	361	47	8
Horned lark (*Eremophila alpestris*)	372	48	7
Sparrows	1,799	49	7
Northern harrier (*Circus cyaneus*)	24	50	8
American robin (*Turdus migratorius*)	159	51	9
Burrowing owl (*Athene cunicularia*)	20	52	5
Barn swallow (*Hirundo rustica*)	486	53	3
Wrens	28	54	6
Terns	45	55	4
Finches	55	56	7
Common nighthawk (*Chordeiles minor*)	38	57	2
Chimney swift (*Hirundo pelagica*)	34	58	5
Pacific golden-plover (*Pluvialis apricaria)*	204	58	4
Purple martin (*Progne subis*)	57	58	3
Western sandpiper (*Calidris mauri*)	31	61	5
Cliff swallow (*Petrochelidon pyrrhonota*)	164	62	2
Nutmeg mannikin (*Lonchura punctulata*)	26	63	3
Chestnut manikin (*Lonchura malacca*)	28	64	0
Wood warblers	30	65	3
Tree swallow (*Tachycineta bicolor*)	109	65	2

The composite rank reflects three variables: (1) the percentage of total strikes (for that species/group) that caused some type of damage to the aircraft, (2) the percentage of total strikes that caused substantial damage to the aircraft, and (3) the percentage of total strikes that caused an effect on flight (EOF). See Dolbeer et al. (2000) for definitions of damage and EOF. Strike data are from the FAA National Wildlife Strike Database.
Source: Travis DeVault, USDA/APHIS/WS Ohio field station, unpublished data.

[1] Other geese = snow goose (*Anser caerulescens*), brant (*Branta bernicla*), greater white-fronted goose (*Anser albifrons*); other ducks = 23 species in the family Anatidae; other hawks = Cooper's hawk (*Accipter cooperii*), sharp-shinned hawk (*A. striatus*), rough-legged hawk (*Buteo lagopus*), red-shouldered hawk (*B. lineatus*), broad-winged hawk (*B. platypterus*), ferruginous hawk (*B. regalis*); blackbirds = red-winged blackbird (*Agelaius phoeniceus*), brown-headed cowbird (*Molothrus ater*), common grackle (*Quiscalus quiscula*); meadowlarks = eastern meadowlark (*Sturnella magna*), western meadowlark (*Sturnella neglecta*), sparrows = 19 species in the family Emberizidae; wrens = house wren (*Troglodytes aedon*), Carolina wren (*Throthorus ludovicianus*), marsh wren (*Cistothorus palustris*); terns = common tern (*Sterna hirundo*), arctic tern (*S. vittata*), Caspian tern (*Hydroprogne caspia*), least tern (*Sternula albifrons*), fairy tern (*Sternula nereis*); finches = house finch (*Caprodacus mexicanus*), American goldfinch (*Carduelis tristis*); wood warblers = 13 species in the family Parulidae.

Abbreviations used without definition in TRB Publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETY-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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