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# Avian Repellents: Options, Modes of Action, and Economic Considerations

J. Russell Mason
*Utah State University, Logan*

Larry Clark
*Colorado State University*, larry.clark@aphis.usda.gov

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# Avian Repellents: Options, Modes of Action, and Economic Considerations

**J. Russell Mason**, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Denver Wildlife Research Center, c/o Predator Ecology and Behavior Project, Utah State University, Logan, UT 84322-5295
**Larry Clark**, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, National Wildlife Research Center, Colorado State University, Engineering Research Center, Foothills Campus, NWRC Room BO5, Fort Collins, CO 80523

## ABSTRACT

The present manuscript considers visual, auditory, tactile, chemosensory, and physiologic repellents currently available for use in the United States. Discussion of tactile, chemosensory, and physiologic repellents is emphasized for three reasons. First, these products are preferred by users. Second, application of these substances is regulated by state and federal agencies. Third, only four active ingredients are legally available at the present time. This lack reflects difficulties in obtaining regulatory approval and limited market size.

## KEY WORDS

*bird, fear, irritation, repellents, sensory, sickness*

## INTRODUCTION

For birds, repellents can be visual (e.g., eyespot balloons [Shirota et al. 1983], flagging [Mason et al. 1993]), auditory (e.g., distress calls [Aubin 1990, Blokpoel 1976], propane exploders [Linz et al. 1993], shell crackers [Cummings et al. 1986, Mott et al. 1990]), tactile (e.g., clay-based seed coatings [Avery et al. 1989], polybutene products [Timm 1983]), chemosensory (e.g., methyl anthranilate [Mason et al. 1993]), or physiologic (e.g., mesurol [Rogers 1980]). Under conditions of normal use, repellents act directly on pests but, importantly, they are not lethal. Hence, 4-aminopyridine, and other lethal "frightening" agents (Eschen and Schafer 1986) are toxicants, not repellents. Of the 43 products registered as bird damage control chemicals in the United States, only seven (16.4%) are repellents. Within this small group of products, the active ingredient in four is polybutene. Capsaicin, denatonium saccharide, and napthalene are the active ingredients in the remaining three products. Only polybutene has demonstrated utility; the available evidence suggests that birds are indifferent to the other materials (Clark et al. 1990, Mason 1987).

## TYPES OF REPELLENTS

### Visual repellents

These often are inexpensive (e.g., $ 0.80/acre for plastic flags, Mason et al. 1993; Mason and Clark 1994), and they tend to be effective, if only for short periods. Typical examples of visual repellents include balloons (Shirota et al. 1983, Mott 1985), kites (Fazlul Haque et al. 1985), plastic flagging, and mylar streamers (Bruggers et al. 1986, Dolbeer et al. 1986*a*, Mason et al. 1993, Mason and Clark 1994, Timm 1983). Functionally, visual repellents cause startle responses, as do aposematic colors (e.g., orange, red, silver; Reidinger and Mason 1983, Lipcius et al. 1980) and cues associated with predators (e.g., hawk silhouettes, eyespots, raptor models; Conover 1982, Inglis 1980, Inglis et al. 1983). However, startle responses eventually diminish (often within days or a few weeks) as a function of several variables, including weather conditions, bird numbers, and the availability of nearby unprotected foods (e.g., Feare et al. 1986).

### Auditory Repellents

These include both sonic and ultrasonic devices. Among the former, propane cannons are commonly used for the control of bird depredation and nuisance problems (Linz et al. 1993). Provided that units are moved every few days, cannons can be effective when one is placed for every 10 acres of crop. Repellency is enhanced when shooting is implemented concurrently, or when other measures are taken to slow birds' habituation to noise (Slater 1980, Inglis 1984). Electronic triggers that detect the presence of birds and selectively fire cannons are now available (Adams Dominion, Inc., Crestwood, KY).

A variety of other sonic frightening devices, including electronic noise systems, synthetic bird calls, and pyrotechnics, are sometimes used in addition to exploders (Aubin 1990, Feare et al. 1986). These systems can be effective against loafing and roosting birds (e.g., Blokpoel 1976). However, they have little utility against feeding birds in agricultural settings and are not any more effective than propane cannons alone (Feare et al. 1986). Repellency is variable, and depends on the persistence and skill of the operator, the attractiveness of the crop, the number of birds present, and the availability of alternative food sources (e.g., Mott 1978; Mott and Timbrook 1986, Salmon and Conte 1981).

Ultrasonic devices are offered as deterrents to roosting and loafing birds (Krzysik 1987). These devices have no demonstrated utility (e.g., Theissen et al. 1957, Theissen and Shaw 1957, Martin and Martin 1984, Kerns 1985, Griffiths 1986, Woronecki 1988), probably because birds are physiologically incapable of detecting ultrasound (i.e., frequencies above 20,000 Hz; e.g., Summers-Smith 1963).

### Tactile Repellents

Clay-based seed coatings that become tacky when wet are effective bird repellents under some conditions (Avery et al. 1989; Decker et al. 1990). For example, the estimated loss of clay-coated rice in a Texas field trial averaged 17%, compared with 36.5% in control plots (Decker et al. 1990). However, when bird numbers are high and/or when alternative foods are relatively unpalatable or sparse, clay-based coatings confer little protection (Avery, pers. commun.).

Polybutene products (e.g., tacky pastes and liquids) repel birds from ledges or other roosting structures (Timm 1983). These products often contain other ingredients, including mineral oil, lithium sterate soap, diphenylamine, zinc oxide, and castor oil (Timm 1983). While effective, polybutene-based repellents are thermally labile, and melting repellent can deface structures to which it is applied. Both clay-coatings and polybutene are considered pesticides.

### Chemosensory and Physiologic Repellents

These substances are effective either because they are painful or because they cause sickness. If the latter, then food avoidance learning is involved (Avery 1985, Reidinger and Mason 1983). If the former, then the repellent often is stimulating pain receptors (i.e., trigeminal chemoreceptors) in the mouth, nose, and eyes (Green et al. 1990). Although many birds possess adequate or even superior olfactory and gustatory capabilities (e.g., Berkhoudt 1985, Clark and Mason 1989), smell and taste, per se, are rarely of consequence for bird damage control (Mason and Otis 1990).

At present, no effective chemosensory and physiologic repellent is legally available in the United States.

## METHODS DEVELOPMENT

The remainder of this discussion is organized into four areas. The first three areas are agricultural repellent needs, nonagricultural repellent needs, and conservation applications. The final area is consideration of a simple economic decision-making model.

### Agricultural Needs

#### *Background*

Reliable measures of economic loss caused by wildlife are unavailable. Nevertheless, national surveys of farmers by the U.S. Agricultural Statistics Service (A. P. Wywialowski, pers. commun.) can be used as a general index of where research may be needed. In the Eastern United States, 52.5% ($n$ = 4,463) of farmers who raised field crops reported some losses. Of these, 86.5% attributed losses to wildlife (Figure 1). For those farmers who raised vegetables, fruits,

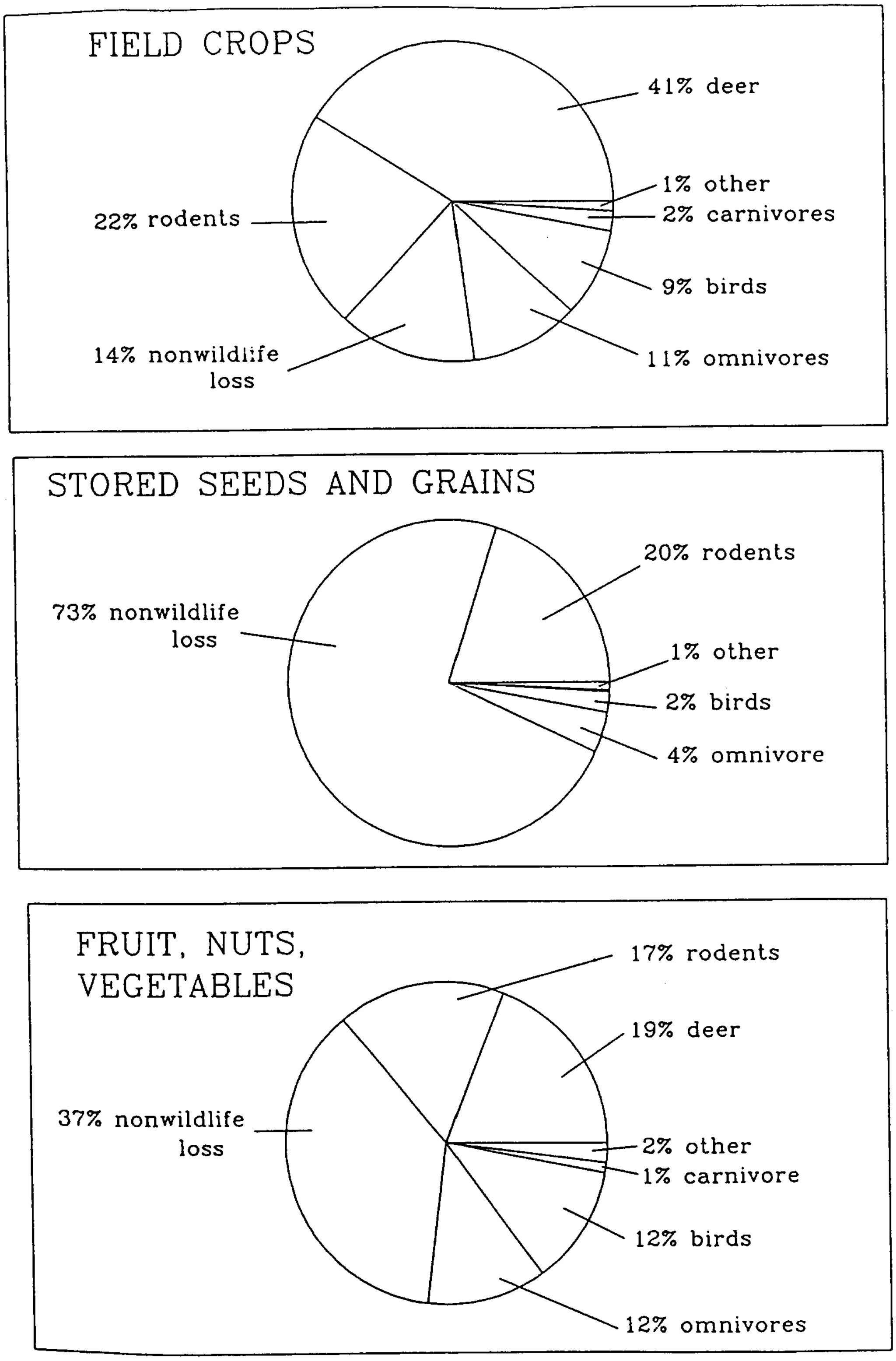

**FIGURE 1.** The percentage loss attributed to various sources by farmers in the eastern United States who raise field crops (top), store seeds and grains (middle), or grow fruits, nuts and vegetatables (bottom). Data from Wywialowski and Beach (1991).

or nuts, 41.8% (*n* = 877) reported some losses, with 62.5% of this damage attributed to wildlife. For those farmers who stored feed, seed, or grain on their properties, 23% (*n* = 2,634) reported some losses, 27% of which was attributed to wildlife.

The economics of damage varies greatly among crops (Table 1). For example, a 1972 survey of sunflower fields in North Dakota and Minnesota showed that the mean loss to birds was only 13 kg/ha (Besser 1978). Because 174,500 ha were planted in sunflower during that year, we can estimate that the national loss was 2,270 metric tons (Putt 1978). At an average value of $230 per metric ton (Cobia 1978), bird damage cost growers $522,100. On the other hand, Avery et al. (1991) estimated that birds destroyed 11% of the national blueberry crop in 1989. Because total blueberry production during that year was 158 million pounds, and the average price was $0.50/pound, Avery estimated that bird damage may have cost growers as much as $8.5 million from a total market size of $77.3 million.

Bird damage has been documented in many agricultural contexts other than food crops. For example, feed consumption and contamination by birds are problems for feedlot and grain storage operators (Feare 1975, 1979, 1980, Twedt and Glahn 1982). Birds associated with livestock and poultry also represent a potential vector for economically important diseases such as transmissible gastroenteritis (Gough and Beyer 1982, Pilchard 1965), tuberculosis (Bickford et al. 1966), and avian influenza (Alexander et al. 1979). Histoplasmosis, a human respiratory disease, is associated with roosting blackbirds and starlings.

An issue that is increasingly significant is the hazard that modern agricultural chemicals present to birds. Pelleted agricultural chemicals and treated seeds are essential components of no-till conservation farming, a practice that will be used on 60% of the cropland in North America within 20 years (Crosson 1982). These farming practices generally benefit wildlife by providing cover and food (Castrale 1987), and they are environmentally safe relative to pesticide spray applications (Greig-Smith 1987). However, pelleted chemicals and treated seeds are dangerous to birds that forage in treated fields (Best and Gionfriddo 1991, Greig-Smith 1988, Schafer et al. 1983, U.S. Environmental Protection Agency 1989). In recognition of this hazard, the U.S. Environmental Protection Agency has threatened a generic ban on the use of granular products. Although the cost of such a ban is difficult to gauge, it is obviously large (Figure 2, Table 2). Particulate formulations are a major fraction of the pesticide market, and the principle source of income for some chemical companies (Mason and Turpin 1990).

### *Existing Repellents*

There are no effective chemicals legally available for use in agricultural settings in North America.

### *New Repellents; Near-Term Possibilities*

These substances may already be registered for agricultural use (e.g., insecticides or fungicides with bird repellent properties; Avery and Nol 1991, Avery et al. 1993, Avery and Decker 1991, Babu 1988, Crocker and Reid 1993). Alternatively, they might be approved for

Table 1. **Estimates of Economic Losses Caused by Birds to Selected Agricultural Commodities for Which Damage and Dollar Values Are Reported**

| | $ Value | % Loss | $ Loss | Reference |
|---|---|---|---|---|
| **FIELD CROPS** | | | | |
| Field Corn | | | | |
| Ohio | 1,726,800,000 | 0.7 | 3,880,000 | Stickley et al. 1979 |
| Ohio | 737,500,000 | 0.8 | 5,900,000 | Dolbeer 1981 |
| Ohio | 968,571,428 | 0.7 | 6,780,000 | Dolbeer 1981 |
| Ohio | 4,507,142 | 0.1 | 450,714 | Andrews and Henze 1985 |
| Ohio | 5,000,000 | 1.0 | 5,000,000 | Dolbeer 1980 |
| Michigan | 544,000,000 | 0.3 | 1,360,000 | Dolbeer 1981 |
| Kentucky | 240,000,000 | 0.5 | 1,200,000 | Stickley et al. 1979 |
| 10 states[a] | 137,241,666 | 0.4 | 380,000 | Stickley et al. 1979 |
| Sweet Corn | | | | |
| Ohio | 1,000,000 | 2.0 | 200,000 | Dolbeer, pers. commun. |
| **FRUIT** | | | | |
| Blueberry | | | | |
| National | 79,000,000 | 10.8 | 8,500,000 | Avery et al. 1991 |
| National | 32,000,000 | 5.0 | 1,600,000 | Mott and Stone 1973 |
| Michigan | 8,333,333 | 6.0 | 500,000 | Stone et al. 1974 |
| Cherries | | | | |
| Britian | 44,726,774 | 11.5 | 5,163,264 | Feare 1979 |
| Michigan | 25,000,000 | 17.4 | 4,250,000 | Guarino et al. 1974 |
| National | 138,888,889 | 17.4 | 24,166,667 | Crase et al. 1976 |
| Grapes | | | | |
| National | 683,920,900 | 0.4 | 2,600,000 | Lee, pers. commun. |

[a] The 10 states were Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. Together, these states produced 79.4% of the corn crop in 1981.

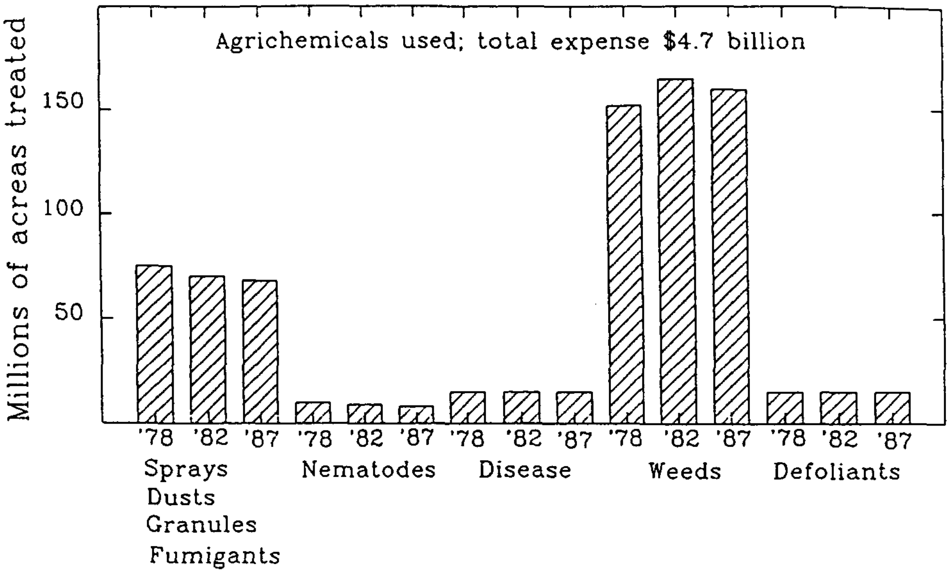

**FIGURE 2.** Quantities of agricultural chemicals used by U.S. farmers by type of application. Data are derived from the 1987 Census of Agriculture.

**Table 2. Estimated Net U.S. and Worldwide Agricultural Chemicals (AgChem) Sales ($ Millions) by the Top 10 Producers (T. Miller, American Cyanamid, Pers. Commun.), and Total Sales of All Products by These Companies (Values are drawn from 1988–90 Annual Reports of These Companies**

| Company | Estimated U.S. Agric. Sales[a] | Estimated World Agric. Sales[b] | Total World Sales[c] |
|---|---|---|---|
| DuPont | 711 | 3,076.5 | 15,064 |
| Ciba-Geigy | 672 | 3,109.6 | 17,600 |
| Dow Elanko | 545 | 1,023.0 | 8,293 |
| Monsanto | 520 | 1,377.0 | 4,825 |
| American Cyanamid | 510 | 1,100.0 | 24,449 |
| ICI | 447 | 4,189.0 | 13,612 |
| Rhone Poulenc | 255 | 2,239.0 | 16,039 |
| BASF | 207 | 3,047.0 | 2,150 |
| Mobay USA | 185 | 358.3 | 3,287 |
| FMC | 183 | 521.0 | 22,297 |
| All others | 850 | 3,176.7 | – |

[a] Net sales estimates for the U.S. market were provided by T. Miller, American Cyanamid Corporation.

[b] Sales estimates for the world agricultural market were extracted from corporate earnings statements contained in annual reports.

[c] Total sales obtained from corporate earnings statements contained in annual reports.

use as human or animal feed additives. Compounds in this category include cinnamic acid derivatives (Avery and Decker 1992, Crocker and Perry 1990, Crocker and Reid 1993), cinnamyl alcohol and benzoate derivatives (Jakubas et al. 1992), anthranilate derivatives (Mason et al. 1989), acetophenone, benzoic acid and triazine derivatives (Clark and Shah 1991*a*, Clark et al. 1991, Mason et al. 1991*a*), and d-pulegone (Mason 1990). Also, a variety of inert materials exert some bird repellency, including bentonite clays (Daneke and Decker 1988, Avery et al. 1989, Decker et al. 1990) and activated charcoal (Mason and Clark 1994).

Whatever the repellent in question, one strategy to contain registration costs may be to target nonagricultural uses where ecological concerns and residue requirements (vis-a-vis food contamination) are relatively less. Such nonagricultural uses are described below.

### *New Repellents; Long-Term Possibilities*

Research that explores fundamental concepts in avian foraging may yield practical results. Four lines of investigation appear especially promising. First, basic examination of structure-activity relationships between the chemistry of known irritants and avoidance behavior may lead to the reliable prediction of new sensory repellents (Mason et al. 1991*a,b*, Clark and Shah 1991*a*, Clark et al. 1991, Shah et al. 1991). Second, basic examination of physiologic repellents (i.e, those that act by causing malaise) could lead to the development of new products. For example, intestinal membrane disaccharidases may constrain the feeding behavior of some birds (e.g., those species that are unable to concentrated sucrose solutions; Martínez del Rio and Stevens 1989; Brugger 1992). Although sucrose may not be repellent in some feeding contexts (Clark and Mason 1993), it is possible that the simple addition of sucrose to livestock feed could economically reduce depredation and disease hazards that birds present at feedlots. Third, selective breeding and genetic engineering of plants could produce crop varieties that are bird tolerant. This approach has been investigated with maize (Dolbeer et al. 1982), sorghum (Bullard et al. 1981), rape (Inglis et al. 1992), sunflower (Dolbeer et al. 1986*b*), and pears (Greig-Smith et al. 1983). More broadly, phenylpropanoids, a class of common phenolic compounds in plants, are bird repellent and insecticidal (Buchsbaum et al. 1984, Crocker and Perry 1990, Jakubas et al. 1992). Because production of phenylpropanoids in plants is focused in specific plant tissues (i.e., husks, pericarp, aleurone; Collins 1986, McCallum and Walker 1990), it may be possible to maximize the repellency of endogenous chemical defenses against birds (e.g., by concentrating chemicals in achene surface tissues) while minimizing the impact of the defense on the nutritive value or palatability of the grain once these surface tissues are removed (Jakubas et al. 1992). Finally, many plant chemical defenses against insect predators are well-described, and some of these materials are repellent to birds as well (Crocker and Perry 1990, Guilford et al. 1987). For example, cucurbitacins are triterpenoid glycosides that occur in plants belonging to the Cucurbitacae and Cruciferae families (Robinson 1983). These substances deter insect feeding (Metcalf 1985) and repel birds (Mason and Turpin 1990).

## Nonagricultural Needs

### *Background*

Nonmigratory waterfowl are a nuisance in urban and suburban locations (Cummings et al. 1991). Grazing geese damage turf (Laycock 1982), and their feces adversely affect public health (Conover and Chasko 1985) and contribute to eutrophy in ponds and streams (Conover and Chasko 1985, Mott and Timbrook 1986). The overall economic impact of problems caused by waterfowl in these settings has not been quantified, but the cost of capturing geese for relocation can exceed $12/bird (Thompson 1991). One survey of golf course superintendents found that they would be willing to pay $60/ha for effective Canada goose control (Cummings et al. 1991). There are about 14,500 golf courses in the continental United States (U.S. Golf Association, pers. commun.).

Other species cause nuisance and public health problems by carrying garbage from dumps (Dolbeer et al. 1988*b*), roosting in urban and suburban areas (Chick et al. 1980, Dolbeer et al. 1988*b,c*, Tosh et al. 1970), and causing structural damage (Stemmerman 1988). In Missouri, the annual cost of damage by woodpeckers to electrical transmission poles exceeds $350,000 (Stemmerman 1988). If the average cost of damage is merely $250,000 per state, then the national annual cost exceeds $12.5 million.

### *Existing Repellents*

Naphthalene and polybutene are registered to repel roosting birds (Timm 1983). However, naphthalene has no demonstrated utility as an avian repellent (e.g., Clark et al. 1990, Dolbeer et al. 1988*a*). In field tests, applications of napthalene 32.5 times higher than the registered rate have no repellent effect (Dolbeer et al. 1988*b*). Undoubtedly, polybutene has bird repellent activity under some circumstances, as the number of products containing this substance attests (100% of commercial roost repellents). Again, however, experimental data in support of this claim are sparse.

### *New Repellents; Near-Term Possibilities*

Some of the materials that we described for agricultural purposes could serve as useful repellents in nonagricultural contexts. These chemicals include food and flavor additives like anthranilate derivatives, and registered agricultural chemicals like ziram. Registrations for the use of methyl anthranilate at land fills and in sterile ponds are expected in 1994 (PMC Specialties Group, Inc., pers. commun.). In addition, materials such as methoxyacetophenones, 4-ketobenztriazine, veratryl amine, and N-acetyl veratryl amine (Mason et al. 1991*b*, Clark et al. 1991) may prove useful. Several of these substances are already used as synthetic intermediates for food additives, pharmaceuticals, and agricultural chemical coatings.

### *New Repellents; Long-Term Possibilities*

Long-term possibilities that we described for agricultural needs also are applicable here.

## Conservation Needs

### *Background*

Industrial byproducts and mine effluvia are frequently stored in open outdoor impoundments that pose serious risks to wildlife (Allen 1990, Kay 1990). Waterfowl, shore birds, and other species are attracted to the freestanding water and risk exposure to both acute and chronic toxicants (Ohlendorf et al. 1989, Williams et al. 1989).

The costs of protecting birds from mine and industrial effluvia is readily quantified. U.S. sales from the gold and silver industry exceeded $3.3 billion in 1989. Because cyanide is used for the extraction of these metals from ore, the leachate impoundments are highly toxic to wildlife. Eliminating cyanide from ponds by quenching is expensive, costing between $240–400,000/year for a mid-sized operation. Excluding birds from ponds until cyanide reclamation or quenching can be achieved is also costly, running between $9,000-$13,000/acre (Schroeder 1990). Echo Bay Minerals Company spent $7.2 million to neutralize cyanide and exclude birds from a 363-acre pond at a mine site. Despite substantial reductions in avian mortality, Echo Bay still paid $500,000 in fines to the U.S. Fish and Wildlife Service.

Airports also pose risks to wildlife (Blokpoel 1976), and frequent collisions between birds and aircraft represent a hazard to human health and safety (Dolbeer et al. 1993). In 1989, bird strikes caused $80 million damage to U.S. military aircraft and $100 million damage to civilian aircraft (Dolbeer, pers. commun.). In many instances, birds are attracted to airports after rains because of the free-standing water which accumulates on runways. As in the case of mining operations, traditional hazing operations are ineffective because birds simply move from one location to another, and quickly become accustomed to the harassment.

### *Existing Repellents*

No repellent chemicals are registered in the United States for any conservation use.

### *New Repellents; Near-Term Possibilities*

A variety of substances may have utility as bird repellent additives to standing water. These include sensory repellents like methyl anthranilate, 4-ketobenztriazene, and anthranilic acid. The major obstacle blocking the practical application of these compounds is the development of delivery systems that (1) preserve the chemical integrity of repellents in the hostile environments that wastewater presents (Clark and Shah 1991*b*, 1993), and (2) assure that chemical is concentrated in ways that maximize the likelihood of contact with target birds (e.g., on the surface of ponds).

### *New Repellents; Long-Term Possibilities*

The development of chemical repellents for use in small, shallow pools of water is a fairly simple matter. However, the development of substances that can be added to large ponds is physically and ecologically more complex. Further, toxic impoundments negatively affect members of all vertebrate classes, not just birds. The identification of broadly repellent materials is likely to be a long-term process, as all the available evidence suggests that there are dramatic differences among vertebrates classes in their responsiveness to chemical irritants (Szolcsanyi et al. 1986, Mason and Otis 1990).

## CONCLUSIONS

The path from discovery of a candidate repellent to product availability can be thought of as a filtering process (Figure 3). Each step along the process constrains development. Accordingly, the smaller the initial number of candidate repellents, the less the likelihood of successfully developing a new product. Because serendipity has too often been responsible for repellent discovery, and registration, manufacturing, and marketing constraints have been ignored, few repellents are presently available. Nevertheless, there are a range of substances that could become available if interested developers can be found. These substances include existing insecticides and fungicides, synthetic intermediates for these products, human and animal feed flavorings, and inert substances such as bentonite clays and activated charcoal. Conceivably, expedited registration of biological pesticides, and other relatively innocuous substances by environmental regulatory agencies (P. Savarie, Denver Wildlife Research Center, pers. commun.) will encourage industry and bring new bird repellents to consumers. At present, however, few tools are available, and the likelihood that more tools will become available in the next few years appears remote.

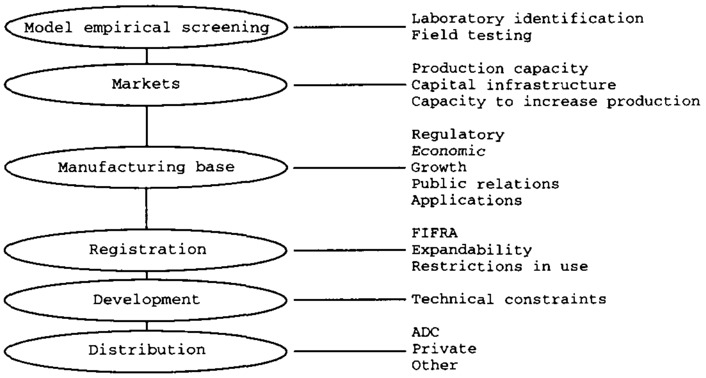

**FIGURE 3.** A heuristic model for factors affecting the discovery and development of a repellent strategy. Abbreviations: FIFRA = Federal Insecticide, Fungicide, and Rodenticide Act; ADC = Animal Damage Control.

## LITERATURE CITED

Alexander, D. J., W. H. Allen, and G. Parsons. 1979. Characterization of influenza isolated from turkeys in Great Britain during 1963-1977. Res. Vet. Sci. 26:17-20.

Allen, C. 1990. Mitigating impacts to wildlife at FMC Gold Company's Paradise Peak Mine. Pages 67-71 *in* R. McQuivey, ed. Proceedings of the Wildlife Mining Workshop, Nevada Mining Association, Nevada Department of Minerals and Nevada Department of Wildlife, Reno, NV.

Andrews, D. A., and L. E. Henze. 1985. Blackbird depredations on field corn—1985. Unpubl. Report., Sandusky, OH. 10 pp.

Aubin, T. 1990. Synthetic bird calls and their application to scaring methods. Ibis 132:290-299.

Avery, M. L. 1985. Application of mimicry theory to bird damage control. J. Wildl. Manage. 49:1116-1121.

———, and D. G. Decker. 1991. Repellency of fungicidal seed treatments to red-winged blackbirds. J. Wildl. Manage. 55:327-334.

———, and ———. 1992. Repellency of cinnamic acid esters to captive red-winged blackbirds. J. Wildl. Manage. 56:800-805.

———, ———, D. L. Fischer, and T. R. Stafford. 1993. Responses of captive blackbirds to a new insecticidal seed treatment. J. Wildl. Manage. 57:652-656.

———, ———, and M. O. Way. 1989. Field evaluation of a nontoxic clay coating for reducing bird damage to newly planted rice. Denver Wildl. Res. Cent. Bird Sec. Res. Rep. No. 444. 9 pp.

———, J. W. Nelson, and M. A. Cone. 1991. Survey of bird damage to blueberries in North America—1989. Denver Wildl. Res. Cent. Bird Sec. Res. Rep. No. 468. 21 pp.

———, and P. Nol. 1991. Evaluation of the repellency of Imidan to fruit-eating birds. Denver Wildl. Res. Cent. Bird Damage Res. Rep. No. 479. 10 pp.

Babu, T. H. 1988. Effectiveness of certain chemicals and fungicides on the feeding behavior of house sparrows. Pavo 26:17-23.

Berkhoudt, H. 1985. Structure and function of avian taste receptors. Pages 463–495 *in* A. S. King and J. McLelland, eds. Form and function in birds, Academic Press, NY.

Besser, J. F. 1978. Birds and sunflower. Pages 263-278 *in* J. F. Carter, ed. Sunflower science and technology. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Inc., Madison, WI.

Best, L. B., and J. P. Gionfriddo. 1991. Characterization of grit use by cornfield birds. Wilson Bull. 103:68–82.

Bickford, A. A., G. H. Ellis, and H. E. Moses. 1966. Epizootiology of tuberculosis in starlings. J. Am. Vet. Med. Assoc. 149:312–318.

Blokpoel, H. 1976. Bird hazards to aircraft. Can. Wildl. Serv., Ottawa, CN. 236 pp.

Brugger, K. E. 1992. Repellency of sucrose to captive American robins. J. Wildl. Manage. 56:794–799.

Bruggers, R. L., J. E. Brooks, R. A. Dolbeer, P. P. Woronecki, R. K. Pandid, T. Tarimo, and M. Hoque. 1986. Responses of pest birds to reflecting tape in agriculture. Wildl. Soc. Bull. 14:161–170.

Buchsbaum, R., I. Valiela, and T. Swain, 1984. The role of phenolic compounds and other plant constituents in feeding by Canada geese in a coastal marsh. Oecologia 63:343–349.

Bullard, R. W., J. O. York, and S. R. Kilburn. 1981. Polyphenolic changes in ripening bird-resistant sorghums. J. Agric. Food Chem. 29:973–981.

Castrale, J. S. 1987. Pesticide use in no-till row-crop fields relative to wildlife. Ind. Acad. Sci. 96:215–222.

Chick, E. W., C. Flanigan, S. B. Compton, T. Pass, C. Gayle, C. Hernandez, F. R. Pitzer, and E. Austin. 1980. Blackbird roosts and histoplasmosis: an increasing medical problem? Chest 77:584–585.

Clark, C., L. Clark, and L. Clark. 1990. Anting behavior of common grackles and European starlings. Wilson Bull. 102:167–169.

Clark, L., and J. R. Mason. 1989. Sensitivity of the brown-headed cowbirds to volatiles. Condor 91:922–932.

———, and ———. 1993. Interaction between sensory and postingestional repellents in starlings: methyl anthranilate and sucrose. Ecol. Appl. 3(2):262–270.

———, and P. S. Shah. 1991*a*. Nonlethal bird repellents: in search of a general model relating repellency and chemical structure. J. Wildl. Manage. 55:538–545.

———, and ———. 1991*b*. Chemical bird repellents: applicability for deterring use of waste water. Pages 157–164 *in* R. D. Comer, ed. Proceedings 5: Issues and technology in the management of impacted wildlife. Thorne Ecological Institute, Snowmass, CO.

———, and ———. 1993. Chemical bird repellents: possible use in cyanide ponds. J. Wildl. Manage. 57:657–664.

———, ———, and J. R. Mason. 1991. Chemical repellency in birds: relationship between chemical structure and avoidance response. J. Exp. Zool. 260:310–322.

Cobia, D. W. 1978. Production costs and marketing. Pages 387–406 *in* J. F. Carter, ed. Sunflower science and technology. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Inc., Madison, WI.

Collins, F. W. 1986. Oat phenolics: structure, occurrence and function. Pages 227–295 *in* F. H. Webster, ed. Oat chemistry and technology. American Society of Cereal Chemists, St. Paul, MN.

Conover, M. R. 1982. Behavioral techniques to reduce bird damage to blueberries: methiocarb and a hawk-kite predator model. Wildl. Soc. Bull. 10:211–216.

———, and G. C. Chasko. 1985. Nuisance Canada goose problems in the Eastern United States. Wildl. Soc. Bull. 13:228–233.

Crase, F. T., C. P. Stone, R. W. DeHaven, and D. F. Mott. 1976. Bird damage to grapes in the United States with emphasis on California. U.S. Fish Wildl. Serv. Spec. Sci. Rep. No. 197. 18 pp.

Crocker, D. R., and S. M. Perry. 1990. Plant chemistry and bird repellents. Ibis 132:300–308.

———, and K. Reid. 1993. Repellency of cinnamic acid derivatives to rooks and chaffinches. Wildl. Soc. Bull. 21:456–460.

Crosson, W. F. 1982. Conservation tillage and conventional tillage: a comparative assessment. EPA Report No. 600/3-82-027. U.S. Environmental Protection Agency, Washington, DC. 72 pp.

Cummings, J. L., C. E. Knittle, and J. L. Guarino. 1986. Evaluating a pop-up scarecrow coupled with a propane exploder for reducing blackbird damage to ripening sunflower. Proc. Vertebr. Pest Conf. 12:286–291.

———, J. R. Mason, D. L. Otis, and J. F. Heisterberg. 1991. Evaluation of dimethyl and methyl anthranilate as a Canada goose repellent on grass. Wildl. Soc. Bull. 19:184–190.

Daneke, D., and D. G. Decker. 1988. Prolonged seed handling time deters red-winged blackbirds feeding on rice seed. Proc. Vertebr. Pest Conf. 13:287–292.

Decker, D. G., M. L. Avery, and M. O. Way. 1990. Reducing blackbird damage to newly planted rice with a nontoxic clay-based seed coating. Proc. Vertebr. Pest Conf. 14:327–331.

Dolbeer, R. A. 1980. Blackbirds and corn in Ohio. U.S. Fish Wildl. Serv. Resource Publication No. 136. 18 pp.

———. 1981. Cost-benefit determination of blackbird damage control for cornfields. Wildl. Soc. Bull. 9:44–51.

———, J. L. Belant, and J. L. Sillings. 1993. Shooting gulls reduces strikes with aircraft at John F. Kennedy International Airport. Wildl. Soc. Bull. 21:442–450.

———, M. A. Link, and P. P. Woronecki. 1988*a*. Napthalene shows no repellency for starlings. Wildl. Soc. Bull. 16:62–64.

———, P. P. Woronecki, and R. L. Bruggers. 1986*a*. Reflecting tapes repel blackbirds from millet, sunflowers, and sweet corn. Wildl. Soc. Bull. 14:418–425.

———, ———, E. C. Cleary, and E. B. Butler. 1988*b*. Site evaluation of gull exclusion device at Fresh Kill Landfill, Staten Island, NY. Denver Wildl. Res. Cent. Bird Sec. Res. Rep. No. 411. 10 pp.

———, ———, T. W. Seamans, B. N. Buckingham, and E. C. Cleary. 1988*c*. Herring gull nesting on Sandusky Bay, Lake Erie, 1988. Denver Wildl. Res. Cent. Bird Sec. Res. Rep. No. 427. 8 pp.

———, ———, and R. A. Stehn. 1982. Effect of husk and ear characteristics on resistance of maize to blackbird *(Agelaius phoeniceus)* damage in Ohio. Prot. Ecol. 4:127–139.

———, ———, ———, G. J. Fox, J. J. Hanzel, and G. M. Linz. 1986*b*. Field trials of sunflower resistant to bird depredation. North Dakota Farm Res. 43:21–24,28.

Eschen, M. L., and E. W. Schafer. 1986. Registered bird damage chemical controls—1985. Denver Wildl. Res. Cent. Bird Damage Res. Rep. No. 356. 16 pp.

Fazlul Haque, A. K. M., and D. M. Broom. 1985. Experiments comparing the use of kites and gas bangers to protect crops from woodpigeon damage. Agric. Ecosyst. & Environ. 12:219-228.

Feare, C. J. 1975. Cost of starling damage to an intensive husbandry unit. Proc. Brit. Insect. Fung. Conf. 8:253-259.

———. 1979. The economics of starling damage. Pages 39-55 *in* E. N. Wright, ed. Bird problems in agriculture. British Crop Protection Council Publications, Croyden, UK.

———. 1980. The economics of starling damage. Econ. Damage 2:39-54.

———, P. W. Greig-Smith, and I. R. Inglis. 1986. Current status and potential of non-lethal means of reducing bird damage in agriculture. Pages 493-506 *in* H. Ouellet, ed. Acta XIX Congressus Internationalis Ornitholgii, Vol. 1. Univ. Ottawa Press, Ottawa, CN.

Gough, P. H., and J. W. Beyer. 1982. Bird-vectored diseases. Proc. Great Plains Wildl. Damage Control Workshop 6:260-272.

Green, B. G., J. R. Mason, and M. R. Kare, eds. 1990. Chemical nociception in the nose and mouth. Chemical Senses, Vol. 2, Irritation. Marcel Dekker, Inc., NY. 361 pp.

Greig-Smith, P. W. 1987. Hazards to wildlife from pesticide seed treatments. BCPC Monograph 39: applications to seeds and soil. 8 pp.

———. 1988. Wildlife hazards from the use, misuse, and abuse of pesticides. Aspects Appl. Biol. 17:247-256.

———, M. F. Wilson, C. A. Blunden, and G. M. Wilson. 1983. Bud-eating by bullfinches, *Pyrrhula pyrrhula* in relation to the chemical constituents of two pear cultivars. Ann. Appl. Biol. 103:335-343.

Griffiths, R. E. 1986. Efficacy testing of an ultrasonic bird repeller. Pages 56-63 *in* S. A. Shumake and R. W. Bullard, eds. Vertebrate Pest Control and Management Materials, Vol. 5, Am. Soc. Testing and Materials, Philadelphia, PA.

Guarino, J. L., W. F. Shake, and E. W. Schafer. 1974. Reducing bird damage to ripening cherries with methiocarb. J. Wildl. Manage. 38:338-342.

Guilford, T., C. Nicol, M. Rothschild, and B. P. Moore. 1987. The biological roles of pyrazines: evidence for a warning odour function. Biol. J. Linnean Soc. 31:113-128.

Inglis, I. R. 1980. Visual bird scarers: an ethological approach. Pages 121-143 *in* E. N. Wright, I. R. Inglis, and C. J. Feare, eds. Bird problems in agriculture. British Crop Protection Council, Croydon, UK.

———. 1984. Bird scaring. Ministry of Agriculture, Fisheries, and Food, London, UK.

———, L. W. Huson, M. B. Marshall, and P. A. Neville. 1983. The feeding behavior of starlings *(Sturnus vulgaris)* in the presence of "eyes." Ziet. Tierpsychol. 62:181-208.

———, J. T. Wadsworth, A. N. Meyer, and C. J. Feare. 1992. Vertebrate damage to 00 and 0 varieties of oilseed rape in relation to SMCO and Glucosinolate concentrations in the leaves. Crop Prot. 11:64-68.

Jakubas, W. J., P. S. Shah, J. R. Mason, and D. M. Norman. 1992. Avian repellency of coniferyl and cinnamyl derivatives. Ecol. Appl. 2:147-156.

Kay, F. R. 1990. Nevada Department of Wildlife's role: past, present, future. Pages 18-23 *in* R. McQuivey, ed. Proceedings of the Nevada Mining and Wildlife Workshop. Nevada Mining Association, Nevada Department of Minerals and Nevada Department of Wildlife, Reno, NV.

Kerns, J. D. 1985. Evaluation of the effectiveness of the "Ultrason ET" ultrasonic device as a means of cliff swallow control. Natural Resources Report 85-2, Fort Wainwright, AK.

Krzysik, A. J. 1987. A review of bird pests and their management (unclassified). Technical Report REMR-EM-1. 145 pp.

Laycock, G. 1982. The urban goose. Audubon 84:44-47.

Linz, G. M., R. A. Dolbeer, J. J. Hanzel, and L. E. Huffman. 1993. Controlling blackbird damage to sunflower and grain crops in the northern Great Plains. U.S. Department of Agriculture Information Bulletin No. 679. 15 pp.

Lipcius, R. N., C. A. Coyne, B. A. Fairbanks, D. H. Hammond, P. J. Mohan, D. J. Nixon, J. J. Staskiewicz, and F. H. Heppner. 1980. Avoidance response of mallards to colored and black water. J. Wildl. Manage. 44:511-518.

Martin, L. R., and P. C. Martin. 1984. Research indicates propane cannons can move birds. Pest Cont. 52:52.

Martínez del Rio, C. M., and B. R. Stevens. 1989. Physiological constraint on feeding behavior: intestinal membrane disaccharidases of the starling. Science 243:794–796.

Mason, J. R. 1987. Ro-pel efficacy: evaluation of active ingredients under optimal conditions with red-winged blackbirds *(Agelaius phoeniceus)*. Denver Wildl. Res. Cent. Bird Damage Res. Rep. No. 384. 10 pp.

———. 1990. Evaluation of D–pulegone as an avian repellent. J. Wildl. Manage. 54:130–135.

———, M. A. Adams, and L. Clark. 1989. Anthranilate repellency to starlings: chemical correlates and sensory perception. J. Wildl. Manage. 53:55–64.

———, N. J. Bean, P. S. Shah, and L. Clark. 1991*b*. Taxon-specific differences in responsiveness to capsaicin and several analogues: correlates between chemical structure and behavioral aversiveness. J. Chem. Ecol. 17:2539–2551.

———, and ———. 1994. Evaluation of plastic and mylar flagging as repellents for snow geese *(Chen caerulescens)*. Crop Prot., 13:531-534.

———, ———, and N. J. Bean. 1993. White plastic flags repel snow geese (Chen caerulescens). Crop Prot. 12:497–500.

———, ———, and T. P. Miller. 1993. Evaluation of a pelleted bait containing methyl anthranilate as a bird repellent. Pestic. Sci. 39:299–304.7

———, ———, and P. S. Shah. 1991*a*. Ortho-aminoacetophenone repellency to birds: perceptual and chemical similarities to methyl anthranilate. J. Wildl. Manage. 55:334–340.

———, and D. L. Otis. 1990. Effectiveness of six potential irritants on consumption by red-winged blackbirds *(Agelaius phoeniceus)* and starlings *(Sturnus vulgaris)*. Pages 309-324 *in* B. G. Green, J. R. Mason, and M. R. Kare, eds. Chemical Senses, Vol. 2, Irritation. Marcel Dekker, Inc., NY.

———, and T. Turpin. 1990. Cucurbitacin-adulterated diet is avoided by captive European starlings. J. Wildl. Manage. 54:672–676.

McCallum, J. A., and J. R. Walker. 1990. Phenolic biosynthesis during grain development in wheat: changes in phenylalanine ammonia-lyase activity and soluble phenolic content. J. Cereal Sci. 11:35–49.

Metcalf, R. L. 1985. Plant kairomones and insect pest control. Ill. Nat. Hist. Surv. Bull. 33:175–198.

Mott, D. F. 1978. Control of wading bird predation at fish-rearing facilities. Pages 131–132 *in* J. C. Ogden and S. Winckler, eds. Wading Birds, National Audubon Society, Washington, DC.

———. 1985. Dispersing blackbird-starling roosts with helium-filled balloons. Proc. East. Anim. Damage Control Conf. 2:156–162.

———, K. J. Andrews, and G. A. Littauer. 1990. The effect of cormorant roost dispersal on numbers of cormorants at nearby catfish ponds. Denver Wildl. Res. Cent. Bird Sec. Res. Rep. No. 462.

———, and C. P. Stone. 1973. Bird damage to blueberries in the United States. Unpubl. Tech. Rep. No. 8, Work Unit DF–102.3, Denver Wildlife Research Center. 18 pp.

———, and S. K. Timbrook. 1986. Alleviating nuisance Canada goose problems with acoustical stimuli. Denver Wildl. Res. Cent. Bird Damage Res. Rep. No. 380. 13 pp.

Ohlendorf, H. M., R. L. Hothem, and D. Welsh. 1989. Nest success, cause-specific nest failure and hatchability of aquatic birds at selenium-contaminated Kesterson Reservoir and a reference site. Condor 91:787–796.

Pilchard, E. I. 1965. Experimental transmission of transmissible gastroenteritis virus by starlings. Am. J. Vet. Res. 26:1177–1179.

Putt, E. D. 1978. History and present world status. Pages 1–30 *in* J. F. Carter, ed. Sunflower science and technology. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Inc., Madison, WI.

Reidinger, R. F., and J. R. Mason. 1983. Exploitable characteristics of neophobia and food aversions for improvements in rodent and bird control. Pages 20–42 *in* D. E. Kaukienen, ed. Vertebrate Pest Control and Management Materials. Am. Soc. Testing and Measurement, Philadelphia, PA.

Robinson, T. 1983. The organic constituents of higher plants. Cordus Press, Amherst, MA 353 pp.

Rogers, J. G. 1980. Conditioned taste aversion: its role in bird damage control. Pages 173–179 *in* E. N. Wright, I. R. Inglis, and C. J. Feare, eds. Bird problems in agriculture. British Crop Protection Council, Croydon UK.

Salmon, T. P., and F. S. Conte. 1981. Control of bird damage at aquaculture facilities. U.S. Department of the Interior, Wildlife Management Leaflet No. 475. 11 pp.

Schafer, E. W., W. A. Bowles, and J. Hurlbut. 1983. The acute oral toxicity, repellency, and hazard potential of 988 chemicals to one or more species of wild and domestic birds. Arch. Environ. Contam. Toxicol. 12:355–382.

Schroeder, M. L. 1990. The netting of cyanide ponds at Copperstone Gold. Pages 72–81 *in* R. McQuivey, ed. Proc. Nevada Wildlife and Mining Workshop. Nevada Mining Association, Nevada Department of Minerals, Nevada Department of Wildlife, Reno, NV.

Shah, P. S., J. R. Mason, and L. Clark. 1991. Prediction of avian repellency from chemical structure: the aversiveness of vanillin, vanillyl alcohol, and veratryl alcohol. Pestic. Biochem. Physiol. 40:169–175.

Shirota, Y., M. Sanada, and S. Masaki. 1983. Eyespotted balloons as a device to scare grey starlings. Appl. Entomol. Zool. 18:545–549.

Slater, P. J. 1980. Bird behavior and scaring by sounds. Pages 105–114 *in* E. N. Wright, I. R. Inglis, and C. J. Feare, eds. Bird problems in agriculture. British Crop Protection Council, Croydon, UK.

Stemmerman, L. A. 1988. Observation of woodpecker damage to electrical distribution line poles in Missouri. Proc. Vertebr. Pest Conf. 13:260–265.

Stickley, A. R., D. L. Otis, and D. T. Palmer. 1979. Evaluation and results of a survey of blackbird and mammal damage to mature field corn over a large, 3-state area. Pages 169–177 *in* Vertebrate Pest Control and Management Materials, ASTM STP 680. Am. Soc. Testing and Materials, Philadelphia, PA. 323 pp.

Stone, C. P., W. F. Shake, and D. J. Langowski. 1974. Reducing bird damage to high bush blueberries with a carbamate repellent. Wildl. Soc. Bull. 2:135–139.

Summers-Smith, D. 1963. The house sparrow. Collins, London. 251 pp.

Szolcsanyi, J., H. Sann, and F-K Pierau. 1986. Nociception in pigeons is not impaired by capsaicin. Pain 27:247–260.

Theissen, G. J., E. R. G. Shaw, R. D. Harris, J. B. Gollop, and H. R. Webster. 1957. Acoustic irritation threshold of Peking ducks and other domestic and wildfowl. J. Acoust. Soc. Am. 29:1301.

———, and E. R. G. Shaw. 1957. Acoustic irritation threshold of ring-billed gulls. J. Acoust. Soc. Am. 29:1307.

Thompson, G. 1991. Canada geese: waterfowl or just plain foul. Annual Meeting of Golf Course Superintendents, Reno, NV.

Timm, R. M. 1983. Anticoagulants. Pages G 27-28 *in* S. Hygnstrom, R. Timm, and G. Larsen, eds. Prevention and control of wildlife damage. Univ. Nebraska Press, Lincoln, NE.

Tosh, F. E., I. L. Doto, S. B. Beecher, and T. D. Y. Chin. 1970. Relationship of starling-blackbird roosts and endemic histoplasmosis. Am. Rev. Resp. Dis. 101:283–288.

Twedt, D. J., and J. H. Glahn. 1982. Reducing starling depredations at livestock feeding operations through changes in management practices. Proc. Vertebr. Pest Conf. 10:159–163.

U.S. Environmental Protection Agency. 1989. Carbofuran: special review technical support document. Office of Pesticides and Toxic Substances, Washington, DC.

Vacca, M. M., and C. M. Handel. 1988. Factors influencing predation associated with visits to artificial goose nests. J. Field Ornithol. 59:215–223.

Williams, M. L., R. L. Hothem, and H. M. Ohlendorf. 1989. Recruitment failure in American avocets and black-necked stilts nesting at Kesterson Reservoir, California, 1984–1985. Condor 91:797–802.

Woronecki, P. P. 1988. Effect of ultrasonic, visual, and sonic devices on pigeon numbers in a vacant building. Proc. Vertebr. Pest Conf. 13:266–272.