Title

Nonlethal repellents: The development of cost-effective, practical solutions to agricultural and industrial problems

Journal

Proceedings of the Vertebrate Pest Conference, 15(15)

ISSN
0507-6773

Authors

Mason, J. Russell
Clark, Larry

Publication Date

1992

NONLETHAL REPELLENTS: THE DEVELOPMENT OF COST-EFFECTIVE, PRACTICAL SOLUTIONS TO AGRICULTURAL AND INDUSTRIAL PROBLEMS[1]

J. RUSSELL MASON and LARRY CLARK, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Denver Wildlife Research Center, c/o Monell Chemical Senses Center, 3500 Market Street, Philadelphia, Pennsylvania 19104-3308

ABSTRACT: Repellents substances and devices cause pest species to avoid otherwise attractive or palatable materials. For birds, repellents can be visual, auditory, pyrotechnic, tactile, chemosensory, physiologic, or physical. Here, we consider chemical agents only. Few substances are registered with the U.S. Environmental Protection Agency (EPA), and thus legally available for use. This lack of available bird repellent technology reflects the small demonstrable economic impact of many agricultural bird damage problems. Accurate information about damage and market size is virtually nonexistent, and private companies are reluctant to invest resources in the unknown. To successfully commercialize new repellents, clearly lucrative markets must be identified. Efforts must be made to empirically quantify damage and to estimate whether control methods are economical relative to the protection that they confer. We intend the present manuscript as a first step in these directions.

Proc. 15th Vertebrate Pest Conf. (J. E. Borrecco & R. E. Marsh, Editors) Published at University of Calif., Davis. 1992

INTRODUCTION

Repellent substances and devices cause pest species to avoid otherwise attractive or palatable materials (Mason et al. 1989, Rogers 1978). For birds, repellents can be visual [e.g., eyespot balloons (Shirota et al. 1983)], auditory [e.g., distress calls (Aubin 1990, Blokpoel 1976)], pyrotechnic [(Cummings et al. 1986, Mott et al. 1990)], tactile [e.g., clay seed coatings (Avery et al. 1989a), polybutene products (Timm 1983)], chemosensory [e.g., anthranilate derivatives (Glahn et al. 1989)], physiologic [e.g., mesurol (Rogers 1980)] or physical [e.g., barrier nets (Andrews and Mott 1990, Blokpoel and Tessier 1984, Dolbeer et al. 1988)]. Under conditions of normal use, repellents are not lethal. Hence, substances like 4-aminopyridine, a lethal 'frightening' agent (Eschen and Schafer 1986) are not discussed here. Also, insecticides like Sevin® which reduce insect populations in crops, and thereby reduce bird damage (Woronecki et al. 1981), are not considered, even though they are non-lethal to birds, and are not avian repellents, *per se*. It is interesting to note that of the 95 products registered as bird damage control chemicals, only 38 (40%) are registered as non-lethal repellents (Eschen and Schafer 1986). Of these 38 chemicals, the active ingredients in 27 (71%) are either methiocarb or polybutene (Tables 1 and 2).

We restrict our discussion to chemical, i.e., tactile, chemosensory, and physiologic agents. These substances are effective either because of aversive sensory effects (i.e., irritation), or because of post-ingestional malaise (i.e., sickness). If the latter, then repellents act through food avoidance learning (Avery 1985, Reidinger and Mason 1983). If the former, then chemicals are nearly always stimulants of trigeminal pain receptors (i.e., undifferentiated free nerve endings) in the nose, mouth, and eyes (Green et al. 1990). Although many birds possess adequate 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).

Development of repellents for use on agricultural commodities is central to the mission of the Denver Wildlife Research Center (e.g., Schafer and Brunton 1971, Glahn et al. 1989). Over the years, discoveries have included mesurol, thiram, ziram, clay seed coatings, and various anthranilate and cinnamic acid derivatives. Although several of these chemicals have been offered to the public, only two (mesurol, thiram) are registered with the EPA and sold for use in restricted settings (as seed treatments) against bird depredation. This lack of success in transferring bird repellent technologies to the private sector reflects the small demonstrable economic impact of many agricultural bird damage problems and an inability to accurately gauge whether a specific repellent is marketable. Given limited research dollars, investigators must increase their focus to allocate resources in areas that are likely to be of practical benefit to agriculture, i.e. indentify those repellents that stand the best chance of being registered and commercialized. Accurate information about damage and market size is vital to this process, but such data also are virtually nonexistent, and heresay and case studies of extreme damage are the rule. In our experience, heresay is unconvincing and, of course, case studies lack statistical worth. Not surprisingly, private companies are reluctant to invest in the unknown. To involve industry in the practical development and aggressive marketing of new repellents (and in the aggressive maintenance of registrations for existing products), broader (not necessarily agricultural) markets must be identified, and costs and profits must be quantified. We intend the present discussion as a first step in these directions.

Our thoughts are organized into four areas: (1) We outline agricultural uses for repellents, (2) non-agricultural uses are covered, (3) we consider the development of repellents that protect birds from human activities, and endangered species from avian predators, and (4) we outline the development of a decision-making model. The factors in the model are economic, though economics alone are not the only metric by which an animal damage control problem should be judged. In many cases, the public relations value of a control technology are valuable assets. And clearly, it is the responsibility of the federal government to alleviate damage to private

---

[1] Order of authorship determined by a flip of a coin.

Table 1. EPA-registered repellents for use on agricultural commodities (from Eschen and Schafer 1986).

Product Name	Chemical	Target Species	Specified Use	Registrant	EPA Reg. No.
Bonide Cro-X	Methiocarb (50%)	Blackbirds	Seed Corn Treatment	Bonide Chemical Co.	4-254
Borderland Black Repellent	Methiocarb (18.75%)	Blackbirds	Seed Corn Treatment	Borderland Chemical Co.	7832-4
Crow-chex Repellent	Copper Oxalate (4%)	Crows	Seed Corn Treatment	Borderland Chemical Co.	7832-2
Gustafson 42-S Fungicide and Repellent	Thiram (42%)	Birds	Conifer Seed Treatment	Gustafson Inc.	7501-14
Gustafson Mesurol 50 HBT	Methiocarb (50%)	Birds	Seed Corn Treatment	Gustafson Inc.	3125-309-7501
Hopkins Mesrepel 50% Hopper Box Treatment	Methiocarb (50%)	Blackbirds	Seed Corn Treatment	Hopkins Agricultural Chemical Co.	23-93-337
Isotox Seed Treater-F	Lindane (25%) & Captan (11.8%)	Pheasants	Seed Treatment	Chevron Chemical Co.	239-677-ZA
Isotox Seed Treater-75	Lindane (75%)	Pheasants	Seed Treatment	Chevron Chemical Co.	239-353-ZB
Sevana Bird Repellent	Capsicum (10%) & *Allium sativum* powder (4%)	Starlings, Sparrows, Larks, Finches, Linnets	Sprouting Crops	Sevana Co.	47319-1
Sevana Bird Repellent	Ibid	Ibid	Fruits, Nuts, Grains	Sevana Co.	47319-2
Stanley's Crow Repellent	Coal Tar (63%) & Creosote Liquid (31%)	Crows	Corn Seed Treatment	Borderland Chemical Co.	7832-1

property caused by federally protected species, no matter how local that damage might be. Be that as it may, economics are certainly the deciding factor from the commercial point-of-view. Conceptually, we believe that government and academic scientists are ideally equipped to discover new repellents and technologies because federal and university laboratories receive long-term funding for this purpose. However, upscaling, product development, and EPA registration are too costly for research and operations arms of the government to pursue, except in isolated instances. Here, industrial participation is essential.

AGRICULTURAL USES

Needs

Reliable estimates of economic loss caused by wildlife are generally not available. National surveys by the Agricultural Statistical Service have focused on farmers' perceived damge to commodities by wildlife and are useful as a general index of where research efforts may be focused (Wywialowski 1991). For example, a survey of eastern states showed that 52.5% (n = 4,463) of farmers who raised field crops reported some losses (Wywialowski 1991). Of those farmers reporting losses, 86.5% attributed losses to wildlife (Fig. 1). For those farmers who raised vegetables, fruits or nuts 41.8% (n = 877) reported some losses. Of those reporting losses, 62.5% attributed losses to wildlife (Fig. 1). Finally, for those farmers who stored feed, seed or grain on their operation 23% (n = 2,634) reported some losses. Of

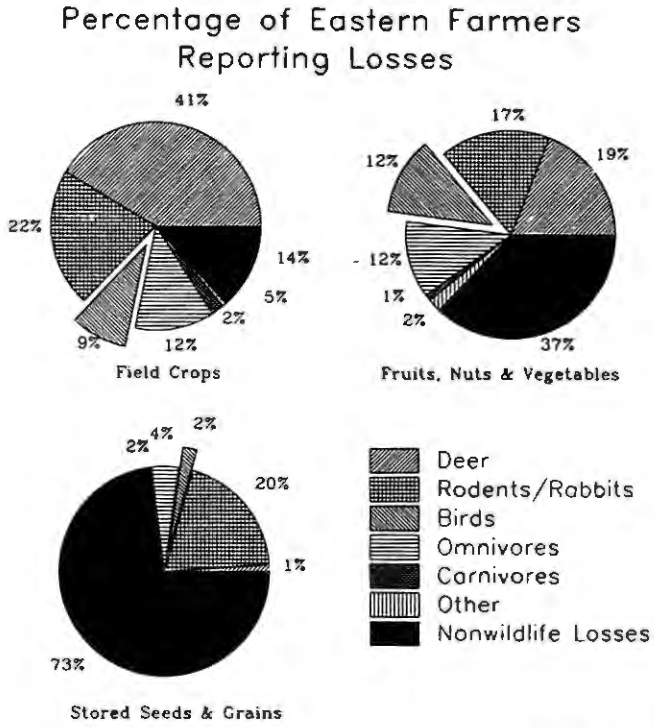

Figure 1. Of those eastern farmers reporting losses to field crops (top left), fruits, nuts and vegetables (top right), and stored seeds and grains (bottom left), the frequency attributed to different wildlife sources. Data derived from Wywialowski (1991).

Table 2. EPA-registered repellents for use in non-agricultural contexts (from Eschen and Schafer 1986).

Product Name	Chemical	Target Species	Specified Use	Registrant	EPA Reg. No.
Bird/Bat Repellent	Naphthalene (100%)	Starlings, Pigeons	Structure Roosts	Chacon Chemical Co.	5719-92
Bird Ban	Polyisobutylene gel (10%)	Starlings, Pigeons, Sparrows	Ibid	Chem-O-Craft Specialties	7818-1
Bird Stop	Polyisobutylene gel (95.5%)	Pigeons, Sparrows	Ibid	Animal Repellents, Inc.	7754-20
Bird Tanglefoot	Polyisobutylene gel (97%)	Birds	Ibid	Tanglefoot Co.	1621-17
Bird Tanglefoot Aerosol	Polyisobutylene gel (48.5%)	Birds	Ibid	Tanglefoot Co.	1621-16
Bye-bye Birdy	Polybutene (80%)	Blackbirds, Starlings,Pigeons Sparrows, Gulls, Crows, Ravens	Ibid	B & G Co.	8254-1-8612
Exelcide Bird Repellent	Polybutene gel (95%)	Starlings,Pigeons, Sparrows	Ibid	Huge Co., Inc.	2270-88
Grosley's Original No Roost Bird Repellent	Polybutene gel (40%) & Diphenylamine (1%)	Starlings, Pigeons, Gulls, Sparrows	Ibid	Aegis Labs, Inc.	7682-1
Guardian AvaTac Nuisance Bird Repellent	Polybutene (10%) & Paloja gel (20%)	Birds	Structures, Trees	Ar Chemical Corp.	7122-50
Hub States Bird Repellent/ Hubsco Bird Repellent	Polybutene gel (97%)	Birds	Structure Roosts	Hub States Corp.	5602-37
Hub States Bird Repellent Aerosol	Polybutene gel (48.5%)	Birds	Ibid	Hub States Corp.	1621-16-5602
Repel-O-Film	Mineral Oil (94.5%)	Birds	Ledges, Structures	Baumes Castorine	1606-3
Roost-No-More Bird Repellent	Polybutene gel (76%)	Starlings,Pigeons, Sparrows	Structures	Velsicol Chemical Co.	7579-2
Roost-No-More Bird Repellent Liquid	Polyisobutylene (48%)	Birds	Structures	Velsicol Chemical Co.	876-435-AA
Roost-No-More Repels Nuisance Birds	Polybutene gel (96%)	Starlings, Pigeons	Structures	Velsicol Chemical Co.	876-437
Roost-No-More Bird Repellent Repels Nuisance Birds	Polyisobutylene (2%) & Petroleum Naphthalenic Oil (86%)	Starlings, Pigeons	Structures	Velsicol Chemical Co.	876-437-AA
Shoo Bird & Bat Repellent	Naphthalene (99%)	Birds	Structures	Petrokem Corp.	2292-76
Tower Grezall NP-4 Bird Repellent	Polybutene (49.7%)	Birds	Structures	Tower Oil & Technology Corp.	10286-1
Wil-Kil	Naphthalene (100%)	Starlings,Pigeons, Sparrows	Structures	Sudbury Laboratories, Inc.	731-42

those reporting losses, 27% were attributed to wildlife (Fig. 1). Although different taxa are blamed for varying degrees of damage, these data fail to indicate the extent of damage done, and hence the economic damage caused by the perceived pests. For example, birds are implicated in causing between 2 and 12% of damage to various commodities, but their impact could be larger if they damaged high value crops (i.e., fruits). Whereas deer are cited as causing a higher frequency of damage, but the commodities affected may have lower per acre market value (i.e. grain). Thus, the relative economic importance of a pest is not accurately measured by such reporting, though it is helpful in identifying the spectrum of pest control methods potentially needed.

Nonetheless, there have been estimates of economic damage caused by wildlife. For example, birds attack nearly all food crops. Damage to corn (Dolbeer et al. 1982), rape

Table 3. Estimates of economic losses caused by birds to selected agricultural commodities (i.e., commodities for which damage is commonly reported, and for which dollar values are reported).

Crop	$ Market Value	% Loss	$ Value Loss	Reference
FIELD CROPS				
Field Corn				
Ohio	5,000,000,000	1.0	5,000,000	Dolbeer 1980
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	0.14	631 bu	Andrews & Henze 1985
Michigan	544,000,000	0.3	1,360,000	Dolbeer 1981
Kentucky	240,000,000	0.5	1,200,000	Stickley et al. 1979
Tennessee	97,435,897	0.4	380,000	Stickley et al. 1979
10 states[a]	137,241,666	2.4	293,800	Besser & Brady 1986
Ontario	560,000 ton	0.7	39,200 ton	Tyler & Kannenberg 1980
Sweet Corn				
Ohio	1,000,000	2.0	200,000	
Wheat				
NW Tennessee	73,000 ton	2.6	1,913 ton	Dolbeer et al. 1978
SC Tennessee	30,900 ton	0.3	87 ton	Dolbeer et al. 1978
SW Tennessee	117,800 ton	0.3	412 ton	Dolbeer et al. 1978
Peanuts				
Oklahoma[b]	3,360,000	1.4	46,670	Mott et al. 1972
FRUIT				
Blueberries				
National	79,000,000	10.8	8,500,000	Avery et al. 1991
National	32,000,000	5.0	1,600,000	Mott & Stone 1973
Michigan[c]	8,333,333	6.0	500,000	Stone et al. 1974
Cherries				
Britain	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.
LIVESTOCK				
Feedlots				
Kansas			2,000,000	Glahn XXXX
Tennessee			4,200,000	Hobson & Geuder
Tennessee[d]	579,000,000	0.7	4,200,000	Stickley XXXX
Catfish				
National	323,000,000	10.0	32,000,000	Anonymous 1991
Mississippi[e]	210,000,000	2.6	5,400,000	Stickley & Andrews 1989

[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.

[b] Estimates of production and bird damage are from 3 counties in 1969.

[c] These values are estimated. Stickley et al (XXXX) report that Michigan, during the period 1968-1971, produced 18% of the national cherry crop. Thus, the national damage could be estimated on the basis of the dollar damage values supplied by Guarino et al. 1974.

[d] Damage estimates were obtained from Hobson and Geuder (1976). Overall sale of feedlot products for the state of Tennessee were obtained from Stickley (XXXX).

[e] Mississippi produces 70% of the catfish raised in the United States (Anonymous 1991).

(Inglis et al. 1989), rice (Wilson 1985), sorghum (Bullard et al. 1981), wheat, rye, oats (Dolbeer, et al. 1978, Summers 1990, Summers and Critchley 1990) and sunflower (Henne et al. 1979) is well-known. Similarly, fruits crops [e.g., grapes (Hothem et al. 1981), cherries (Stevens and DeBont 1980, Tobin et al. 1989), blueberries (Avery et al. 1991, Conover 1985), citrus (Hobbs and Leon 1988, Rappole et al. 1989)], and apples (Tobin et al. 1989) suffer significant damage. Although bird depredation on vegetables, nut crops, and legumes is less publicized, it is a common complaint among growers (Fig. 1). In addition to bird losses, *per se*, damage can result in higher levels of insect damage and spoilage (e.g., Woronecki et al. 1980).

Not surprisingly, the few available reports show that the economics of damage varies greatly among food crops (Table 3). 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 nearly 11% of the national blueberry crop in 1989. Because total blueberry production in 1989 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.

Non-food crops also are attacked by birds. Turf (Laycock 1982), flowers [e.g., orchids and anthurium (Cummings et al. 1990)], and cover crops such as clover (D. Sheppard pers. commun.) are damaged. As with food crops, losses can begin early in development and continue until the date of harvest. Because some non-food crops remain in the field for years (e.g., turf), depredation can occur during any season.

As for food crops, the cost of bird damage to non-food crops is variable but sometimes severe (Table 3). For example, estimates of annual bird damage to orchids grown in the Hawaiian Islands are as high as 75% of the total crop; the 1985 market value of Hawaiian orchids exceeded $ 12 million (Kefford et al. 1987), representing a potential loss of $ 9 million.

Apart from field crops, bird damage has been documented in a variety of other agricultural contexts. For example, feed depredation and feed contamination are problems for feedlot and grain storage operations (Feare 1975, 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), beef tapeworm and avian influenza (Lipkind et al. 1979, Alexander et al. 1979). As predators, birds prey on livestock (Phillips and Blum 1988), and take fish from pound nets (Craven and Lev 1987) and fish-culture ponds (Mott 1978). Losses to aquaculture can be extremely high; the third greatest cause (behind disease and oxygen depletion) of loss to catfish producers is said to be birds eating fish (Anonymous 1991). Estimates of bird damage to catfish operations in the Mississippi delta exceed $5 million annually (Stickley and Andrews 1989), and $32 million nationally (from a total $332 million pond-side value nationally).

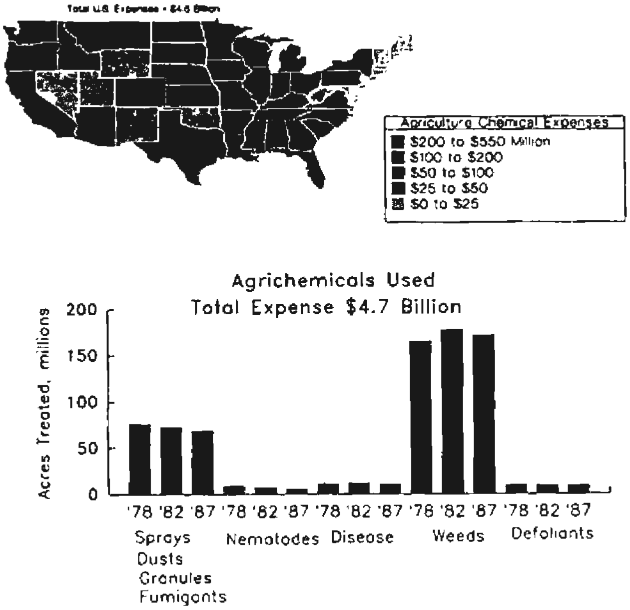

Figure 2. Expenses for agricultural chemicals for U.S. farmers by state (top). Quantities of agricultural chemicals used by U.S. farmers by type of application. Data based upon the 1987 Census of Agriculture.

Depredation and disease transmission are two traditionally recognized conflict areas between birds and agriculture. A less studied but potentially more important problem (from an economic point of view and the standpoint of wildlife perservation) is the hazard that modern agricultural practices present to birds. Pelleted agricultural chemicals and chemically treated seeds are essential components of no-tillage conservation farming, a practice that is predicted to be used on 60% of the nation's cropland by the year 2010 (Crosson 1982). These farming practices generally benefit wildlife by providing cover and food (Castrale 1987). Also, they are environmentally safe, relative to pesticide spray applications (Greig-Smith 1987). However, pelleted chemicals and treated seeds present dangers to birds that accidentally ingest them (Greig-Smith 1988). Most if not all granular insecticides are highly toxic to birds (Schafer et al. 1983). Many are formulated in particles that have the same size and shape as grit (Best and Gionfriddo 1991), and there are numerous reports of avian mortality associated with these materials (U.S. Environ. Protect. Agency 1989). Predators and scavengers that consume poisoned birds also are at risk, and the EPA has threatened a generic ban on the use of granular products (J. F. Wright, FMC Corporation, pers. commun.). There is ample statutory justification for this position. The Migratory Bird Treaty Act (16 USC 703-711) sets zero tolerance for bird mortality from human activities (see also; Lacey Act, 18 USC 42-44; Black Bass Act 16 USC 851-856; Bald Eagle Protection Act, 16 USC 668-668d; Tariff Classification Act of 1962, 19 USC 1202 (Schedule 1, Part 15D, Headnote 2, T.S.U.S.); Endangered Species Conservation Act of 1969, 16 U.S.C. 668aa-668cc-6). Although the cost of a generic ban on granular chemicals has not been estimated publically, it is clearly enormous (Fig. 2, Table 4). These products represent a major fraction of the pesticide market, and are a principal source of income for major chemical companies (Mason and Turpin 1990).

Table 4. Net U.S. and worldwide agricultural chemical (Ag. Chem.) sales ($ millions) by the top 10 producers (T. Miller, American Cyanamid, pers. commun.), and total sales of all products by these companies. Values drawn from the latest available annual reports (1988-1990) of these companies.

Company	Estimated U.S. Ag. Sales[a]	Estimated World Ag.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 United States 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.

Repellents—Existing Compounds

There are few EPA registered chemical repellents available, and the restricted situations in which they can be used are decreasing (Table 1). For example, mesurol [3,5-dimethyl-4-(methylthio)phenol methylcarbamate] was once used on a wide variety of crops (Eschen and Schafer 1986, Guarino 1972), but it is now available only as a corn seed treatment. Although this chemical appears to pose little direct threat to wildlife (Dolbeer et al. 1988), maintenance of the broad registration package has not been pursued by the manufacturer (Mobay USA), perhaps reflecting the fact that mesurol sales are very low when compared to the sales of other Mobay products and sales by Bayer Chemical, the parent company.

Besides mesurol, the only other effective repellent available for use is lindane (Eschen and Scahfer 1986, Timm 1983). It too is registered only as a seed treatment. Although lindane does not appear acutely or chronically toxic to birds at concentrations that are repellent (Blus et al., 1984), it is carcinogenic (Windholtz et al. 1983). Both mesurol and lindane cause food avoidance learning, i.e., birds eat treated foods and become sick, associate the sickness with the food, and subsequently show avoidance (Rogers 1978).

Other registered chemicals include capsaicin and garlic (broadcast applications to vegetation not intended for human consumption), coal tar (seed treatment), and copper oxalate (seed treatment) (Timm 1983). All of these substances are putative irritants, and may repel mammals. However, there is no evidence that any of them repel birds. At least for the chemical senses, birds and mammals do not share the same sensory universe (Mason et al. 1991c). For example, 20 ppm of capsaicin is aversive to mammals, but up to 20,000 ppm is inoffensive to birds. This is the limit of solubility, and 2000x the capsaicin concentration in a jalepeno pepper (Szolcsanyi et al. 1986). There are other problems as well. At least one of these putative repellents is carcinogenic: coal tar contains a variety of potent mutagens including benzene, xylene, and anthracene (Windholtz et al. 1983).

No chemical repellents are available for use in aquaculture or as deterrents to avian predation on livestock. Further, no effective chemicals are available for broadcast applications to food crops or for agricultural commodities like turf or flowers. Although industry should be encouraged to preserve the registration of substances like mesurol for as long as possible, concerns about the safety of these materials will eventually preclude their use. In the next section, we offer candidate repellents that have greater potential for long-term availability. However, there are added initial costs associated with these materials in terms of EPA registration and commercialization.

Repellents—Short-term Possibilities

These are known bird repellents that are not registered with the EPA for use in areas of interest. Preferably, chemicals in this category are registered either as bird repellents for use in settings other than the one of interest, or as agents useful for some other agricultural purpose (e.g., as a fungicide). Alternatively, these substances might be listed with the U.S. Food and Drug Administration for use as human or animal feed additives. The advantages of such compounds are that toxicological and environmental data are already in place, thus lowering the eventual registration costs. Candidate compounds that meet these requirements include several pesticides [e.g., trimethacarb (Avery et al. 1989b), thiram, ziram (Cummings et al. 1991)], chemicals registered as bird repellents in other countries (e.g., anthraquinone), mammalian food additives [e.g., cinnamic acid derivatives (Crocker and Perry 1990), cinnamyl alcohol and benzoate derivatives (Jakubas et al. 1991), anthranilate derivatives (Mason et al. 1989), acetophenone, benzoic acid and triazine derivatives (Clark and Shah 1991, Clark et al. 1991a, 1991b), pulegone (Mason 1990)], and inert materials [e.g., clay seed coatings (Dancke and Decker 1988, Avery et al 1989a)]. Trimethacarb, thiram, ziram, and some of the cinnamic acid derivatives are repellent because they cause food avoidance learning. Conversely, anthranilate derivatives, cinnamyl alcohol and benzoate derivatives, other cinnamic acid derivatives and pulegone cause sensory pain (i.e., irritation), but (probably) not gastrointestinal malaise. Clay coatings are (presumably) tactile repellents—birds avoid treated seeds because they are tacky, and thus cannot be handled efficiently.

Registration costs of clay seed coatings would be low, and their use, obviously, cost-efficient. Similarly, chemicals that are registered for other agricultural purposes, or that are registered as bird repellents in other countries should be inexpensive to register as bird repellents in the United States because much of the toxicological and environmental data already exist. Whether or not the use of agricultural chemicals is cost effective relative to the bird damage they prevent is a matter for case by case investigation, rather than an industry wide assessment. There is evidence that the application of ziram is economical for high cash value crops like orchids (Cummings et al. 1990). Similarly, thiram may represent an economical repellent to deter grazing birds on turf and cover vegetation, particularly in specialized applications where damage to the crop is not the only consideration.

Repellent chemicals currently used as human and animal feed flavorings (e.g., anthranilate derivatives, cinnamyl alcohol and benzoate derivatives) will have relatively low registration costs, although such costs would probably exceed those for inert repellents. Because flavorings have not been used as pesticides, it is typically the case that few comparative data on toxicity exist, especially with regard to aquatic species. Nevertheless, there is sufficient data to suggest that methyl anthranilate might be an economical repellent to deter grazing birds (Cummings et al., in press).

Whatever the repellent in question, one strategy to contain registration costs may be to target non-agricultural uses where ecological concerns and residue requirements (vis-a-vis food contamination) are relatively few. Such non-agricultural uses are described below. Further, since registration expenses are affected by the amount of chemical applied in the environment, it is logical that reduced costs will follow from reduced chemical application rates. Reduced application rates may be possible without loss of effectiveness if several substances are combined and applied in 'cocktails'. Synergisms in such mixtures do occur in the laboratory (Mason 1989) using less than otherwise effective concentrations of the ingredients.

There are no clear short-term possibilities for repellents designed to control livestock predation and losses at aquaculture facilities. While it may be possible to develop topical repellents that deter birds under some conditions (e.g., starlings picking at cattle, Bauer 1978), repellents are unlikely solutions to predator attacks (cf. Davies 1988). As for aquaculture, we foresee no short-term possibilities for chemical repellents, although it may be possible to develop repellents that float on the surface of ponds and deter wading and diving birds, without affecting aeration (see conservation uses, below). We predict that the private sector will support short-term repellent research when this support is clearly in their self-interest. Therefore, in our view, experiments on short-term repellent possibilities should be collaborative in nature, with both industrial and government scientists involved. Both groups bring unique capabilities to the research endeavor, and industry has the capital and expertise to bring finished technologies to market.

Repellents—Long-term Possibilities

Extended programs that explore fundamental concepts in avian foraging are likely to yield practical results. Starting points for these long-term studies may be known substances with repellent activity, or the evaluation of biologically active and potentially repellent materials identified through investigation of plant and animal (mainly insect) chemical defenses against birds. Four lines of research appear especially promising. First, basic examination of structure-activity relationships between the chemistry of known irritants and avoidance behavior will lead to the reliable prediction of new sensory repellents (Mason et al. 1991a, 1991b, Clark and Shah 1991a, Clark et al. 1991a, 1991b, Shah et al. 1991). Such studies also may lead to an explanation for the dramatic differences between mammals and birds in their responses to repellents (Mason et al 1991c). Second, basic examination of the physiological effects of repellents that act by causing malaise could lead to the prediction of new repellents. For example, Martinez del Rio and his colleagues (e.g., Martinez del Rio and Stevens 1989) have shown that intestinal membrane disaccharidases constrain the feeding behavior of some passerines (i.e., some birds are unable to consume complex sugars without becoming sick). Perhaps something as simple as the addition of sucrose to livestock feed could effectively and economically reduce depredation and disease hazards that birds present at feedlots. Although recent evidence suggests that sucrose may not function as a repellent in a feeding context (Clark and Mason, ms) Third, selective breeding and genetic engineering of plants might produce crop varieties that are bird tolerant. For example, it might be possible to selectively breed fruits that store energy as one sugar (e.g., sucrose) rather than another (Brugger and Nelms 1991). This approach has been tried with maize (Dolbeer et al. 1988), sorghum (Bullard et al. 1981), sunflower (Dolbeer et al. 1986), 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. 1991). One of these substances, coniferyl alcohol, is the primary precursor of lignin (Lewis and Yamamoto 1990). 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. 1991). Finally, the molecular identity of many plant and insect chemical defenses against insect predators are well described. Some of these materials could be bird repellent as well (Crocker and Perry 1990). For example, cucurbitacins are triterpenoid glycosides that occur in plants belonging to the Cucurbitacae and Cruciferae families (Robinson 1983). These substances both protect plants against attack by herbivorous insects (Metcalf 1985) and are bird repellent (Mason and Turpin 1990). The possibility exists that cucurbitacins could be used as bird-safe insecticides, although we hasten to add that there is no *a priori* reason to assume that natural products are any less likely to be acutely toxic or mutagenic than so-called synthetic chemicals (Ames and Gold 1990).

Because of the long-term nature of these research projects, it is unlikely that industry can be actively and financially involved (i.e., at the outset, there are no clear products for commercialization). Therefore, in our opinion, these investigations are best carried out with public funds by government and university scientists until the point that short-term possibilities for new repellents become clear. It is our belief that the discovery of new, environmentally safe repellents benefits the public, the cause of wildlife preservation, and American agriculture, regardless of the companies or groups that ultimately benefit financially from the sale of finished products.

NON-AGRICULTURAL USES

Needs

Waterfowl are cited as nuisance problems in urban and suburban areas (Cummings, et al. 1991). Grazing geese damage turf (Laycock 1982), and their feces may represent a hazard to public health (Conover and Chasko 1985). In the eastern United States, resident Canada goose flocks contribute significantly to the eutrophication of ponds and streams (Conover and Chasko 1985, Mott and Timbrook 1986). The overall economic impact of waterfowl damage in these settings has not been quantified, but the cost of capturing geese for relocation can exceed $12.00/bird (Thompson 1991). Relocation of captured geese costs even more. Further, one survey of golf courses found that superintendents would pay in excess of $60.00/hectare 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.). If a fraction of these courses experience goose damage, then losses (and the price managers would pay for control) is substantial.

Other species cause nuisance and public health problems by carrying garbage from dumps (Dolbeer et al. 1988b), roosting in urban and suburban areas (Chick et al. 1980, Dolbeer et al. 1988c, Tosh et al. 1970), and causing structural damage (Stemmerman 1988). In Missouri, the annual cost of damage by woodpeckers to electrical transmission poles has been estimated to be as high as $364,000 (Stemmerman 1988). If the average cost of damage were only $250,000 per state, then the national cost of this problem could be as high as $12.5 million per year.

Repellents—Existing Compounds

Currently, naphthalene, mineral oil with dialkyl ammonium bentonite and alkyl benzyl dimethyl ammonium bentonite, and polybutenes are registered for non-agricultural bird control (Timm 1983; Table 2). Generally, the registered purpose of these repellents is the control of birds roosting on or in structures (Timm 1983). However, neither naphthalene nor mineral oil solutions of dialkyl ammonium bentonite and alkyl benzyl dimethyl ammonium bentonite have demonstrated utility as avian repellents (e.g., Clark et al. 1990, Dolbeer et al. 1988a). Undoubtedly, polybutenes have some bird repellent activity under some circumstances, as the number of products containing this substances (80% of commercial roost repellents; Table 2) attest (also, see Fitzwater 1988). Again, however, experimental data in support of this claim are sparse.

At present, there are no repellents registered for the control of geese, for the dispersal of roosting flocks (outside the restricted applications above) or the prevention of structural damage. Although Southwest Research Institute publicized ST-138 as a commercially available woodpecker repellent in 1984, the product was never approved for distribution by the EPA, apparently because the active ingredient (3,5,5-trimethyl-2-cyclohexene-1-one) is one of the most toxic ketones known (S. Tomlinson, pers. commun.).

Repellents—Short-term Possibilities

Some of the materials that we described for agricultural purposes could serve as useful repellents in non-agricultural contexts. These chemicals include food and flavor additives like anthranilate derivatives, and registered agricultural chemicals like thiram. As we stated above, the evidence suggests that these substances could serve as effective and economical repellents on turf [i.e., golf courses, (Cummings et al. 1991)], and methyl anthranilate might serve to deter geese from ponds under certain conditions (e.g., water holes on golf courses). In addition, materials such as methoxyacetophenones, 4-ketobenztriazine, veratryl amine, N-acetyl veratryl amine (Mason et al. 1991, Clark et al. 1991) may prove useful. Registration of these latter substances undoubtedly will be more expensive than registration of anthranilates, or bird repellent fungicides. However, costs might not be excessive as aminoacetophenone, 4-ketobenztriazine, and veratryl amine are already used as synthetic intermediates for food additives, pharmaceuticals, and agricultural chemical coatings.

At present, we foresee no short-term possibilities for the development of new repellents that deter roosting birds, or that prevent birds from causing structural damage. The development of such materials awaits understanding of the basic physicochemistry of avian irritation.

Repellents—Long-term Possibilities

Long-term strategies that we described above under agricultural uses apply here as well.

CONSERVATION USES

Needs

Industrial by-products and mine effluvia are frequently stored in open outdoor impoundments until they can be processed. Although the impoundments meet federal and state regulations for the protection of ground water, they pose serious risks to wildlife (Allen 1990, Kay 1990). Waterfowl, shorebirds, 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. United States sales from the gold/silver mining industry exceeded $3.3 billion in 1989. Because cyanide is used for 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). FMC Gold Company spent $8 million (in netting) at its' Paradise Peak mine to exclude waterfowl; this investment reduced avian mortality from 1,548 in 1986-87 to 88 in 1988-89 (Allen 1990). Similarly, Echo Bay Minerals Co. 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, the results of attempted exclosure obviously do not meet the requirements set forth by the U.S. Fish and Wildlife Service, i.e., zero mortality. The failure to meet these requirements has resulted in substantial fines. Echo Bay Minerals was fined $500,000 for causing the deaths of 900 birds, and McCoy Ore spent $ 250,000 to mitigate the deaths of 21 ducks, 2 hawks, 1 sandpiper and 1 ibis.

Economic figures for the petroleum industry are not readily available, but the problem is no less dramatic. Similarly, agricultural wastewater basins are a hazard to wildlife. Kesterson Reservoir near San Francisco is contaiminated with selenium, and illustrates this point. While acute mortality is low, successful breeding has all but ceased due to bioaccumulation of selenium in eggs (Ohlendorf et al. 1989). The U.S. Fish and Wildlife Service is seeking methods to discourage birds from breeding at contaminated reservoirs. Methods proposed have been as drastic as poisoning the aquatic invertebrate and plant communities in the reservoirs so as to eliminate bird food resources. This strategy, apart from being extreme, is counterproductive. At least some aquatic vegetation types are planted to stabilize pond sites.

A second area of conflict between wildlife and humans that falls under the rubric of conservation arises at airports (Blokpoel 1976). Collisions between birds and aircraft are frequent (DeHaven et al. 1989). In 1989, the economic loss to U.S. military operations caused by bird strikes was estimated to be about $80 million, and civilian losses were estimated to be as high as $100 million (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.

Finally, avian depredation on endangered and protected species poses a significant threat to species preservation and biodiversity (e.g., Vacca and Handel 1988). In particular, corvids take the eggs of waterfowl and ground-nesting game birds (Dimmick and Nicolaus 1990, Parker 1984). Ravens also prey on endangered species such as the California least tern (Belloumini et al. 1988) and the desert tortoise (Woodman and Juarez 1988). Undoubtedly, the economic impact of this predation, per se is small; however, the impact in terms of lost recreational dollars (generated by tourism, sportsmen, etc.) may be substantial.

Repellents—Existing Compounds

No repellent chemicals are registered for any conservation use. The most commonly used strategy to deter birds from ponds and airports are traditional hazing methods. Hazing, although effective at reducing bird numbers, is ineffective at achieving zero mortality, a primary requirement of the Migratory Bird Act (Kay 1990, Jackson 1990). Netting also is used to exclude birds from ponds, but waste water impoundments are frequently large, and physical exclusion is sometimes impractical.

Repellents—Short-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. Already, pen tests have shown that methyl anthranilate can dramatically reduce water use (drinking, swimming) by diverse species of birds [e.g., mallards, herring gulls, starlings (Dolbeer et al. 1991)]. Further, laboratory trials have demonstrated that some of the chemical repellents mentioned above (see: Non-Agricultural Uses, Repellents: short-term possibilities) effectively deter birds from drinking lethal doses of cyanide-laced pond water (Clark and Shah 1991b). The effectiveness of these chemicals might be further enhanced if synergized with a color cue (Lipcius et al. 1980). The major obstacle blocking the practical application of these compounds is the development of delivery systems that (a) preserve the chemical integrity of repellents in the hostile environments that wastewater presents (Clark and Shah, ms), and (b) assure that chemical is concentrated in ways that maximize the likelihood of contact with target birds (e.g., on the surface of ponds).

Regarding predation on endangered and protected species, several investigators have suggested the use of conditioned food avoidance methods as deterrents (e.g., Dimmick and Nicolaus 1990, Nicolaus et al. 1983). These techniques may be relatively simple to register, as exceedingly small quantities of relatively harmless materials are put into the environment at restricted baiting locations. However, it remains unclear whether conditioned food avoidance actually reduces damage in field settings as it appears to do in the laboratory (Sheaffer and Drobney 1986).

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 vertebrate classes in their responsiveness to chemosensory stimuli (Szolcsanyi et al. 1986, Mason and Otis 1990). Long-term strategies that we described for agricultural and non-agricultural uses should apply to the present context as well.

DECISION-MAKING CRITERIA

No matter the use or the repellent under consideration, we consider industrial participation to be essential for the development and commercialization of new bird repellent chemicals. We view the role of government scientists as that of performing basic laboratory and field research needed to identify candidate repellents. Also, government scientists can identify potential uses for new materials, and can quantify the economic damage that birds cause in various situations. However, in our opinion, only the private sector has the financial and legal resources, the experience with various complex bureaucracies, and the persistence necessary to successfully commercialize new repellent technologies for a variety of applications. To actively involve industry in the realization of new repellents, it will be necessary to assist them in evaluating whether particular applications are worth the investment. In this last section of our paper, we present a basic schemata that might serve to assist industry in this purpose.

The path from discovery to product availability can be thought of as a filtering process (Fig. 3). Each step along the filtering process places constraints on product development. Thus, if the initial number of candidate repellents are few, then the likelihood of any compound passing through all the filters is small. Specifically, the historical means of discovery of candidate repellents has been serendipitous. Such chance discovery without any regard to the constraints imposed upon development by manufacturing, market, registration, technical and distribution considerations has severely limited the number of economically viable and environmentally safe repellents (Tables 1 & 2).

Recently, we have developed a structure-activity model for sensory bird repellents (Clark and Shah 1991, Clark et al. 1991, Mason et al. 1991a, 1991b, Shah et al 1991). While this model is by no means a definitive predictor of avian repellents, it does have good power for certain classes of compounds. Briefly, bird repellents are those compounds with the

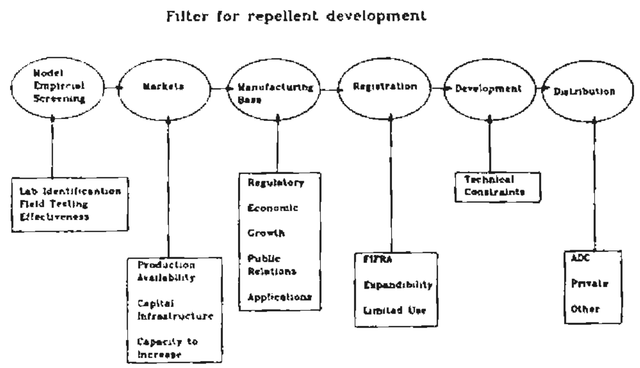

Figure 3. A heuristic model for factors affecting the discovery and development of a repellent strategy.

following attributes:

1. A phenyl ring with an electron donating or basic group is critical;
2. An electron withdrawing group in resonance with a basic group decreases the repellency (as well as the toxicity) of a substance. These effects are pronounced when the groups are ortho to one another;
3. The presence of an acidic group decreases repellency;
4. The presence of an H-bonded ring or a covalently bonded fused ring that possess the required features (e.g., electron donating and withdrawing groups ortho to each other) can enhance repellency, but is not essential;
5. Steric hindrance can overpower the features described above, and can weaken the effectiveness of potentially aversive substances.

With the avian repellent model we can now identify large lists of candidate repellents. A second step in the process is to identify the manufacturing base for the candidate repellents. Some compounds may only be manufactured on a small scale, and even if the compound were a potent avian repellent the markets might be too small to justify large capital outlays to increase production capacity. Thus, a good candidate repellent will already be manufactured in reasonably large quantities by one or more manufacturers and there should be sufficient capacity in manufacturing infrastructure to meet projected market demands. Thus researchers should be able to track down manufacturers and obtain information on production capacity for candidate repellents.

A third step in the development process requires some evaluation of the market for a candidate repellent. From an economic standpoint estimates of market values of commodities (e.g., Figs. 4, 5) as well as projections of losses for those commodities (Table 4, Fig. 1) are useful in determining the potential market size. Additionally, estimates of the marginal increase in production if a repellent were used, and its effect on market value, would be useful to the private sector in evaluating whether the candidate repellent should be developed. An evaluation of non-agricultural markets should also be made. In some cases the total market size may not actually provide sufficient incentive for private investment because the profit margin for a given commodity may be sufficiently small so as to preclude the costs of repellents. In this case repellent developers may wish to focus on regional commodities where the value of the crops is highest and presumably there is a greater willingness and ability for consumers to afford the commercial price of repellent protection (Fig. 6).

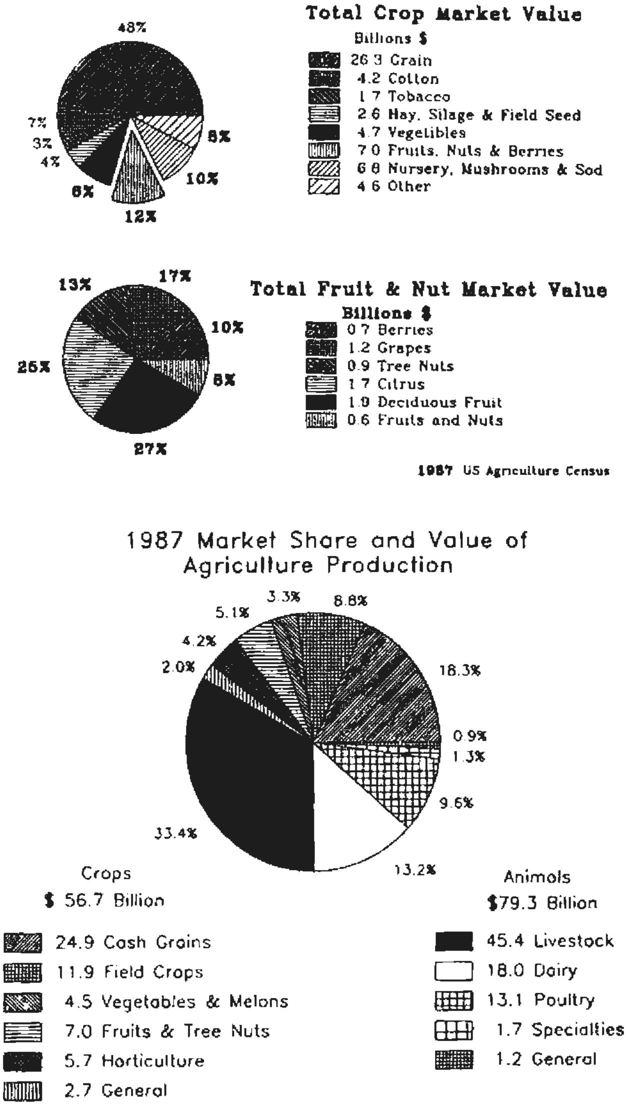

Figure 4. Top: The total market value and relative market share of agricultural commodities for the U.S. (top). Market value for crops is $56.7 billion annually, while that for animals is $79.3 billion. Percentages are given by the figure while commodity value is given in the legend. Middle: The market share and value of crops by industrial classification. Bottom: The total market share and market value for fruits and nuts. Data are derived from the 1987 Census of Agriculture.

Increasingly, there is a need to develop nonlethal repellents for wildlife conservation and urban animal damage control. In some cases seeking registration for these restricted uses may allow the private sector to realize a more rapid return on its investment. Once limited registrations are obtained, expansion into agricultural markets, where profit margins are usually slimmer may be more attractive. Additionally, in some cases repellents may be required due to regulatory considerations. These markets may even prove to be a source of development capital. Motivation of this type of market is most likely high because penalties may apply to operators, e.g. protection of wildlife from tailings pond water at mining operations. Finally, development of a candidate repellent may stand a better chance if there is some exclu-

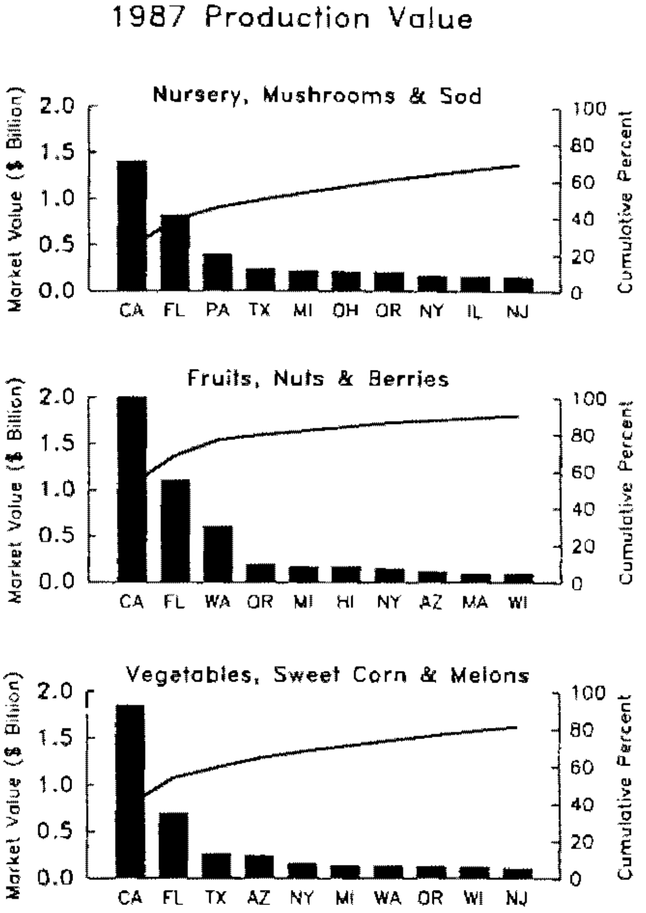

Figure 5. Top: Ranking of the top 10 states for production of horticulture, sod and mushrooms. Middle: Ranking of the top 10 states for production of fruits, nuts and berries. Bottom: Ranking of the top 10 states for production of vegetables. Data based upon the 1987 Census of Agriculture.

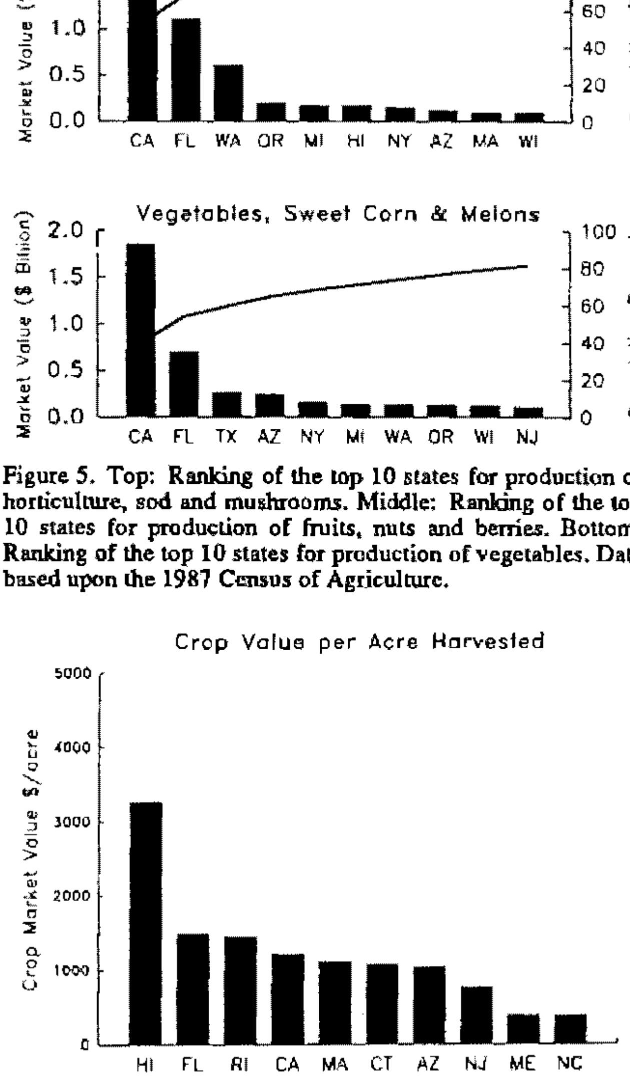

Figure 6. Ranking of the top 10 states for market value per unit acre harvested.

sivity, either in patent protection or registration for the developer.

A fourth filtering step is the likelihood of obtaining specified registration for the candidate repellent. Registration can cost between $2-4 million. Some of these costs can be eliminated by selecting candidate repellents that either have proven safety to humans and/or the environment. This selection can be done at the initial stages of development because the model allows some reasonable assurance of effectiveness.

Once a suite of candidate repellents has been winnowed by the above considerations further laboratory and field testing can occur to validate effectiveness. Thus, the limited research dollars available for discovery and development can be optimized towards those candidate repellents that have reasonable chances of commercial development. The costs for steps 1–4 are minimal when compared to the potential costs of empircally conducting lab and field trials for repellent effectivenss for a large suite of candidate repellents. It is during this active research phase that technical constraints on delivery technology specific to the application can be addressed.

The last step in the development process is to settle upon the distribution system. Optimally, the repellent should not be an entirely restricted substance, i.e. available only to governmental operations. Such repellents ultimately do not have large markets and therefore the private sector would not have an incentive for product development. The nature of the repellent should be amenable to multiple use with restrictions placed on apllication set by environmental concerns.

We conclude by suggesting that the approach towards chemical repellent discovery and development outlined here does not only apply to chemical repellents. The strategy can be applied equally well with other repellent strategies, i.e. hazing.

ACKNOWLEDGEMENTS

We thank M. L. Avery, J. L. Cummings, R. A. Dolbeer, J. G. Glahn, G. M. Linz, D. F. Mott, D. L. Otis, and P. P. Woronecki for comments and additions to earlier manuscript drafts. Research for and preparation of the manuscript was supported by U.S.D.A. cooperative agreement # 12-34-41-0040 (CA) between the Denver Wildlife Research Center and the Monell Chemical Senses Center.

LITERATURE CITED

ALEXANDER, D. J., W. H. ALLEN, and G. PARSONS. 1979. Characterisation of influenza isolated from turkeys in Great Britian during 1963-1977. Res. Vet. Sci. 26:17-20.

ALLEN, C. 1990. Mitigating impacts to wildlife at FMC Gold Company's Paradise Peak Mine. in R. McQuivey, ed. Proc. Nevada Wildl. Mining Workshop. Nevada Mining Assoc., Nevada Dept. Minerals and Nevada Dept. Wildl. pp. 67-71.

AMES, B. N., and L. S. GOLD. 1990. Science article about risk.

ANDREWS, D. A., and L. E. HENZE. 1985. Blackbird depredation on field corn - 1985. unpubl. rep. 10pp.

ANDREWS, K. J., and D. F. MOTT. 1990. An evaluation of perimeter netting to reduce wading bird predation at catfish raising facilities. Denver Wildlife Research Center Bird Section Research Report No. 456. 12pp.

ANONYMOUS. 1991. Disease losses high. The Catfish J. 5(7):2

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.

———, D. G. DECKER, and M. O. WAY. 1989a. Field evaluation of a nontoxic clay coating for reducing bird damage to newly planted rice. Denver Wildlife Research Center Bird Section Research Report No. 444. 9pp.

———, C. O. NELMS, and J. R. MASON. 1989b. Preliminary evaluation of a granular trimethacarb formulation for deterring grazing by American coots. Denver Wildlife Research Center Bird Section Research Report No. 445. 11pp.

———, J. W. NELSON, and M. A. CONE. 1991. Survey of bird damage to blueberries in North America - 1989. Denver Wildlife Research Center Birs Section Research Report No. 468. 21pp.

BAUER, M. S. 1978. Warble-infested cattle attacked by starlings. Mod. Vet. Prac. 59:536-538.

BELLUOMINI, L. A., K. KEANE, D. STATLANDER, J. TUTTON, and C. COLLINS. 1988. The status of the California least tern at Camp Pendleton, California in 1988. Natural Resources Management Branch, Western Division Naval Facilities Engineering Command, San Bruno, California, 40pp.

BERKHOUDT, H. 1985. Structure and function of avian taste receptors. pp. 463-495, in A. S. King and J. McLelland, eds., Form and Function in Birds. Academic Press, New York.

BESSER, J. F. 1978. Birds and sunflower. pp. 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., Publishers, Madison, Wis.

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. Canad. Wildl. Serv., Ottawa, Canada. 236pp.

———, and G. D. TESSIER. 1984. Overhead wires and monofilament lines exclude ring-billed gulls from public places. Wildl. Soc. Bull. 12:55-58.

BLUS, L. J., C. J. HENNEY, D. J. LENHART, and T. E. KAISER. 1984. Effects of heptachlor- and lindane-treated seed on Canada geese. J. Wildl. Manage. 48:1097-1111.

BRUGGER, K.E., and C.O. NELMS. 1991. Sucrose avoidance by American robins (*Turdus migratorius*): implications to control of bird damage in fruit crops. Crop Protection (in press).

BULLARD, R.W., J. O. YORK, and S. R. KILBURN. 1981. Polyphenolic changes in ripening bird-resistant sorghums. J. Agr. Food Chem. 29:973-981.

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.

CASTRALE, J. S. 1987. Pesticide use in no-till row-crop fields relative to wildlife. Indiana 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, JR. 1980. Blackbird roosts and histoplasmosis: An increasing medical problem? Chest 77:584-585.

CLARK, L. Odor detection thresholds in tree swallows and cedar waxwings. Auk 108:177-180.

———, and J. R. MASON. 1989. Sensitivity of brown-headed cowbirds to volatiles. Condor 91:922-932.

———, and C. A. SMERASKI. 1990. Seasonal shifts in odor acuity by starlings. J. Exp. Zool. 255:22-29.

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

———, and P.S. SHAH. 1991b. Chemical bird repellents: applicability for deterring use of waste water. pp. 157-164. in R.D. Comer (ed.) Proceedings V: Issues and technology in the management of impacted Wildlife. Thorne Ecological Institute, Snowmass, CO.

———, and P.S. SHAH. ms. Chemical bird repellents: possible use in cyanide ponds associated with mining operations.

———, P.S. SHAH and J.R. MASON. 1991. Chemical repellency in birds: relationship between chemical structure and avoidance response. J. Exp. Zool. 260:310-322.

———, J. R. MASON, P. S. SHAH, and R. A. DOLBEER. 1991. Bird repellents: Water additive, waste water additive, edible additive, and methods for using same. U. S. Patent Application No. 679432

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

COBIA, D. W. 1978. Production costs and marketing. pp. 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., Publishers, Madison, Wis.

COLLINS, F. W. 1986. Oat phenolics: structure, occurence, and function. pp. 227-295 in F. H. Webster, ed. Oat Chemistry and Technology. American Association of Cereal Chemists, St. Paul, Minn.

CONOVER, M. R. 1985. Using conditioned food aversions to protect blueberries from birds: comparison of two carbamate repellents. Appl. Anim. Behav. Sci. 13:383-386.

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

CRASS, 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, 18pp.

CRAVEN, S. R., and E. LEV. 1987. Double-crested cormorants in the Apostle Islands, Wisconsin, USA: Population trends, food habits and fishery depredations. Colonial Waterbirds. 10:64-71.

CROCKER, D. R. and S. M. PERRY. 1990. Plant chemistry and bird repellents. Ibis 132:300-308.

CROSSON, W. F. 1982. Conservation tillage and conventional tillage: a comparative assessment. EPA Report No. 600/3-82-027. U.S. Environ. Protect. Agency, Washington, D.C. 72pp.

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. Verte. Pest Conf. 12:286-291.

———, J. R. MASON, D. L. OTIS, and J. E. DAVIS. 1990. Evaluation of methiocarb, zinc dimethyldithiocarbamate, and methyl anthranilate for reducing bird damage to dendrobium orchids. Interim Report to the State of Hawaii Governer's Agriculture Coordinating Committee and the Hawaii Farm Bureau Federation. 22pp.

———, J. R. MASON, D. L. OTIS, and J. F. HEISTERBERG. 1991. Evaluation of methyl anthranilate as a Canada goose repellent on grass. J. Wildl. Manage. in press.

DANEKE, D. E., and D. G. DECKER. 1988. Prolonged seed handling time deters red-winged blackbirds feeding on rice seed. Denver Wildlife Research Center Research Report 405, 15pp.

DAVIES, R. 1988. Problem eagles and conservation solutions. Gabar 3:60-66.

DAY, A. D., and W. C. ROYALL, JR. 1961. Thiram as a bird repellent on wheat seed crops. Annual Wheat Newsletter 8:29.

DEHAVEN, R. W., P. P. WORONECKI, L. W. LEFEBVRE, P. W. LEFEBVRE, R. L. HOTHEM, and J. L. GUARINO. 1989. Bird hazards at airports: Standardized assessment techniques. Denver Wildlife Research Center Bird Section Research Report No. 439, 211pp.

DIMMICK, C. R., and L. K. NICOLAUS. 1990. Efficiency of conditioned aversion in reducing depredation by crows. J. Appl. Ecol. 27:200-209.

DOLBEER, R. A. 1980. Blackbirds and corn in Ohio. U.S. Fish and Wildlife Res. Publ. 136, 18pp.

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

———, M. L. AVERY, and M. E. TOBIN. 1988. Assessment of field hazards to birds and mammals from methiocarb applications to fruit crops. Denver Wildlife Research Center Bird Section Research Report No. 421. 42pp.

———, L. CLARK, P. P. WORONECKI, and T. W. SEAMANS. 1991. Pen tests of methyl anthranilate as a bird repellent in water. Denver Wildlife Research Center Bird Section Research Report No. 467 11pp.

———, M. A. LINK, and P. P. WORONECKI. 1988a. Naphthalene shows no repellency for starlings. Wildl. Soc. Bull. 16:62-64.

———, A. R. STICKLEY, JR., and P. P. WORONECKI. 1978. Starling, *Sturnus vulgaris*, damage to sprouting wheat in Tennessee and Kentucky, U.S.A.. Prot. Ecol. 1:159-169.

———, P. P. WORONECKI, E. C. CLEARY, and E. B. BUTLER. 1988b. Site evaluation of gull exclusion device at Fresh Kill Landfill, Staten Island, New York. Denver Wildlife Research Center Bird Section Research Report No. 411, 10pp.

———, P. P. WORONECKI, T. W. SEAMANS, B. N. BUCKINGHAM, and E. C. CLEARY. 1988c. Herring gull nesting on Sandusky Bay, Lake Erie, 1988. Denver Wildlife Research Center, Bird Section Research Report No. 427, 8pp.

———, P. P. WORONECKI, and R. A. STEHN. 1982. Effects of husk and ear characteristics on resistance of maize to blackbird (*Agelaius phoeniceus*) damage in Ohio, USA. Protection Ecol. 4:127-139.

———, P. P. WORONECKI, R. A. STEHN, G. J. FOX, J. J. HANZEL, and G. M. LINZ. 1986. Field trials of sunflower resistant to bird depredation. North Dakota Farm Res. 43:21-24, 28.

ESCHEN, M. L., and E. W. SCHAFER, JR. 1986. Registered bird damage chemical controls—1985. Denver Wildlife Research Center Bird Damage Research Report No. 356. 16pp.

FEARE, C. J. 1975. Cost of starling damage to an intensive husbandry unit. Proc. Br. Insecticide and Fungicide Conf. 8:253-259.

———. 1979. The economics of starling damage. Pp. 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. of Damage 2:39-54.

FITZWATER, W. D. 1988. Solutions to urban bird problems. Proc. Verte. Pest Conf. 13:254-259.

GLAHN, J. F. XXXX. Blackbird and starling depredations at Tennessee livestock farms. XXXX

———, J. R. MASON and D. R. WOODS. 1989. Effects of dimethyl anthranilate as a bird repellent livestock feed additive. Wildl. Soc. Bull. 17:313-320.

GOUGH, P. H. and J. W. BEYER. 1982. Bird-vectored disease. Proc. Great Plains Wildl. Dam. Cont. Workshop 6:260-272.

GREIG-SMITH, P. W. 1987. Hazards to wildlife from pesticide seed treatments. BCPC Monograph 39: Application to seeds and soil. pp. 127-134.

———. 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. WILSON. 1983. Bud-eating by bullfinches, *Pyrrhula pyrrhula*, in relation to the chemical constituents of two pear cultivars. Ann. Appl. Biol. 103:335-343.

GUARINO, J. L. 1972. Methiocarb, a chemical bird repellent: a review of its effectiveness on crops. Proc. Verte. Pest Conf. 5:108-111.

———, W. F. SHAKE, and E. W. SCHAFER, JR. 1974. Reducing bird damage to ripening cherries with methiocarb. J. Wildl. Manage. 38:338-342.

HENNE, D. R., W. D. PFEIFER, and J. R. BESSER. 1979. Bird damage to sunflower in North Dakota in 1978. pp. 16-17, in D. Lilliboe, ed. Proc. Third Sunflower Forum, Fargo, North Dakota, National Sunflower Association, Fargo, North Dakota.

HOBBS, J., and F. G. LEON III. 1988. Great-tailed grackle predation on south Texas citrus (identifying a unique problem). pp. 143-148 in N. R. Holler, ed. Proc. Third Eastern Wildl. Damage Control Conf., Gulf Shores, Alabama.

HOBSON, R., and J. GEUDER. 1976. Tennessee blackbird damage survey, October 1976. Tennessee Crop Reporting Service, Nashville, Tenn. 3pp.

HOTHEM, R. L., D. F. MOTT, R. W. DEHAVEN, and J. L. GUARINO. 1981. Mesurol as a bird repellent on wine grapes in Oregon and California. Am. J. Enology Viticulture 32:150-154.

INGLIS, I. R., R. J. P. THEARLE, and A. J. ISAACSON. 1989. Woodpigeon (*Columba palumbus*) damage to oilseed rape. Crop Protection 8:209-309.

JACKSON, W. B. 1990. Bird repelling techniques. Proc. Nevada Wildlife/Mining Workshop, Nevada Mining Association, Nevada Department of Minerals, Nevada Department of Wildlife. pp.46-50.

JAKUBAS, W. J., P. S. SHAH, J. R. MASON, and D. NORMAN. 1991. Avian repellency of coniferyl and cinnamyl derivatives. U. S. Patent Application No. XXXXXX.

KAY, F. R. 1990. Nevada Department of Wildlife's role: past, present, future. in Proc. Nevada Wildl. Mining Workshop. R. McQuivey, ed. Nevada Mining Assoc., Nevada Dept. Minerals and Nevada Dept. Wildl. pp.

KEFFORD, N. P., K. W. LEONHARDT, T. TANAKA, and K. G. ROHRBACH. 1987. Orchid Industry Analysis. College of Tropical Agriculture and Human Resources. University of Hawaii, Report No. 3, 9pp.

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

LEWIS, N. G., and E. YAMAMOTO. 1990. Lignin: occurrence, biogenesis and biodegradation. Ann. Rev. Plant Physiol. Plant Mol. Biol. 41:455-496.

LIPCIUS, R. N., C. A. COYNE, B. A. FAIRBANKS, D. H. HAMMOND, P. J. MOHAN, D. J. NIXON, J. J. STASKIEWICZ, and F. N. HEPPNER. 1980. Avoidance response of mallards to colored and black water. J. Wildl. Manage. 44:511-518.

LIPKIND, M. A., J. WEISMAN, E. SHIHMANTER, D. SHOHMAN, A. DOUGLAS, and J. J. SKEHEL. 1979. Characteristics of avian influenza viruses isolated in Israel in 1978 and 1979. Symp. Int. Grippes Animales et Humaines. 10pp.

MARTINEZ 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. 1989. Avoidance of methiocarb-poisoned apples by red-winged blackbirds. J. Wildl. Manage. 53:836-840.

———, M. A. ADAMS, and L. CLARK. 1989. Anthranilate repellency to starlings: Chemical correlates and sensory perception. J. Wildl. Manage. 53:55-64.

———, and L. CLARK. 1990. Evaluation of Blockout (Northwest Chemicals, Inc.) and its chemical components as avian contact repellents. Denver Wildlife Research Center Bird Damage Research Report No. 457. 10pp.

———, L. CLARK, and P.S. SHAH. 1991. Ortho-aminoacetophenone repellency to birds: perceptual and chemical similiarities 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*). in B. G. Green, J. R. Mason, and M. R. Kare, eds. Chemical Senses: Volume 2, Irritation, Marcel Dekker, Inc.,New York, pp. 309-324.

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

———, N.J. BEAN, P.S. SHAH and L. CLARK. 1991. Taxon-specific differences in reponsiveness to capsaicin and several analogues: correlates between chemical structure and behavioral aversiveness. J. Chem. Ecol. 17:2539-2551.

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. in Wading Birds, J. C. Ogden and S. Winckler, eds. Research Report No. 7, National Audubon Society. pp. 131-132.

———, K. J. ANDREWS, and G. A. LITTAUER. 1990. The effect of cormorant roost dispersal on numbers of cormorants at nearby catfish ponds. Denver Wildlife Research Center Bird Section Research Report No. 462.

———, J. F. BESSER, R. R. WEST, and J. W. DEGRAZIO. 1972. Bird damage to peanuts and methods for alleviating the problem. Proc. Verte. Pest Conf. 5:118-120.

———, and C. P. STONE. 1973. Bird damage to blueberries in the United States. Unpubl. Tech. Rep. 8, Work Unit DF-102.3, Denver Wildlife Research Center, 18pp.

———, and S. K. TIMBROOK. 1986. Alleviating nuisance Canada goose problems with acoustical stimuli. Denver Wildlife Research Center Bird Damage Research Report No. 380, 13pp.

NICOLAUS, L. K., J. F. CASSEL, R. CARLSON, and C. GUSTAVSON. 1983. Taste aversion conditioning of crows to control predation on eggs. Science 220:212-214.

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.

PARKER, H. 1984. Effect of corvid removal on reproduction of willow ptarmigan and black grouse. J. Wildl. Manage. 48:1197-1205.

PARKHURST, J. A., and R. P. BROOKS. 1988. American kestrels eat trout fingerlings. J. Field Ornithol. 59:286-287.

PHILLIPS, R. L., and F. S. BLOM. 1988. Distribution and management of eagle/livestock conflicts in the western United States. Proc. Verte. Pest Conf. 13:241-244.

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. pp. 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., Publishers, Madison, Wis.

RAPPOLE, J. H., A. R. TIPTON, A. H. KANE, R. H. FLORES, J. HOBBS, and J. PALACIOS. 1989. Seasonal effects on control methods for the great-tailed grackle. Proc. Ninth Great Plains Wildl. Dam. Cont. Workshop, Fort Collins, Co.

REIDINGER, R. F., JR., and J. R. MASON. 1983. Exploitable characteristics of neophobia and food aversions for improvements in rodent and bird control. pp. 20-39. in D. E. Kaukeinen, ed. Vertebrate Pest Control and Management Materials: Fourth Symposium, American Society for Testing and Materials, Philadelphia, Penn.

ROBINSON, T. 1983. The organic constituents of higher plants. Cordus Press, Amherst, Mass. 353pp.

ROGERS, J. G. 1978. Repellents to protect crops from vertebrate pests: Some considerations for their use and development. pp. 150-165 in R. W. Bullard, ed. Flavor Chemistry of Animal Foods. American Chemical Society Symposium Series No. 67, American Chemical Society, Washington, D.C.

———. 1980. Conditioned taste aversion: its role in bird damage control. in E. N. Wright, I. R. Inglis, and C. J. Feare, eds. Bird Problems in Agriculture, British Crop Protection Council, Croydon U.K. pp. 173-179.

SCHAFER, E. W., JR., W. A. BOWLES, JR., 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.

———, and R. B. BRUNTON. 1971. Chemicals as bird repellents: two promising agents. J. Wildl. Manage. 35:569-572.

SCHROEDER, M. L. 1990. The netting of cyanide ponds at Copperstone Gold. in Proc. Nevada Wildl. Mining Workshop. R. McQuivey, ed. Nevada Mining Assoc., Nevada Dept. Minerals and Nevada Depart. Wildl. pp. 72-81.

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. Pest. Biochem. Physiol. 40:169-175.

SHEAFFER, S. E. and R. D. DROBNEY. 1986. Effectivenes of lithium chloride induced taste aversions in reducing waterfowl nest predation. Trans. Missouri Acad. Sci. 20:59-63.

SHIROTA, Y., M. SANADA and S. MASAKI. 1983. Eyespotted balloons as a device to scare gray starlings. Appl. Ent. Zool. 18:545-549.

STEMMERMAN, L. A. 1988. Observation of woodpecker damage to electrical distribution line poles in Missouri. Proc. Verte. Pest Conf. 13:260-265

STEVENS, J., and A. F. DEBONT. 1980. Choice by starlings (*Sturnus v. vulgaris L.*) among different cherry cultivars. Agricultura 28:421-436.

STICKLEY, A. R., JR., XXXX. Extended use of starlicide in reducing bird damage in southeastern feedlots. XXXX.

———, and K. J. ANDREWS. 1989. Survey of Mississippi catfish farmers on means, effort, and costs to repel fish-eating birds from ponds. Proc. Eastern Wildl. Damage Cont. Conf. 4:105-108.

———, and C. R. INGRAM. XXXX. Two tests of the avian repellent, methiocarb, in Michigan sweet cherry orchards. XXXX

———, 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. pp. 169-177. in Vertebrate Pest Control and Management Materials. ASTM STP 680, Philadelphia, Pa. 323pp.

STONE, C. P., W. F. SHAKE, and D. J. LANGOWSKI. 1974. Reducing bird damage to highbush blueberries with a carbamate repellent. Wildl. Soc. Bull. 2:135-139.

SUMMERS, R. W. 1990. The effect on winter wheat of grazing by brent geese. J. Appl. Ecol. 27:821-833.

———, and C. N. R. CRITCHLEY. 1990. Use of grassland and field selection by brent geese. J. Appl. Ecol. 27:834-846.

SZOLCSANYI, J., H. SANN, and F-K. PIERAU. 1986. Nociception in pigeons is not impaired by capsaicin. Pain 27:247-260.

THOMPSON, G. 1991. Canada geese: waterfowl or just plain foul. Annual Mtng. Gol Course Superintendents, Reno, Nevada.

TIMM, R. M. 1983. Prevention and control of wildlife damage. University of Nebraska Press, Lincoln, Ne. (pages G27-G28).

TOBIN, M. E., R. A. DOLBEER, and C. M. WEBSTER. 1989. Alternate-row treatment with the repellent methiocarb to protect cherry orchards from birds. Crop Prot. 8:461-465.

———, R. A. DOLBEER, and P. P. WORONECKI. 1989. Bird damage to apples in the Mid-Hudson Valley of New York. Hort. Sci. 24:859-863.

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.

TYLER, M. J., and L. W. KANNENBERG. 1980. Blackbird damage to ripening field corn in Ontario. Canad. J. Zool. 58:469-472.

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, D.C.

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.

WILSON, E. A. 1985. Blackbird depredation on rice in southwestern Louisiana. M. S. Thesis, Louisiana State University, Baton Rouge, La. 91pp.

WINDHOLZ, M., S. BUDAVARI, R. F. BLUMETTI, and E. S. OTTERBEIN. 1983. The Merck Index, 10th edition, Merck and Co., Rahway, N.J.

WOODMAN, A. P., and S. M. JUAREZ. 1988. Juvenile desert tortoises utilized as primary prey of nesting common ravens near Kramer, California. Paper presented at the 13th annual meeting and symposium of the Desert Tortoise Council, March 26-27, Laughlin, Nevada.

WORONECKI, P. P., R. A. STEHN, and R. A. DOLBEER. 1980. Compensatory response of maturing corn kernels following simulated damage by birds. J. Appl. Ecology 17:737-746.

WYWIALOWSKI, A.P., and R.H. BEACH. 1991. Agrigultural Producers' estimates of wildlife causing damage in the eastern United States. Proceedings of the Fifth Eastern Wild. Damage. Conf. (in press).