CALIFORNIA CAGED LAYER PEST MANAGEMENT EVALUATION[1]

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Primary Audience: Regulators, Legislators, Egg Producers, Researchers

SUMMARY

California caged-layer poultry producers were surveyed regarding current pest management practices for insects, mites, weeds, pathogens, rodents, and other vertebrate pests. In order of perceived importance, producers identified house flies, *Fannia* flies (little house flies), northern fowl mites, and mice as the most significant pests. Less serious pests included ground squirrels, rats, wild birds, darkling beetles, weeds, and pathogens; typically these pests were not present in high numbers or were considered easy to control. While biological, mechanical, and cultural controls are regularly employed in most pest suppression systems, pesticides are still considered an important component of virtually all poultry pest management programs.

Key words: Flies, insect control, insecticides, pesticides, pests, rodents, weeds
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DESCRIPTION OF PROBLEM

The Food Quality Protection Act and other regulatory initiatives have pointed up the dearth of information available on current pest management practices employed in animal agriculture. In an effort to address this lack, the California Pest Management Alliance for the Egg Industry (composed of egg producers, allied industries, regulatory agencies, and California Cooperative Extension) developed an assessment plan to survey producers regarding pests and suppression strategies.

One of the major animal agriculture commodities in California is the egg industry. There are over 26 million caged laying hens in California, down from 30 million less than a decade ago [1], with approximately equal numbers in southern California (primarily Riverside, San Diego, and San Bernardino counties) and northern California.

The major arthropod pests of caged layers are house flies (*Musca domestica*), little house

[1] The statements and conclusions in this report are those of the authors and not necessarily those of the California Department of Pesticide Regulation or the Pacific Egg and Poultry Association. Mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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flies (*Fannia* spp.), northern fowl mites (*Ornithonyssus sylviarum*), and the darkling beetle or lesser mealworm (*Alphitobius diaperinus*). There is a noticeable dichotomy in perception of pest significance between northern and southern California poultry ranches.

Flies are the most significant pest group on California caged layer operations. Both *Musca domestica* and *Fannia* species are considered major pests due to their public nuisance impact and vectorial capabilities. *Musca* are considered both nuisance pests and potential public health threats. In addition, their fecal and regurgitant materials cause egg spotting, which necessitates additional egg cleaning and may cause undervaluing of affected eggs. *Fannia* are a problem for the neighborhood because they migrate away from the ranch.

Northern fowl mites (*Ornithonyssus sylviarum*) have been shown to have only minor impact on the birds, somewhat depressing egg production at high population levels [2]. As birds age, they develop immunity, which enables the birds themselves to keep mite numbers at tolerable levels [3]. The main problem with northern fowl mites is the irritation they cause to egg collectors, who often refuse to work under mite infestation conditions.

The major vertebrate pests on poultry ranches are mice (*Mus musculus*), ground squirrels (*Spermophilus beecheyi*), wild birds, and rats (*Rattus norvegicus* and *Rattus rattus*). Recent demonstration of *Salmonella* associated with mice has raised visibility and concern about mice in and around poultry ranches. In addition to heightened awareness of the significance of mice due to the California Egg Quality Assurance Program, recent discovery and isolation of *Salmonella enteritidis* phage type 4 from 12.5% of mice sampled on southern California poultry ranches [4] has made poultry producers particularly sensitive to mouse activity on their ranches. Ground squirrels are destructive to property, burrowing under buildings and undermining structures. In addition, these squirrels harbor fleas capable of transmitting plague bacteria, and are thus a public health threat as well. Wild birds introduce various disease organisms and ectoparasites into commercial flocks. Passerine birds can serve as reservoirs of numerous avian parasites and pathogens. Both lice and northern fowl mites are maintained on wild birds and transmitted to caged flocks when feral birds are permitted entry to the houses. The Norway rat (*Rattus norvegicus*) and the black rat (*Rattus rattus*) are destructive animal pests found around poultry ranches. These rodents eat and contaminate large amounts of feed, damage structures by their gnawing and burrowing, and may spread diseases that affect poultry and people. Not only do they affect flock health and performance, damage due to their feeding, gnawing, and burrowing can have economic and safety consequences.

Materials and Methods

A one-page survey instrument (Figure 1) was developed and faxed to California caged layer operators, accompanied by a cover letter describing the Pest Management Alliance and the study's purposes. Respondents were given the options of faxing or mailing the completed questionnaire back. A telephone follow-up for each producer was also part of the survey procedure. Because production practices, climate, and other factors vary between the two regions, the survey was designed to assess regional effects, as well as to describe the industry statewide.

The five major pest groups of interest included arthropods, rodents, wild birds, weeds, and pathogens. In addition to defining the major pests, as identified by the producers, the survey also attempted to determine pest management strategies being employed against them. Efforts were made to quantify time, effort, cost, and ancillary impact of the various control components.

Results and Discussion

ARTHROPOD PESTS

Survey results are based on responses from about 90 farms representing over half California's caged laying hens. In order of perceived importance, producers identified house flies, *Fannia* flies (little house flies), northern fowl mites, and mice as the most significant pests, statewide (Table 1). Less serious pests included ground squirrels, rats, wild birds, darkling beetles, and weeds; typically these pests were not present in high numbers or were considered easy to control.

California Pest Management Alliance for the Egg Industry
Pesticide Use Survey

The results from this survey will help this industry understand their pesticide usage and the potential economic impact that the Food Quality Protection Act may have on the poultry industry if certain compounds become unavailable. Your personal responses will be kept confidential and added to the overall summary and report which will be published in the PePa newsletter.

#	Question	Response
1	Which pests are the most difficult to control on your farm: (1 = most difficult, 10 = least difficult)?	_____Darkling Beetles _____House Flies _____Fowl Mites _____Fannia _____Pathogens _____Mice _____Squirrels _____Rats _____Wild birds _____Weeds _____Others(write in)_____
2	Please list the pests, in order of their importance, which cause the most economic loss to you. (Consider all factors including bird quality, building damage, disease transmission, public nuisance complaints, etc.)	
3	What insecticide sprays and baits do you use for FLIES?	
4	How many times per year do you treat for flies?	
5	What other methods do you use for reducing flies?	Fly bottles Fly tape Fly parasites Electric zappers Other_____
6	How much do you spend on fly control?	
7	How much do you spend on mite/louse control?	
8	What RODENTICIDES do you use?	
9	How often do you bait per year?	
10	What other methods do you use for reducing/eliminating rodents?	Weed control Live traps Shotgun Other_____
11	How much do you spend on rodent control each year?	
12	What HERBICIDES do you use?	
13	When do you apply herbicides?	
14	What other methods do you use for eliminating weeds?	Tillage Mowing Other_____
15	How much do you spend on herbicides?	
16	What DISINFECTANTS/SANITIZERS do you use for cleaning the houses?	
17	How many times per year do you treat?	
18	How much do you spend on disinfectants?	
19	What do you use for reducing/eliminating WILD BIRDS on your farm?	Bird balls Bird netting Live traps Other_____
20	How many farms and buildings are you responsible for treating?	_____Farms _____Buildings
21	How do you make your decisions to treat for pests?	Monitor Spray on a schedule Personal discomfort Animal discomfort Neighbor complaints Other_____
22	What is your most serious concern about controlling the pests on your farm?	

FIGURE 1. Questionnaire faxed to California poultry producers for the California Caged Layer Pest Management Evaluation survey

TABLE 1. Producer ranking of California poultry ranch pests (100 = most severe)

	SOUTH	NORTH	STATEWIDE
House flies	78	77	78
Fannia flies	78	52	70
Fowl mites	64	73	65
Mice	54	76	61
Squirrels	41	55	44
Rats	28	62	38
Wild birds	38	30	36
Beetles	27	60	36
Weeds	34	28	33
Pathogens	17	27	19

Pathogens are perceived as a minor problem throughout the state.

Northern and southern California poultry producers differ in their perceptions of the importance of various pests (Tables 1 and 2). While house flies and *Fannia* are almost equal in significance in southern California, house flies are viewed as much more significant than *Fannia* on northern ranches. Northern fowl mites, which are a cool-season pest, are considered more significant on northern California ranches than in the south. Darkling beetles are ranked as a problem on northern ranches, but much less so in the south. Rats and mice are noticeably more severe on northern ranches than in the south, as are squirrels. Of the other vertebrate pests, wild birds are considered somewhat more pestiferous on southern ranches than on northern ones. Weeds are ranked higher on southern ranches than in the north. Pathogens, which are considered relatively easy to control, are not ranked as significant problems in either part of the state.

TABLE 2. Percentages of respondents listing pest as most significant

	NORTH	SOUTH	STATEWIDE
	%		
Fannia flies	0	44	44
Fowl mites	0	20	20
Musca	8	0	8
Rats	4	0	4
Birds	4	0	4
Mice	12	0	12
Beetles	4	0	4
Squirrels	0	4	4

HOUSE FLIES AND *FANNIA* FLIES

Because house flies transmit the causative agents of both human and animal diseases, their suppression is important from both economic and public health perspectives. Although *Fannia* present little threat of disease transmission, they are perceived as an annoyance and regulated by health departments as public nuisances.

Interestingly, only one southern California producer ranked *Fannia* as "not a problem," while 38% of northern California producers do not consider *Fannia* a problem. Typically, *Fannia* were ranked a significant problem by producers whose ranches are located near residential areas, and particularly near "sensitive sites" such as schools and hospitals.

TRADITIONAL PEST MANAGEMENT PRACTICES

Poultry manure management systems have historically been based on coning and drying techniques, using ambient air movement and low humidities to rapidly dry manure deposits and establish a stable and complex manure architecture to maximize evaporative surface area. This system enables producers to minimize fly production; reduce odors, dusts, and feathers as public nuisances; and maintain fertilizer value of poultry manure [5]. It has long been recognized that combining cultural, biological, and chemical control practices in an integrated program yields the best control of poultry pests and ectoparasites [6].

Water management is a critical component of this strategy. Roof overhangs must extend sufficiently to ensure that water is carried away from foundations, and the area near foundations must be graded so that water flows away from the building. Roof leaks should be identified and repaired. Many open-sided poultry houses use exterior roof sprinkling systems to lower within-house temperatures. This additional moisture has potential for wetting manure and favoring fly development if the equipment is not installed and maintained properly. Waterers likewise require daily inspection and repair, with wet manure being removed for drying outside the building.

Manure is managed in a way that encourages establishment and growth of beneficial arthropod populations. Development and maintenance of a stable self-sustaining manure ecosystem is dependent on practices that help maintain extant fly predators and parasites [7]. These include such activities as avoiding or minimizing pesticide application to the manure, water management to avoid manure flooding, and allowing manure to build up for prolonged periods between cleanouts. To promote manure drying and preserve a reservoir of beneficial organisms, producers maintain a dry manure pad at cleanout [7, 8].

Manure removal is a market-driven phenomenon, contingent upon weather, worker availability, and the hauler's schedule. Poultry manure is a valuable fertilizer and must be transported to application sites in a timely manner – when the crop requires it. Frequent manure ecosystem disruption, such as complete manure removal, causes fly population increases that endure until stability is restored [9, 10]. Reduced pest fly emergence is correlated with manure depth (*i.e.*, time since cleanout), with a recommended optimum depth of more than 30 cm to foster beneficial arthropods [9].

The beneficial arthropod complex includes predators such as *Ophyra leucostoma, Muscina stabulans, Carcinops pumilio, Gnathoncus nanus, Philonthus sordidus*, and various anthocorids, predaceous mites, and earwigs [11, 12]. Significant scavengers include representatives of the Scarabaeidae, Tenebrionidae, and Anthicidae. Commonly encountered parasitic Hymenoptera include *Muscidifurax raptor, M. zaraptor, Spalangia endius* and *S. cameroni* [9].

Some poultry ranches use machines to till the manure under the cages once or twice a week. These devices, similar to rotor-tillers, turn the manure in place, mechanically disrupting fly habitat and assisting in aeration [13]. No northern California producers reported tilling manure (Table 3). Likewise, none of the high-rise operators in northern California reported practicing weekly cleanout (Table 3). However, in southern California, frequent (weekly to daily) manure removal is becoming a more prevalent practice where rapid undercage drying is impractical. For effective fly control, manure cleanout frequency must prevent fly larvae from reaching maturity. The schedule of operations depends on ultimate manure disposition and regional climatic conditions. Belt removal and drying systems permit constant, ongoing manure transfer concurrent with drying and loading. New designs of layer houses, cleanout machines, mechanical removal methods, and manure processing techniques make frequent cleanout feasible for some poultry ranches. Both frequent cleanout and manure tillage are becoming more common on southern California poultry ranches.

TABLE 3. Fly control methods (% of producers using)

	SOUTH	NORTH	COMBINED
	%		
Methomyl bait	100	100	100
Dibrom	82	38	68
Traps	65	38	56
Permethrin	47	50	48
Pyrethrum	24	38	28
Ravap	24	38	28
Larvadex	29	13	24
Parasitoids	24	25	24
Fly tape	24	25	24
Zappers	18	38	24
Weekly cleanout	29	0	20
Dimethoate	18	0	12
Cyfluthrin	6	20	8
Manure tilling	12	0	8

While traps may eliminate large numbers of flies, their primary usefulness is for monitoring, with secondary effects of supplementing sanitation and chemical control measures. They cannot be depended on to provide satisfactory control of fly populations by themselves. Perimeter trap placement can reduce off-site emigration of flies by intercepting migrants. Standard practice incorporates fly traps (water or bottle traps, solar traps, sugar- or molasses-baited traps) both as monitoring tools and to reduce adult fly numbers [14]. All surveyed California caged layer producers indicated that they use fly baits. Typically, higher volumes are used per building on southern ranches than in the north, but northern and southern ranches use similar quantities per farm (Table 4).

TABLE 4. Amounts of toxic fly baits used annually on California poultry ranches

	POUNDS PER BUILDING		POUNDS PER FARM	
	Range	Average	Range	Average
North	0.4–6.4	2.6	50–727	291.2
South	1.6–80.0	17.1	25–1000	230.9
Statewide	0.4–80.0	15.4	25–1000	252.2

EFFECTS OF MANAGEMENT SYSTEMS ON PEST COMPLEXES

As with any intensive confined animal agriculture, the potential for pest population increases is high in caged layer operations. The proximity of birds to one another permits ready movement of ectoparasites (such as northern fowl mites) between animals. The concentration of wastes provides adequate fly and beetle developmental habitat. The stable environmental conditions allow year-round perpetuation of both vertebrate and invertebrate pest populations.

For the past half century, the standard poultry management system for open-sided layer houses in southern California has been based on beneath-cage coning and drying [15]. This system favored development of a stable self-sustaining manure ecosystem, with establishment of a complement of predators, parasites, competitors, and scavengers to supply biological control of pest flies [16]. However, because of increasing suburban encroachment into previously rural areas, potential fly breeding sources (such as poultry ranches) often are found close to human dwellings. Cultural and biological control methods alone are seldom adequate to meet standards set by local health statutes and societal pressures. It is frequently necessary to supplement biological and cultural components with inputs such as mechanical and chemical controls [17].

Insecticides play a significant role in poultry pest management. Annual mean numbers of insecticide applications for fly control (including *Musca* and *Fannia*) are 48 (range 2 to 200) in southern California and 34 (range 10 to 120) on northern California egg ranches. Products used for adult fly control include dibrom (Fly Killer D), permethrin (*e.g.,* Permectrin, Atroban, and Ectiban), pyrethrum, Ravap (tetrachlorvinphos and dichlorvos), dimethoate, and cyfluthrin (Table 3).

Larvadex (cyromazine) is a chitin synthesis inhibitor and a highly selective larvicide, being active against *Musca* larvae and impacting non-Dipteran taxa virtually not at all. Unfortunately, it demonstrates little efficacy against *Fannia* [18]. Label restrictions limit its use to once every 3 wk, making it ineffective in suppressing flies that can complete two generations between Larvadex treatments. Statewide, 24% of producers use Larvadex (Table 3), but its cost and timing restrictions reduce its desirability for inclusion in an IPM program.

Interestingly, on southern California poultry ranches, insecticide costs for fly control ranged from 0.1 to 5.3¢ per bird annually. On a per-house basis, annual costs were from $16 to $635 per house, with a mean of $170; costs are not normalized for house size or for numbers of birds. By comparison, on northern California poultry ranches per-house expense ranged from $40 to $833, with a mean of $250. These numbers reflect only insecticide costs, not equipment, labor, or other components.

While cultural and mechanical control form the backbone for fly suppression programs on caged layer operations in both northern and southern California, costs of clean-out are not attributed to fly control, nor are expenses related to building construction, water management, inspection, equipment, or other procedures that directly influence fly populations [19]. Thus, the true costs of fly suppression are significantly higher than is reflected in insecticide costs alone. New poultry facilities are being constructed as enclosed environmental houses instead of traditional open-sided style houses. This requires greater initial capital investment and increased energy inputs to maintain temperatures and force-air ventilate.

NORTHERN FOWL MITES

Maintaining good biosecurity on the poultry ranch is the most effective cultural practice for limiting the introduction and spread of ectoparasites such as northern fowl mites [20]. Biosecurity includes maintaining an effective rodent control program, keeping buildings in good repair to limit entry by wild birds, personnel changing clothing and other protective gear before moving between houses or farms to prevent accidentally transporting ectoparasites from an infested flock to a

clean flock, and cleaning and disinfecting all incoming materials (egg flats, cartons, pullet crates, racks, etc.) before they enter the facility.

Other than prevention via good biosecurity, there is no alternative to chemical control for suppression of northern fowl mites on birds (Table 5). Although most registered chemicals are still considered efficacious against northern fowl mites, the limitation to successful control is delivery of the active ingredient to the infestation site. With the large numbers of birds on today's poultry ranch, the only practical treatment strategy is high-pressure spray delivered to the vent area of the birds. Because young birds and recently molted birds are heavily feathered, chemical penetration to the skin is typically hindered and control obtained is seldom satisfactory. On southern California egg ranches, treatments for northern fowl mites are made 1 to 3 times/yr (mean 1.7); each treatment involves two applications, with the second typically following a week or two after the first to kill any mites that have hatched since the first.

One promising non-chemical northern fowl mite control strategy is use of mite-resistant hen strains; however, these strains do not yet exist and the impetus to select for mite-resistance over production-related attributes such as egg yield is not prevalent [21]. Off-bird populations can be suppressed by environmental manipulation, specifically protracted exposure to very high (>49°C) or very low (<-20°C) temperatures [21]. There are no comparable on-host mechanical mite control options.

DARKLING BEETLES

Darkling beetles are considered by some poultry producers to be beneficial organisms, due to their predation on fly larvae and their activity in tunneling through manure, which aids air flow and drying. However, darkling beetles are pests because they damage structures, tunneling into wooden members to form pupation chambers [20]. In colder climates where extruded or planar styrofoam insulation is employed, darkling beetles have been shown to essentially destroy the insulative capacity of styrofoam within 3 to 4 yr.

More significantly, *Alphitobius* larvae and adults have been demonstrated competent reservoirs of several poultry disease agents including poultry tapeworms, *Eschericia coli, Salmonella typhimurium*, and infectious bursal disease virus [22, 23, 24]. Because of their mobility within and between poultry houses, these beetles may be responsible for accelerating transmission of many poultry disease agents. The stable ecosystems that permit establishment of beneficial predators are also conducive to darkling beetle growth, providing habitat for population explosions. These omnivorous beetles thrive on spilled feed, but can subsist on other manure constituents, even serving as facultative predators of fly larvae.

The only treatment listed against darkling beetles was use of cyfluthrin to treat houses at cleanout between flocks. No respondents included other registered insecticides for beetle control.

TABLE 5. Acaricides used on California poultry ranches for northern fowl mite control

NORTHERN FOWL MITE ACARICIDES	S. CALIFORNIA RANCHES USING
	%
Ravap	59
Sevin	24
Permethrin	24
Malathion	18

VERTEBRATE PESTS

The most significant vertebrate pests on California poultry ranches are mice (Table 2). In addition, ground squirrels, rats, and wild birds are also pests on many poultry facilities. Rodents serve as pathogen reservoirs and vectors in addition to contaminating animal feed with their waste products. Rats and mice, in particular, damage and destroy property, including buildings and equipment. Squirrels undermine building integrity by burrowing under structures, which results in structural damage and concomitant repair expense.

MICE AND RATS. Rodents are known to produce structural damage, to consume animal feed, to damage and consume eggs, and to contaminate feed and the environment with their urine and feces. In addition, some feral animals have been demonstrated to harbor Salmonella, including *S. enteritidis* phage type 4, which has been responsible for many human food poisoning cases [4].

Rodent-proofing involves determining access points and sealing them to prevent

rodent entry. Glue boards and traps can be used to control rodent populations, especially when initially high infestations have been lowered, but in large houses baits are often more practical (Table 6).

Rodenticides (Table 7) include such products as brodifacoum, which poisons both by ingestion and skin contact and is effective at low rates. Chlorophacinone and diphacinone are multiple-dose rodenticides. Brodifacoum, bromadiolone, bromethalin, cholecalciferol, and zinc phosphide are single-dose rodenticides. Adequate bait must be available over a sufficient length of time to provide a lethal dose to each individual. If bait box inspection shows all bait has been removed, then the amount provided was insufficient for the rodent population present. California poultry ranches use approximately 30 pounds of rodenticide per building annually, with higher amounts typical on northern properties (Table 8). Bait placement and continuing availability are crucial to successful rodent baiting. Use of tamper-resistant bait boxes provides a safeguard to people, pets, and other non-target animals. Bait stations should be secured to a fixed object to prevent their being moved.

Poor sanitation and suitable rodent harborage encourage rat infestation of poultry ranches. Because it is impossible to prevent rodent access to layer feed, it is particularly essential to remove shelter that rats can use for hiding, resting, and nesting. The most successful and permanent form of rat control is to "build them out" by eliminating their access to structures. This type of solution must be integrated into the design and construction of the building; it is virtually impossible to implement subsequent to construction.

Traps have the advantages of not relying on hazardous poisons, permitting disposal (to prevent odors), and serving as a monitoring tool. Perimeter traps can assist in limiting off-site movement of pests, as well as on-site intrusion.

SQUIRRELS. Ground squirrels (*Spermophilus beecheyi*) are of greater concern to southern California poultry operations than to their northern neighbors. Squirrels undermine buildings by constructing their tunnels underneath. Abandoned tunnels can then be used by other vertebrate pests, such as skunks. An unvoiced concern is that ground squirrels can serve as a reservoir for *Yersinia pestis*, the causative agent of bubonic plague, as well as harboring vector-competent fleas such as *Oropsylla (Diamanus) montana* and *Hoplopsyllus anomalus* [25].

The most commonly mentioned squirrel control activities included weed control, live trapping, flooding burrows, and shooting.

TABLE 6. Rodent control strategies used on California poultry ranches

	SOUTH	NORTH	STATEWIDE
	%		
Weed control	59	75	64
Live trap	47	50	48
Tin cats	24	0	16
Cats	24	0	16
Snap traps	12	0	8
Shotgun	12	0	8
Pellet gun	6	0	4
Harborage control	6	0	4
Flooding	6	0	4
Glueboards	6	0	4
Gas cartridge	0	13	4

TABLE 7. Products used for rodent control on California poultry ranches

	NORTH	SOUTH	STATEWIDE
	%		
Bromadiolone	75	47	52
Diphacinone	38	35	36
Brodifacoum	38	0	12
Chlorophacinone	13	12	12
Cholecalciferol	25	0	8
Unspecified anticoagulant	0	12	8

TABLE 8. Amounts of rodenticide used annually on California poultry ranches

	POUNDS PER BUILDING		POUNDS PER FARM	
	Range	Average	Range	Average
North	1–14.5	51.2	112–1640	553.2
South	0.06–1.46	18.5	50–1280	258.0
Statewide	0.06–14.5	30.1	50–1640	362.4

Wild Birds. None of the survey respondents indicated use of any California registered avicides or bird repellents. Instead, the majority of poultry ranches employ exclusion and attempt to "build them out," using construction practices that prevent access by wild birds (Table 9). The effectiveness of this technique is dependent, as several indicated, on keeping doors closed and maintaining buildings so that access points are not breached.

WEEDS

Weeds are problems because they present fire danger to the property, support and encourage other pests, and are unsightly. Vegetation around the houses reduces air movement; the resulting limitation of manure drying maintains manure conditions suitable for fly development. Weeds provide food, cover, harborage, and shelter for rodents and other vertebrate pests. Weeds also provide resting sites and alternative food sources for flies and darkling beetles. Numerous weeds are found around poultry ranches; the particular species vary by both region and season. However, most of these weeds are managed similarly. Vegetation management is typically achieved more through mechanical means (mowing or disking) than via herbicide usage.

Herbicides are used only once or twice annually (Table 10), with Round-Up (glyphosate) being the most commonly employed (Table 11). In general, there is less public and regulatory concern about herbicides because human physiological systems are so different from those of plants that their mode of action is assumed to be sufficiently different to avoid risk to humans and other mammals. However, several herbicides are on the Food Quality Protection Act evaluation list.

TABLE 9. California caged layer producer responses to wild birds

	NORTH	SOUTH	STATEWIDE
	%		
Do nothing	63	41	48
Bird netting	25	29	28
Closed houses	13	29	24
Pellet gun	0	6	4
Live traps	0	6	4

PATHOGENS

No attempt was made to identify specific pathogens of concern to producers; rather, the survey sought to determine what measures have been instituted to prevent their introduction to and spread among poultry facilities. Biosecurity measures including all-in/all-out management practices, equipment decontamination prior to movement between ranches, limiting access to ranch premises, and personal hygiene have had significant impacts on reducing disease transmission. The standard disinfectants and sanitizers include quaternary ammonium compounds, phenols, glutaraldehyde, formaldehyde, and sodium hypochlorite solution (Table 12). Some ranches use these products continuously; others apply treatments periodically (Table 13).

Hygiene and sanitation play major roles in poultry disease control programs, including pathogen exclusion and containment. One important requirement facilitating hygiene and sanitation is adoption of the all-in/all-out method (i.e., all birds within a single establishment should be of the same age group). Another supportive practice is restriction of each enterprise to a single type of bird (*i.e.,* not permitting game birds or other fowl on a com-

TABLE 10. Frequency of herbicide application on California caged layer operations

	SOUTH	NORTH	STATEWIDE
	%		
1 time/yr	35	38	36
2 times/yr	29	25	28
Year round	12	0	8
As needed	6	13	8
25 times/yr	0	13	4

TABLE 11. Herbicides used on caged layer operations in California

	SOUTH	NORTH	STATEWIDE
	%		
Round-Up	71	88	76
Goal	0	62	20
Simazine	6	26	12
Krovar	6	0	4
Oust	6	0	4
Karmex	6	0	4

TABLE 12. Disinfectants and sanitizers used by California caged layer producers

PRODUCT	RANCHES THAT USE
	%
Environ One Stroke (phenols)	36
Germex (quaternary ammonium)	16
DC & R (aldehyde)	12
Unspecified iodine	12
Iofec (iodophores)	8
Chlorine (sodium hypochlorite)	8
Unspecified quaternary ammonium	8
BioSentry (quaternary ammonium)	4
Tektrol (phenols)	4
Bioguard X-185 (phenols)	4
Unspecified formaldehyde	4
Unspecified glutaraldehyde	4

TABLE 13. Frequency of disinfectant and sanitizer use on California caged layer ranches

	NORTH	SOUTH	STATEWIDE
	%		
1 time/yr	38	0	12
2 times/yr	0	18	12
3 times/yr	0	12	8
4 times/yr	0	12	8
5–6 times/yr	12	23	20
12 times/yr	12	0	4
Each flock	12	0	4
Continuous	0	23	16

mercial operation). Poultry premises and buildings should comply with requirements for isolation from the environment and strict observance of principles of hygiene and disease prevention (*e.g.,* restrictions on movement of staff, equipment, and vehicles). Methodical preparation for the entry of each new flock involves several steps, such as removal of birds, litter, and manure; vector and rodent control; dry and wet cleaning; disinfection; and fumigation. Disposal methods for dead and diseased birds include incineration, rendering, and composting. The method chosen should prevent disease organism dissemination and be non-conducive to fly development. Regular visual inspection combined with routine microbiological monitoring methods provides verification of efficacy of cleaning and disinfection [26], creating a preventive environment that mitigates risks for food-borne pathogen contamination.

MONITORING

The majority of producers throughout the state base their treatment decisions on pest monitoring (Table 14). The key to any pest management program is proper monitoring. Pest population levels need to be monitored to determine when control interventions are needed. Small numbers of some pests are not economically damaging, and no control is needed. Other pests can be most economically controlled when population levels are low or before they increase rapidly [20]. Because public nuisance is a significant component of many of the pests produced on caged layer ranches, aesthetic and public health concerns must be factored into action thresholds. For instance, economic or treatment threshold for flies varies from ranch to ranch, depending on proximity of neighbors.

FUTURE CONCERNS

The need to develop new non-chemical pest management strategies is magnified by loss of many pesticides formerly used in animal agriculture, by decreased pesticide development efforts by industry, and by an increase in arthropod pest resistance to the few remaining pesticides. The problem is further compounded by the fact that many urban inhabitants have the perception that peridomestic flies originate only on poultry ranches, when in fact stable flies, little house flies, and house flies frequently develop in urban habitats [27].

TABLE 14. Basis for treatment decisions

	NORTH	SOUTH	STATEWIDE
	%		
Monitor pests	88	82	84
Personal discomfort	50	41	44
Treatment schedule	50	29	36
Animal discomfort	12	41	32
Neighbor complaints	0	18	12

We can anticipate further loss of pesticides due to concern about environmental impacts or non-target toxicity, development of resistance in target pests, or non-renewal of registration (due to lack of market potential). For instance, flies have already developed resistance (both behavioral and physiological) to the only commercial fly bait available [28]. *Fannia* were demonstrating resistance to available insecticides three decades ago [13].

In some cases, producers are limited in their options. For instance, most poultry ranches attempt to rotate chemicals, such as alternating Sevin and Ravap for northern fowl mite control. Sevin and Ravap (carbamates and organophosphates), although of different chemical classes, typically share a similar mode of resistance, acetylcholinesterase insensitivity [29]. So this rotation is ineffectual in suppressing acaricide resistance development.

Biological control, by its nature, requires maintenance of a pest population to support the beneficial organisms [16]. Currently the action threshold (the aesthetic injury level as defined by the ranch's neighbors) is typically lower than achievable using biological control. Proximity of homes and schools to animal agriculture facilities has resulted in fly control action thresholds lower than the historically acceptable levels associated with isolated poultry ranches.

Expectations of health department inspectors must be factored into the consideration of pest management strategies. Typically field inspectors are newly hired employees with little or no training; by the time they become experienced and knowledgeable about fly suppression and poultry production, they are transferred or promoted. Regulatory restrictions may stifle creativity, experimentation, and inventiveness in control methodologies. Some county health departments mandate specific abatement procedures [7], leaving little flexibility for producers.

The future of sustainable animal production systems requires research that promotes development of pest management strategies that do not rely solely on pesticides to prevent damage by arthropod pest populations. However, potential barriers to their adoption include societal pressures, regulatory strictures, lowering of action thresholds, economics, public perception, and practicality. Narrow profit margins, increasing production costs, and other economic realities limit pest management options.

Assessment of the present situation allows projection of future directions and identifies both limitations and opportunities. Operating as a Pest Management Alliance, producers, producer associations, allied industries, regulatory agencies, and Cooperative Extension can evaluate current pest management practices and use the information gained to direct knowledge-based pest management decisions.

Conclusions and Applications

1. In the California caged layer industry, flies are the number one pest of concern, followed by northern fowl mites and mice. Other vertebrate and invertebrate pests are of secondary concern, as are weeds and pathogens.
2. Regional differences exist (even within a state) in pest severity and in availability of effective control options.
3. This kind of background information is essential for decision-making by regulatory agencies, educational organizations, and producers themselves.
4. Loss of pesticides currently under Food Quality Protection Act evaluation may significantly affect ability to effectively manage on-farm pests.
5. Pest management alliances permit producers to work with other concerned entities to identify pest complexes and strategies that may be directed against them.

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