FINAL REPORT

for

Vertebrate Pest Control Research Advisory Committee

STUDY TITLE:

Vertebrate pest "research needs" assessment for California agricultural commodities.

PROJECT LEADER:

Roger A. Baldwin
University of California – Kearney Agricultural Research and Extension Center
9240 South Riverbend Ave, Parlier, CA 93648

COLLABORATORS:

Terrell P. Salmon
University of California Cooperative Extension – San Diego County
5555 Overland Ave. Suite 4101, San Diego, CA 92124

Robert H. Schmidt
Utah State University
5215 Old Main Hill, Logan UT 84322

Robert M. Timm
University of California – Hopland Research and Extension Center
4070 University Road, Hopland, CA 95449

July 2011

EXECUTIVE SUMMARY

Many wildlife species such as the California ground squirrel (*Spermophilus beecheyi*), pocket gopher (*Thomomys* spp.), and meadow vole (*Microtus* spp.) cause extensive damage to a variety of agricultural commodities in California, with estimates of damage in excess of $168 million annually. Controlling these pests is obviously warranted, but the scope of the problem far exceeds our ability to properly address all aspects of the problem. Given a limited availability of resources to solve all human-wildlife conflicts, we should focus our efforts on issues that will provide the greatest benefit to agricultural commodities in California. Therefore, we developed a survey to provide quantitative data on research needs to better guide future research efforts in developing more effective, practical, and appropriate methods for managing these pests. Results from our study included:

1. Ground squirrels (21% of respondents) and pocket gophers (18%) were listed as the primary wildlife pests. Birds (15%), coyotes (*Canis latrans*; 11%), voles (9%), and wild pigs (*Sus scrofa*; 8%) were also frequently listed. We did observe a significant pest × region interaction. Ground squirrels were considered a bigger pest in the central and desert valleys, coyotes were listed more frequently in the mountain region, while birds were considered a bigger pest in the statewide region. No other wildlife species differed regionally.
2. The wildlife pests deemed most in need of advancements in control methods were birds (21% of respondents), ground squirrels (18%), and gophers (17%). We observed no regional difference in response. Survey respondents indicated that a disproportionate amount of effort should be expended to develop better control methods for birds and wild pigs.
3. Wild pigs (6.8% loss), ground squirrels (5.9%), gophers (5.7%), and voles (5.3%) all caused equivalent levels of damage to agricultural commodities. However, this varied across crops with highest levels of damage reported for voles (11.3%) and gophers (8.8%) in alfalfa, wild pigs (10.0%), birds (9.6%), and ground squirrels (8.7%) in nut crops, and coyotes (8.9%) in rangelands.
4. Common forms of damage varied regionally for coyotes, but not for other wildlife pests. For coyotes, we observed no significant difference in types of damage caused in the central and desert valley region, although damage to irrigation structures received the greatest proportion of responses (57% of responses). In all other regions, depredation of livestock was the primary form of damage (84%).
5. Loss of crop production through consumption of foods was the primary form of damage caused by birds (77% of responses) and ground squirrels (69%). For gophers, loss of vigor or direct mortality of the plant was the primary form of damage (70%). No difference in forms of damage was noted for voles or wild pigs.
6. Control methods used most frequently and those deemed most effective differed regionally for birds. For the coastal region, exclusionary devices were used most frequently (75% of responses) and were considered most effective (82%). These values did not differ. For all other regions, frightening devices were used most frequently (84%), while frightening devices (37%) and shooting (22%) were considered most effective. These values did differ, indicating that frightening devices were not a preferred method for bird control.

7. Control methods used most frequently for ground squirrels differed regionally. However, this difference was due to small sample sizes in the mountain region. As such, we combined all regions for analysis. Poison baits were used most frequently (85% of responses) and were considered to be the most effective (77%) control method for ground squirrels. These values did not differ.
8. We observed no regional difference in the control methods used most frequently and those deemed most effective for all other wildlife pests. For gophers, poison baits were used most frequently (57% of responses), while poison baits (40%), traps (30%), and fumigants (19%) were considered most effective. The use of poison baits was both the most frequently used (68%) and most effective (63%) method for controlling voles. For wild pigs, shooting and trapping were considered to be both the most frequently used (61% and 26%, respectively) and most effective (50% and 28%, respectively) methods of control. Shooting (68%) was also the most frequently used method for controlling coyotes. Both shooting and trapping (34% and 44%, respectively) were considered equally effective. Values for the most frequently used and most effective methods did not differ for ground squirrels, gophers, voles, or wild pigs, but did differ for coyotes primarily due to the lower efficacy associated with shooting.
9. We observed no regional differences in why survey respondents felt the most frequently used and most efficacious methods differed for all pests. However, combined responses did differ for birds, gophers, wild pigs, and coyotes. For these pests, the most effective method was considered too costly (43%, 40%, 33%, and 18% of responses for birds, gophers, wild pigs, and coyotes). Other common responses were that the most effective method often required special certification to apply or was too restrictive to use (41%, 27%, and 22% for coyotes, birds, and wild pigs), and that there was a lack of knowledge on which control method was most effective (28% and 27% for wild pigs and gophers).
10. For all pests, greater advancements in control methods were listed as a top research priority ($\bar{x}$ rank = 3.7–4.6). A better understanding of the economic damage caused by wild pigs ($\bar{x}$ rank = 3.6) and the juxtaposition of crop fields and natural areas on the distribution and population dynamics of wild pigs ($\bar{x}$ rank = 3.0) and voles ($\bar{x}$ rank = 3.4) were also considered high priorities. A greater understanding of the biology of pest species ($\bar{x}$ rank = 2.1–3.0) and greater knowledge of the impact of control methods to the environment ($\bar{x}$ rank = 2.3–3.1) were frequently the lowest scoring responses. We observed no regional differences for any pest.
11. Collectively, the use of poison baits ($\bar{x}$ rank = 3.9), trapping ($\bar{x}$ rank = 3.8), and biocontrol ($\bar{x}$ rank = 3.6) were considered the most appealing methods of control, while frightening ($\bar{x}$ rank = 3.2) and gas explosive devices ($\bar{x}$ rank = 2.9) were least appealing. However, we observed a significant control method × region interaction which illustrated substantial differences for various control methods across regions. In general, the coastal region was most different, with a stronger preference for non-lethal control methods such as exclusionary devices ($\bar{x}$ rank = 4.0) and habitat modification ($\bar{x}$ rank = 3.8). The central and desert valley region exhibited the opposite trend with a strong preference for lethal removal approaches such as baiting ($\bar{x}$ rank = 4.2), burrow fumigants ($\bar{x}$ rank = 3.6), and shooting ($\bar{x}$ rank = 3.5). The statewide region trended toward approaches that are often more effective yet practical

(poison baits [$\bar{x}$ rank = 4.4]; burrow fumigation [$\bar{x}$ rank = 4.0]; trapping [$\bar{x}$ rank = 4.0]), while avoiding those that are not typically effective (e.g., biocontrol [$\bar{x}$ rank = 3.0]; gas explosive devices [$\bar{x}$ rank = 3.0]).

12. Most (61%) survey respondents believed that individuals involved in wildlife pest control in agriculture rely on an IPM approach for controlling these pests. However, this response varied regionally, as respondents in the central and desert valleys felt that most individuals used a single method that has proven effective (53% of respondents). The primary reasons provided as to why some individuals do not use an IPM approach were primarily due to a preference to use a single approach that has proven effective (43% of respondents), and a lack of effective control methods thereby eliminating the possible use of an IPM program (30%).
13. Of the listed attributes for control methods, efficacy was the most important ($\bar{x}$ rank = 4.5). Methods that were quick and inexpensive were also highly preferred ($\bar{x}$ rank = 3.6), while the humaneness of a control method was least important ($\bar{x}$ rank = 1.8). We did observe a strong attribute × region interaction. This interaction was primarily driven by differences in rankings between the attributes of environmental safety and applicator safety, where coastal and mountain region respondents believed that environmental safety was more highly preferred than applicator safety.

Collectively, our findings suggest that research and extension efforts should focus on developing better control methods for ground squirrels, pocket gophers, birds, wild pigs, coyotes, and voles. These control methods should be woven into an IPM program to maximize efficacy while minimizing negative effects to the environment. Special emphasis should be placed on control methods that are both efficacious and quick and inexpensive to apply. Regional differences should also be considered when developing an appropriate control strategy. Lastly, our survey provides the framework with which to reassess these important factors at a later date. We strongly encourage such a reassessment at least every 10–15 years as changes in research needs are likely to occur.

TABLE OF CONTENTS

INTRODUCTION

Agriculture is an essential part of the California economy, accounting for $39 billion annually (Shwiff et al. 2009). Agricultural commodities in California are also extremely diverse, with over 400 commodities produced in 2009 (California Department of Food and Agriculture 2011). This high economic value combined with a broad diversity in commodities makes controlling wildlife pests in California imperative, yet quite challenging. For example, a recent study investigating the economic damage caused by bird and rodent pests to just 22 commodities across 10 counties in California indicated a loss of $168–$504 million annually (Shwiff et al. 2009). This value takes into account only a portion of the agricultural production that occurs throughout California, and does not account for additional impacts such as structural damage to dams and levees (e.g., loss of structural integrity of irrigation canals caused by burrowing rodents), ecological damage (e.g., nesting failures for song birds), and disease transmission (e.g., spread of bubonic plague, hanta virus, or leptospirosis by rodents). Clearly, controlling wildlife pests is warranted in many situations to reduce these deleterious impacts.

Currently, we advocate the use of an integrated pest management (IPM) approach for controlling wildlife pests. IPM is a concept that arose in the 1960's in California that incorporates the use of multiple tools to control a variety of pest taxa (Smith and van den Bosch 1967), and has more recently been effectively incorporated into wildlife pest control (Sterner 2008). One of the primary benefits of an IPM program includes a more targeted and strategic use of pesticides to maximize efficacy while minimizing risk to nontarget species (e.g., Ramsey and Wilson 2000). The threat of non-target exposure to pesticides is currently a major concern for many agricultural producers, wildlife management agencies, and the general public and will likely continue to be a prominent issue well into the future (Abhat 2010, Baldwin and Salmon 2011). That being said, perhaps the greatest selling point of an IPM program to most agricultural producers may simply be the increase in efficacy associated with an IPM approach rather than a reliance on a single control method (Engeman and Witmer 2000, Sterner 2008). However, we are unsure how widely IPM programs are used to control wildlife pests. Information on the level of use of IPM programs combined with insight into ways to increase its incorporation into management programs should yield positive results both for agricultural producers as well as the ecosystem.

Management tools that are incorporated into an IPM program will vary depending on the pest species involved. Many wildlife species are considered major pests of agricultural commodities including the California ground squirrel (*Spermophilus beecheyi*), pocket gopher (*Thomomys* spp.), meadow vole (*Microtus* spp.), and coyote (*Canis latrans*) although we are unsure which species pose the greatest threat to agricultural production. Greater insight into the methods used to control these pests and ways to increase the efficacy of control programs are also needed. Quantifiable data on these issues would aid the development of more effective control programs to deal with these damaging pests.

Although wildlife pests cause damage to many commodities, controlling these pests can be quite costly. As such, situations may exist where it is economically more beneficial to incur some loss to wildlife rather than to implement an extensive control program (Gebhart et al. 2011). Unfortunately, there is often a lack of data available to assist agricultural producers in making a decision on whether or not to implement a management program for a particular wildlife pest, and if so, which methods are most appropriate. Research into this area is clearly warranted to provide information to agricultural producers to better answer these questions.

Therefore, our goal was to develop a survey that would target individuals involved with assisting or regulating agricultural producers who experience wildlife pest problems to provide quantitative data on research needs to better guide future research efforts in developing more effective, practical, and appropriate methods for managing these pests. More specifically, our primary objectives for this survey were as follows: 1) to ascertain which pests were most frequently identified as the major wildlife pests in California agriculture, 2) to determine which wildlife pests were most in need of additional research to develop more effective control methods for managing these pests, 3) to estimate the economic damage caused by each of these pests, 4) to identify the most costly form of damage caused by each pest, 5) to identify which methods are used most frequently and which are most effective for controlling these pests, and if these methods differ, why, 6) to determine areas where advancements are most needed to manage these pests, 7) to identify which control methods are most appealing to individuals involved in wildlife pest control, 8) to determine if individuals involved in wildlife pest control in agriculture follow an IPM approach for managing these pests, and if not, why, and 9) to identify the most important attributes for wildlife pest control methods.

Individuals often have varying viewpoints on these issues depending on a variety of factors including the local agricultural systems and wildlife species, personal upbringing, social status, and political beliefs. These viewpoints are often represented by regional differences in responses. As such, we have separated survey participants into 4 separate regions (coastal, mountain, central and desert valley, and statewide regions; see Table 1 for county inclusion into each region) that are believed to be relatively similar in agricultural and socio-political composition. This will allow us to account for regional differences in these objectives as well.

METHODS

We developed a 10-question electronic survey with multiple parts to some questions (see Appendix for survey) via SurveyMonkey (http://www.surveymonkey.com/). This survey was disbursed via e-mail in 2010 to California County Agricultural Commissioner's offices, members of UCCE, University affiliates other than UCCE, Commodity Boards, CDFG, and USDA Wildlife Services given their knowledge on the impact of wildlife pests to agricultural commodities. This survey was approved by the University of California, Davis, Institutional Review Board for human subject research (Protocol number 201018437-1)

We began the survey with 3 employment-related questions to provide insight into the demographic composition of survey participants. Specifically, these questions provided information into the survey participants' source of employment, which agricultural commodities or wildlife resources they managed, and their primary counties of employment. This demographic information was used to help discuss our findings, and with respect to their primary county of employment, allowed us to ascertain potential regional differences in responses. The remaining survey questions were developed to address our primary objectives.

Table 1. The number and percentage of survey participants from each county throughout California as well as their respective classification for regional analyses. Survey participants could provide more than one response. Therefore, the percentage provided is out of the total number of participants (n = 143) who provided a response.

County	Number	Percentage	Region	County	Number	Percentage	Region
Alameda	5	3%	Coastal	Nevada	1	1%	Mountain
Contra Costa	6	4%	Coastal	Placer	5	3%	Mountain
Lake	8	6%	Coastal	Plumas	2	1%	Mountain
Los Angeles	5	3%	Coastal	Shasta	3	2%	Mountain
Marin	2	1%	Coastal	Sierra	2	1%	Mountain
Mendocino	6	4%	Coastal	Siskiyou	2	1%	Mountain
Monterey	14	10%	Coastal	Trinity	2	1%	Mountain
Napa	10	7%	Coastal	Tuolumne	5	3%	Mountain
Orange	3	2%	Coastal	Butte	5	3%	Valley
San Benito	8	6%	Coastal	Colusa	4	3%	Valley
San Diego	10	7%	Coastal	Fresno	14	10%	Valley
San Francisco	2	1%	Coastal	Glenn	5	3%	Valley
San Luis Obispo	8	6%	Coastal	Imperial	4	3%	Valley
San Mateo	4	3%	Coastal	Kern	8	6%	Valley
Santa Barbara	5	3%	Coastal	Kings	5	3%	Valley
Santa Clara	6	4%	Coastal	Madera	10	7%	Valley
Santa Cruz	8	6%	Coastal	Merced	11	8%	Valley
Sonoma	11	8%	Coastal	Riverside	9	6%	Valley
Ventura	7	5%	Coastal	Sacramento	11	8%	Valley
Alpine	1	1%	Mountain	San Bernardino	4	3%	Valley
Amador	3	2%	Mountain	San Joaquin	9	6%	Valley
Calaveras	3	2%	Mountain	Solano	10	7%	Valley
Del Norte	2	1%	Mountain	Stanislaus	7	5%	Valley
El Dorado	2	1%	Mountain	Sutter	9	6%	Valley
Humboldt	2	1%	Mountain	Tehama	5	3%	Valley
Inyo	1	1%	Mountain	Tulare	9	6%	Valley
Lassen	3	2%	Mountain	Yolo	15	10%	Valley
Mariposa	4	3%	Mountain	Yuba	7	5%	Valley
Modoc	2	1%	Mountain	Statewide[a]	12	8%	Statewide
Mono	1	1%	Mountain				

[a] The number of individuals who listed Statewide as the area where they worked was 12. However, for analysis, we had n = 28 for this regional classification given overlap of counties across multiple regions for 16 additional survey respondents.

Survey design

For Objective 1, a score of 1–3 was provided by each survey participant for the top 3 wildlife pests for which they felt resulted in the greatest number of complaints annually; all other pests received a score of 0. This same approach was followed for Objective 2 although instead of the number of complaints, we were interested in the pests most in need of additional research on control methods. We anticipated minimal responses to some of the pest species provided. Therefore, if at least 5% of the respondents did not list a particular pest for these objectives, this pest was removed from further analysis.

Responses for Objectives 3–6 corresponded to the pests selected by each individual in Objective 1. For Objective 3, respondents were asked to rate the amount of damage caused by each of their 3 selected pests for 1 of 9 commodities (nut crops, tree fruit, berries, grapes, vegetable and row crops, alfalfa, rangelands, dairy and feedlots, and other). Response options included "no damage", "slight damage (<5% reduction in profit)", "moderate damage (5–15% reduction in profit)", heavy damage (>15% reduction in profit)", and "I don't know". Respondents were encouraged to select "I don't know" if they had no experience with a particular commodity group. For analysis, "no damage" through "heavy damage" received a score of 1–4. For descriptive purposes, we also converted these scores to estimate losses in profit using the following conversion: no damage = 0%, slight damage = 2.5%, moderate damage = 10%, and heavy damage = 20%.

Objective 4 focused on the most costly form of damage caused by wildlife pests. Possible responses included: 1) loss of crop production through direct consumption of fruit, nut, seed, or vegetation, 2) loss of vigor or direct mortality of the plant, 3) loss of irrigation water down burrow systems, 4) damage to irrigation infrastructure, 5) consumption or contamination of feed in dairies and feedlots, 6) transmission of disease to crop or livestock, 7) depredation of livestock, and 8) other. Due to a low number of responses for options 3 ($n = 5$) and 6 ($n = 5$), options 3–4 and 5–6 were combined for analysis.

For Objective 5, we were interested in the frequency and effectiveness of control methods used to manage wildlife pests. Potential options included: 1) poison baits, 2) burrow fumigants, 3) traps, 4) habitat modification/cultural practices, 5) biocontrol, 6) physical exclusionary devices, 7) chemical repellents, 8) frightening devices, 9) gas explosive devices, 10) shooting, and 11) other methods. We were also interested in the survey participant's opinion as to why the most frequently used and most effective methods might differ. Potential responses included: 1) the methods did not differ, 2) the most effective method was too costly and/or required too much time to apply, 3) the most effective method was not as effective at certain times of the year when it was most needed, 4) there was a lack of knowledge on which control methods were most effective, 5) the most effective method required special certification to apply or was too restrictive to use, 6) users did not feel the most effective method was as humane or ecologically safe as alternatives, 7) the presence of endangered species often reduced or eliminated the use of the most effective method, 8) damage frequently occurred in an organic setting for which the use of the most effective method was not allowable, or 9) other response. Given the uninformative nature of response 1, it was not included in analysis. Rather, it was included as a response option for those individuals who did not feel that the most frequently used and most effective methods differed.

Objective 6 involved ranking where the greatest advancements and research are needed to better manage wildlife pests. Possible responses included: 1) greater knowledge on the biology of the pest, 2) greater knowledge on the impact of control methods to the environment, 3) greater knowledge on the economic damage caused by the pest, 4) greater advancements in control methods, and 5) a greater understanding of how the juxtaposition of crop fields and natural areas influences the distribution and population dynamics of the pest. These rankings could be used only once per pest.

We were also interested in the appeal of various control methods to individuals involved in wildlife pest control (Objective 7). The proposed control methods are the same as those listed for Objective 5. Potential scores ranged from 1–5 (5 = highly desirable, 1 = highly undesirable).

Objective 8 addressed the level of use of an IPM approach for controlling wildlife pests. We were also interested in why survey participants believed that some individuals did not use an IPM approach. Possible responses included: 1) most individuals do use an IPM approach, 2) they prefer to use a single method that has proven effective, 3) they are not aware of what an IPM program is or how it is implemented, 4) there is a lack of effective tools to control some pests, thereby eliminating the possibility of implementing an IPM program, 5) there is a lack of research indicating the effectiveness of an IPM program, 6) there is a lack of cost-benefit studies showing the potential financial savings using an IPM program, and 7) other reasons. Given the uninformative nature of response 1, it was not included in analysis. Rather, it was included as a response for those individuals who felt that most individuals do use an IPM approach for controlling wildlife pests.

For Objective 9, we wanted to determine the most important attributes for wildlife pest control methods. Survey participants were allowed to rank possible outcomes from 1–5 with 5 being most important and 1 being least important; ranks could be used only once. Possible attributes included: 1) efficacy, 2) quick and inexpensive to apply, 3) environmentally safe, 4) humane, and 5) minimal hazard to the applicator.

Statistical analysis

We used multiple techniques for analysis depending on the data format. For continuous rank data (Objectives 1–3, 6–7, 9), we used two way analysis of variance (ANOVA) to test for the influence of the two explanatory variables (Objective 1–2: pest and region; Objective 3: pest and crop; Objective 6: research-needs and region; Objective 7: control method and region; Objective 9: attribute and region) and their interaction. When a model was significant, we used Fisher's least significant difference (LSD) post hoc test to determine which values were different (Zar 1999). Additionally, we were interested in testing for differences in ranks for selected wildlife pests for Objectives 1 and 2. For this, we used a Mann–Whitney *U*-test (Zar 1999) for each or the pests that yielded greater than 5% of the responses.

For nominal responses (Objectives 4–5, 8), we used Fisher's exact test (i.e., test of independence; Zar 1999) when we had two nominal variables, and the exact multinomial test (i.e., goodness-of-fit test; McDonald 2009) when we had one nominal variable. When these tests indicated a significant difference, we used multiple Fisher's exact tests or exact binomial tests (McDonald 2009) to determine which responses were different. We used $\alpha = 0.05$ for all tests.

Many objectives allowed survey participants to select "other" as an option and then write in their response. The "other" category has been eliminated from all statistical analyses given few responses.

RESULTS

Because the survey was provided on-line, we do not have a count of the number of potential survey participants. As such, we cannot calculate a response rate. However, we were able to track the number of individuals who initiated (n = 180) and completed (n = 143) the survey thereby providing an estimated response rate of 79%. The majority of the responses came from California Agricultural Commissioner's offices (31%) and UCCE (41%; Table 2). The largest percentage of survey participants worked with agricultural crops (67%; Table 3). Individuals who worked with dairy or livestock in feedlots comprised the smallest percentage (8%). Every county in the state was represented by at least one survey participant (Table 1). Regionally, the breakdown of respondents was as follows: central and desert valley region = 57, coastal region = 43, mountain region = 16, and statewide category = 26. This breakdown is consistent with where most agricultural production occurs in California and should be reflective of the state as a whole.

Common wildlife pests

The pests most commonly listed as primary and secondary pests were ground squirrels (21%) and pocket gophers (18%; Table 4). Other commonly listed pests included coyotes (11%) and wild pigs (*Sus scrofa*; 8%), while voles (9%) were frequently listed as tertiary pests (Table 4). Because of the relatively low number of responses for deer (4%), rabbits and hares (2%), rats (3%), mice (1%), and tree squirrels (0.3%; Table 4), we have excluded them from further analysis. Additionally, because of the low number of responses for each bird pest, combined with the relative similarity in control methods for these species, we combined them all into a single bird category for further analysis.

Comparison of the 6 most common pest groupings (birds, gophers, ground squirrels, voles, wild pigs, and coyotes) indicated significantly different rankings ($F_{23,810}$ = 4.94, P < 0.001). These rankings differed by pest ($F_{5,810}$ = 10.16, P < 0.001) but not by region ($F_{3,810}$ = 0.69, P = 0.556). Of these pests, ground squirrels ($\bar{x}$ = 1.31) and gophers ($\bar{x}$ = 1.09) were the highest ranking, followed by birds ($\bar{x}$ = 0.67), coyotes ($\bar{x}$ = 0.63), wild pigs ($\bar{x}$ = 0.47), and voles ($\bar{x}$ = 0.37) (Table 5).

We also observed a significant pest × region interaction ($F_{15,810}$ = 2.05, P = 0.011) indicating that the importance of pests varied depending on which region of the state the survey participant was located (Table 6). For regional comparisons within each pest, mean ranks for birds were higher for the statewide region ($\bar{x}$ rank = 1.19) than for all other regions ($\bar{x}$ rank = 0.19–0.64), while ranks for ground squirrels were highest for the central and desert valley region ($\bar{x}$ rank valley region = 1.64, $\bar{x}$ rank for all other regions = 0.81–1.19; Table 6). Coyote ranks were highest for the mountain region ($\bar{x}$ rank = 1.25) and lowest for the coastal ($\bar{x}$ rank = 0.50) and valley ($\bar{x}$ rank = 0.51) regions. Regional ranks for other pests did not differ (Table 6). For pest comparisons within the same region, ground squirrels and gophers were the most consistent high ranking pests (Table 6), although coyotes were the highest ranking in the mountain region

Table 2. The number and percentage of survey participants who worked for various employers in California.

Employer	Number	Percentage
County Agricultural Commissioner's office	44	31%
University of California Cooperative Extension (UCCE)	59	41%
University affiliation other than UCCE	13	9%
Commodity board	13	9%
USDA Wildlife Services	6	4%
California Department of Fish and Game	5	3%
Not provided	3	2%

Table 3. The number and percentage of responses on how survey participants defined their position. Survey participants could provide more than one response. Therefore, the percentage provided is out of the total number of participants (*n* = 143) who provided a response.

Job description	Number	Percent
Work with agricultural crops	96	67%
Work with wildlife pests associated with agricultural crops	70	49%
Work with livestock on rangelands	33	23%
Work with wildlife pests associated with livestock and rangelands	45	31%
Work with dairy cattle or livestock in feedlots	11	8%
Work with wildlife pests associated with dairy cattle or livestock in feedlots	20	14%
Work with landscapers and landscape horticulturalists	40	28%
Work with wildlife pests associated with landscape and garden-type settings	44	31%
Conduct research associated with wildlife	28	20%
Manage wildlife resources	15	10%

Table 4. The number of times various wildlife pests were listed as resulting in the first, second, or third most complaints annually, as well as a similar listing for those pests most in need of additional research. The combined (Comb) totals as well as the overall percentage of these totals are provided for comparison.

Wildlife pest	Wildlife pests with most complaints					Wildlife pests most in need of research				
	First	Second	Third	Comb	Percent	First	Second	Third	Comb	Percent
Crows[a]	2	1	12	15	4.1%	4	5	8	17	5.2%
Ravens[a]	0	0	2	2	0.5%	0	4	1	5	1.5%
Blackbirds[a]	6	5	3	14	3.8%	7	7	2	16	4.9%
Starlings[a]	2	11	5	18	4.9%	4	10	6	20	6.2%
Magpies[a]	0	1	0	1	0.3%	0	0	0	0	0.0%
Scrub jays[a]	0	0	0	0	0.0%	0	0	0	0	0.0%
Horned larks[a]	0	2	1	3	0.8%	3	3	1	7	2.2%
House finches[a]	3	0	1	4	1.1%	1	1	2	4	1.2%
Pocket gophers	32	23	10	65	17.6%	22	18	14	54	16.6%
Ground squirrels	41	26	11	78	21.1%	23	20	17	60	18.5%
Tree squirrels	0	0	1	1	0.3%	0	2	3	5	1.5%
Meadow voles	7	6	19	32	8.6%	9	4	12	25	7.7%
Mice	2	1	1	4	1.1%	2	0	1	3	0.9%
Rats	3	6	2	11	3.0%	1	2	3	6	1.8%
Rabbits and hares	2	2	3	7	1.9%	3	1	4	8	2.5%
Deer	4	5	6	15	4.1%	4	5	4	13	4.0%
Wild pigs	10	14	7	31	8.4%	16	16	9	41	12.6%
Coyotes	21	9	11	41	11.1%	13	12	9	34	10.5%
Other[b]	7	7	14	28	7.6%	2	1	4	7	2.2%

[a] All of these species were included into a single bird category for further analysis.

[b] Other species and the number of times they were listed include: black bear ($n = 6$), beaver ($n = 5$), Canada goose ($n = 5$), mountain lion ($n = 5$), coot ($n = 3$), pigeon ($n = 2$), raccoon ($n = 2$), striped skunk ($n = 2$), red fox ($n = 1$), swallow ($n = 1$), and white-faced ibis ($n = 1$).

Table 5. Mean rank scores for the 6 wildlife pests in California most frequently listed as 1 of the top 3 wildlife pests resulting in the greatest number of complaints annually (Frequent) as well as most in need of research to develop more effective methods of control (Need). Multiple comparisons (MC) using Fishers LSD were conducted to test for differences in rank scores across species for both Frequent and Need questions. The difference in rank scores for both Frequent and Need responses are also provided to show potential contrasts.

	Frequent		Need		
Wildlife pest	Rank[a]	MC[b]	Rank[a]	MC[b]	Difference
Ground squirrel	1.31	A	1.10	A	–0.21
Gopher	1.09	A	1.02	AB	–0.07
Bird	0.67	B	1.07	A	0.40[c]
Coyote	0.63	B	0.61	CD	–0.02
Wild pig	0.47	BC	0.76	BC	0.29[c]
Vole	0.37	C	0.41	D	0.04

[a] For each survey participant, the highest ranking pest received a score of 3, the second highest ranking pest received a score of 2, and the third highest ranking pest received a score of 1. All other pests received a score of 0.

[b] Means with the same letter did not differ ($P < 0.05$).

[c] Differences between "Frequent" and "Need" scores were significant ($P < 0.05$).

Table 6. Mean rank scores for the 6 wildlife pests most frequently listed as 1 of the top 3 wildlife pests that result in the greatest number of complaints annually across 4 separate regional classes in California. Multiple comparisons (Fishers LSD) were conducted to test for differences in rank scores for each species across regional classes (Reg) and for differences in rank scores across each species within the same regional class (Spp).

	Bird			Gopher			Ground squirrel			Vole			Wild pig			Coyote		
Region	Rank[a]	Reg[b]	Spp[c]	Rank[a]	Reg[b]	Spp[c]	Rank[a]	Reg[b]	Spp[c]	Rank[a]	Reg[b]	Spp[c]	Rank[a]	Reg[b]	Spp[c]	Rank[a]	Reg[b]	Spp[c]
Coastal	0.57	B	Y	1.19	A	X	1.19	B	X	0.19	A	Y	0.57	A	Y	0.50	B	Y
Mountain	0.19	B	Y	0.88	A	XY	0.81	B	XY	0.38	A	Y	0.56	A	XY	1.25	A	X
Valley	0.64	B	Z	1.15	A	Y	1.64	A	X	0.58	A	Z	0.36	A	Z	0.51	B	Z
Statewide	1.19	A	X	0.96	A	XY	1.12	B	X	0.19	A	Z	0.46	A	YZ	0.73	AB	XYZ

[a] For each survey participant, the highest ranking pest received a score of 3, the second highest ranking pest received a score of 2, and the third highest ranking pest received a score of 1. All other pests received a score of 0.

[b] Means in the same column with the same letter did not differ ($P < 0.05$).

[c] Means in the same row with the same letter did not differ ($P < 0.05$).

($\bar{x}$ rank = 1.25) while birds were the highest ranking for the statewide region ($\bar{x}$ rank = 1.19; Table 6).

The wildlife pests deemed most in need of advancements in control were similar to those that resulted in the greatest number of complaints (Table 4). The model comparing needed advancements in control methods to pest species and region was significant ($F_{23,660} = 2.62$, $P < 0.001$). We observed different rankings for pests ($F_{5,660} = 4.97$, $P < 0.001$), but not for region ($F_{3,660} = 0.13$, $P = 0.945$) or for a pest × region interaction ($F_{3,660} = 1.58$, $P = 0.073$). Of these pests, ground squirrels ($\bar{x} = 1.10$) were still the highest ranking pest (Table 5). However, they did not differ from either gophers ($\bar{x} = 1.02$) or birds ($\bar{x} = 1.07$). Voles received the lowest ranking ($\bar{x} = 0.41$) of these 6 common pest groups (Table 5). Of all of the pests, only wild pigs and most bird species consistently scored higher in the area of needed advancements (Table 4); these differences were significant (wild pigs: Mann–Whitney $U = 6{,}872.5$, $P = 0.022$; birds: Mann–Whitney $U = 6{,}458.5$, $P = 0.005$; Table 5).

Economic damage by common wildlife pests

Economic damage estimated to be caused by the 6 most common wildlife pests varied ($F_{47,819} = 5.95$, $P < 0.001$), as pest ($F_{5,819} = 11.83$, $P < 0.001$), crop ($F_{7,819} = 5.55$, $P < 0.001$), and a crop × pest interaction ($F_{35,819} = 4.83$, $P < 0.001$) were all significant factors. For pest species, ground squirrels (loss = 5.9%), wild pigs (loss = 6.8%), gophers (loss = 5.7%), and voles (loss = 5.3%) were equivalent in the estimated loss of profit associated with their presence (Table 7). Collectively, coyotes resulted in the least loss in profit (loss = 3.4%). However, the influence of wildlife pests on crop-associated profits was strongly influenced by the interaction of both crop and pest (Table 8). For example, although coyotes resulted in the least overall damage, they predictably caused an extensive loss in rangeland profits (loss = 8.9%). Birds caused extensive damage in grape (loss = 9.0%), nut (loss = 9.6%), and berry crops (loss = 5.7%), but caused little damage in rangeland (loss = 0.0%) or alfalfa fields (loss = 0.5%; Table 8). Voles (loss = 11.3%) and gophers (loss = 8.8%) were quite damaging in alfalfa, while ground squirrels and wild pigs were very damaging in rangelands (ground squirrel loss = 8.4%, wild pig loss = 8.2%) and nut orchards (ground squirrel loss = 8.7%, wild pig loss = 10.0%; Table 8). We did not test for regional differences in economic damage due to limited samples sizes.

Common forms of damage

We observed a significant difference in the regional response of survey participants to the most common form of damage caused by coyotes (Fisher's exact test, $P = 0.026$); the coastal region was similar with all regions (Fisher's exact test, $P \geq 0.214$), but the central and desert valley region was different from the mountain (Fisher's exact test, $P = 0.016$) and statewide (Fisher's exact test, $P = 0.048$) regions. As such, we analyzed differences in responses separately among the coastal, valley, and mountain and statewide regions combined (Table 9). We found that in the coastal (exact multinomial test, $P = 0.022$) and mountain and statewide (exact multinomial test, $P < 0.001$) regions, depredation of livestock was the primary form of damage (70% and 93% of responses, respectively; Table 9). However, in the central and desert valley region, damage to irrigation structures and loss of irrigation water down burrow systems received the greatest number of responses (57%; Table 9), although there was no significant difference in the

Table 7. Mean rank scores and estimated percent loss in profit caused by the 6 most damaging wildlife pests across 8 common agricultural commodity groupings[a] in California. Differences in rank scores across species were assessed through Fishers LSD post hoc test.

Wildlife pest	Rank[b]	% loss[c]	Multiple comparison[d]
Ground squirrel	1.35	5.90	A
Wild pig	1.31	6.76	A
Gopher	1.28	5.74	A
Vole	1.19	5.28	AB
Bird	1.04	5.52	B
Coyote	0.81	3.39	C

[a] The commodity groupings assessed included nuts, tree fruit, berries, grapes, vegetable and row crops, alfalfa, rangelands, and dairy and feedlots.
[b] The higher the rank, the greater the estimated damage. A score of 3, 2, 1, and 0 meant > 15%, 5–14%, < 5%, and 0% reduction in profits, respectively.
[c] Actual estimates of loss were determined by using the median percent reduction in profit value for each respective rank (e.g., ranks of 3, 2, 1, and 0 equated to loss estimates of 20%, 10%, 2.5%, and 0%, respectively) except for heavy damage for which we used 20% as the estimate of damage for this rank.
[d] Means with the same letter did not differ ($P < 0.05$).

Table 8. Mean rank scores and estimated percent loss in profit caused by the 6 most damaging wildlife pests across 8 common agricultural commodity groupings in California. Differences in rank scores were assessed (Fishers LSD) across species within commodity groupings (Spp) as well as across commodity groupings within each pest species (Crop).

	Nuts				Tree fruit				Berries			
Wildlife pest	Rank[a]	% loss[b]	Spp[c]	Crop[d]	Rank[a]	% loss[b]	Spp[c]	Crop[d]	Rank[a]	% loss[b]	Spp[c]	Crop[d]
Birds	1.76	9.6	AB	X	1.13	5.0	AB	Y	1.27	5.7	A	XY
Gophers	1.42	6.1	AB	XY	1.32	5.3	A	XY	1.30	5.3	A	XY
Ground squirrels	1.78	8.7	A	X	1.34	5.3	A	Y	1.14	4.5	AB	Y
Voles	1.22	4.2	B	Y	1.23	4.4	AB	Y	1.00	3.5	AB	YZ
Wild pigs	1.82	10.0	AB	X	1.27	6.4	AB	X	1.25	6.9	AB	X
Coyotes	0.60	1.5	C	Y	0.74	2.5	B	Y	0.69	2.3	B	Y

	Grapes				Vegetable and row crops				Alfalfa			
Wildlife pest	Rank[a]	% loss[b]	Spp[c]	Crop[d]	Rank[a]	% loss[b]	Spp[c]	Crop[d]	Rank[a]	% loss[b]	Spp[c]	Crop[d]
Birds	1.75	9.0	A	X	1.11	4.2	A	Y	0.20	0.5	C	Z
Gophers	1.48	6.7	AB	XY	1.40	5.8	A	XY	1.68	8.8	AB	X
Ground squirrels	1.20	4.6	BC	Y	1.37	5.5	A	Y	1.33	5.5	B	Y
Voles	1.00	2.9	BC	YZ	1.36	5.7	A	Y	2.08	11.3	A	X
Wild pigs	1.58	7.7	AB	X	1.29	6.3	A	X	1.20	6.0	B	X
Coyotes	0.87	2.6	C	Y	0.44	1.1	B	Y	0.44	1.4	C	Y

	Rangelands				Dairy and feedlots			
Wildlife pest	Rank[a]	% loss[b]	Spp[c]	Crop[d]	Rank[a]	% loss[b]	Spp[c]	Crop[d]
Birds	0.00	0.0	C	Z	1.11	5.0	A	Y
Gophers	1.07	4.3	B	YZ	0.56	1.9	AB	Z
Ground squirrels	1.73	8.4	A	X	0.94	2.9	AB	Y
Voles	1.38	6.6	AB	Y	0.25	0.6	B	Z
Wild pigs	1.70	8.2	A	X	0.38	2.5	B	Y
Coyotes	1.73	8.9	A	X	0.93	3.9	AB	Y

[a] The higher the rank, the greater the estimated damage. A score of 3, 2, 1, and 0 meant > 15%, 5–14%, < 5%, and 0% reduction in profits, respectively.
[b] Actual estimates of loss were determined by using the median % reduction in profit value for each respective rank (e.g., ranks of 3, 2, 1, and 0 equated to loss estimates of 20%, 10%, 2.5%, and 0%, respectively) except for heavy damage for which we used 20% as the estimate of damage for this rank.
[c] Means in the same column with the same letter did not differ ($P < 0.05$).
[d] Means in the same row with the same letter did not differ ($P < 0.05$).

Table 9. The number and percentage of responses (in relation to the pest species) of the most common forms of damage for all regional categories combined for 5 of the most frequently identified wildlife pests in California, and for the coastal, valley, and mountain and statewide regions for coyotes.

Form of damage	Bird[a]	Gopher[a]	G. squirrel[a]	Vole[ab]	Wild pig[ab]	Coyote[ac] Coastal	Coyote[ac] Valley[b]	Coyote[ac] Mt & Stwd
Loss of crop production through direct consumption of fruit, nut, seed, or vegetation	41 A (77%)	9 B (15%)	49 A (69%)	10 (34%)	10 (38%)	0 B	1 (7%)	0 B
Loss of vigor or direct mortality of plant	2 BC (4%)	43 A (70%)	12 B (17%)	14 (48%)	4 (15%)	--	--	--
Damage to irrigation infrastructure or loss of water down burrow system	1 C (2%)	9 B (15%)	9 B (13%)	5 (17%)	4 (15%)	3 AB (30%)	8 (57%)	1 B (7%)
Disease transmission or consumption or contamination of feed in dairies and feedlots	8 B (15%)	--	1 C (1%)	--	8 (31%)	--	--	--
Depredation of livestock	1 C (2%)	--	--	--	--	7 A (70%)	5 (36%)	14 A (93%)

[a] Values in the same column with the same letter did not differ ($P < 0.05$).
[b] There was no significant difference ($P > 0.05$) in the reported forms of damage for this species or region.
c Analysis was divided into three groupings given significant differences between the Coastal, Valley, and Mountain and Statewide (Mt & Stwd) regions.

number of responses for each potential form of damage for this region (exact multinomial test, $P = 0.080$).

For all other pests, we did not observe a regional effect (Fisher's exact test, $P \geq 0.073$), but we did observe a difference in the most commonly identified forms of damage for birds (exact multinomial test, $P < 0.001$), gophers (exact multinomial test, $P < 0.001$), and ground squirrels (exact multinomial test, $P < 0.001$), though not for voles (exact multinomial test, $P = 0.135$) or wild pigs (exact multinomial test, $P = 0.275$; Table 9). For birds and ground squirrels, loss of crop production through direct consumption of fruit, nut, seed, or vegetation (77% and 69% of responses, respectively) was the most common form of damage (Table 9). For gophers, loss of vigor or direct mortality of the plant (70% of responses) was the primary form of damage.

Methods of control

The methods used most frequently (Fisher's exact test, $P < 0.001$) and most effectively (Fisher's exact test, $P < 0.001$) to control bird pests differed regionally (Table 10); methods of control were substantially different between the coastal region and all other regions (most frequently and most effectively: Fisher's exact test, $P < 0.001$). For both the coastal region and all other regions, there was a significant difference in the methods most frequently (exact multinomial test, $P < 0.001$) and most effectively (exact multinomial test, $P < 0.001$) used to control bird pests. For the coastal region, exclusionary devices (75% of all responses) were the primary method used to control bird pests and were also considered the most effective approach (82% of responses; Table 10). There was no difference between the methods used most frequently and those deemed most effective for the coastal region (Fisher's exact test, $P = 0.590$; Table 10).

For all other regions, frightening devices were used most frequently (84% of responses) to control bird pests, while frightening devices (37% of responses) and shooting (22% of responses) were considered to be the most effective methods of control (Table 10). In contrast to the coastal region, we observed a significant difference between those methods indicated as the most frequently used and those deemed most effective (Fisher's exact test, $P < 0.001$). This was due in large part to a significant difference in the percentage of survey participants who identified frightening devices as the most frequently used method (84% of responses) compared to those individuals who thought these devices were the most effective method of control (37% of responses; Fisher's exact test, $P < 0.001$; Table 10). Additionally, we saw a significantly larger percentage of respondents (Fisher's exact test, $P = 0.023$) who felt that shooting (22% of responses) was the most effective method of control for bird pests when compared to the number or individuals who thought that shooting was the most frequently used method of control (5% of responses; Table 10). No other control methods differed between the proportion listed as most frequently used and those identified as most effective (Fisher's exact test, $P \geq 0.102$; Table 10).

For ground squirrels, we also observed a significant regional difference in the methods most frequently used to control this pest (Fisher's exact test, $P = 0.008$). This difference was solely due to the mountain region (comparisons between the mountain and all other regions: Fisher's exact test, $P \leq 0.006$; comparisons between all other regions: Fisher's exact test, $P \geq 0.480$). Given that we only had 4 responses for this region (Table 11) combined with the fact that we noted no regional difference for the methods deemed most effective for ground squirrel control (Fisher's exact test, $P = 0.070$), we decided to combine the mountain region with all other

Table 10. A comparison of control methods used most frequently (Freq) and those considered most effective (Effect) for controlling bird pests in California. Data were separated into the coastal region and all other regional categories combined given differences in responses between the coastal region and all other regions.

	Coastal					Combined[d]				
Control method	Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]	Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]
Poison baits	0	B	0	B	0	1 (2%)	B	4 (10%)	BC	+3
Traps	0	B	0	B	0	1 (2%)	B	5 (12%)	BC	+4
Habitat modification	1 (8%)	B	2 (18%)	AB	+1	2 (5%)	B	1 (2%)	C	–1
Biocontrol	0	B	0	B	0	1 (2%)	B	0	C	–1
Exclusionary devices	9 (75%)	A	9 (82%)	A	0	1 (2%)	B	5 (12%)	BC	+4
Chemical repellents	0	B	0	B	0	0	B	2 (5%)	BC	+2
Frightening devices	2 (17%)	AB	0	B	–2	36 (84%)	A	15 (37%)	A	–21**
Shooting	0	B	0	B	0	2 (5%)	B	9 (22%)	AB	+7**

[a] Data provided includes the number of responses for each region as well as the percentage of total responses for that same region.
[b] MC = mulitiple comparisons. All comparisons were conducted using the exact multinomial test. Control methods in the same column with the same letter did not differ ($P < 0.05$).
[c] The difference (Dif) in the number of responses by region between control methods listed to be most frequently used and those listed to be most effective. Proportions that were significantly different are indicated with **.
[d] The proportion of responses for control methods used most frequently and those deemed most effective differed ($P < 0.05$).

Table 11. A comparison of control methods used most frequently (Freq) and those considered most effective (Effect) for controlling common wildlife pests in California.

Control method	Gopher Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]	Ground squirrel Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]	Vole Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]
Poison baits	35 (57%)	A	23 (40%)	A	–12	62 (85%)	A	55 (77%)	A	–7	21 (68%)	A	19 (63%)	A	–2
Fumigants	4 (7%)	C	11 (19%)	A	+7	3 (4%)	B	10 (14%)	B	+7	0	B	0	C	0
Traps	17 (28%)	B	17 (30%)	A	0	2 (3%)	B	1 (1%)	C	–1	3 (10%)	B	2 (7%)	BC	–1
Habitat modification	3 (5%)	C	2 (4%)	B	–1	1 (1%)	B	2 (3%)	C	+1	7 (23%)	B	7 (23%)	BC	0
Biocontrol	0	C	2 (4%)	B	+2	3 (4%)	B	1 (1%)	C	–2	0	B	0	C	0
Exclusionary devices	0	C	1 (2%)	B	+1						0	B	0	C	0
Chemical repellents											0	B	1 (3%)	BC	+1
Frightening devices											0	B	1 (3%)	BC	+1
Explosive	2 (3%)	C	0	B	–2	1 (1%)	B	0	C	–1					
Shooting	0	C	1 (2%)	B	+1	4 (5%)	B	2 (3%)	C	–2					

Control method	Wild pig Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]	Coyote[d] Freq[a]	MC[b]	Effect[a]	MC[b]	Dif[c]
Poison baits						1 (3%)	C	2 (6%)	B	+1
Fumigants						0	C	0	B	0
Traps	8 (26%)	AB	9 (28%)	AB	+1	9 (24%)	B	14 (44%)	A	+5
Habitat modification	1 (3%)	C	2 (6%)	BC	+1	1 (3%)	C	2 (6%)	B	+1
Biocontrol										
Exclusionary devices	2 (6%)	BC	5 (16%)	BC	+3	1 (3%)	C	2 (6%)	B	+1
Chemical repellents										
Frightening devices	1 (3%)	C	0	C	–1	0	C	1 (3%)	B	+1
Explosive										
Shooting	19 (61%)	AB	16 (50%)	AB	–3	25 (68%)	A	11 (34%)	A	–14**

[a] Data provided includes the number of responses for each species as well as the percentage of total responses for that same species.
[b] MC = mulitiple comparisons. All comparisons were conducted using the exact multinomial test. Control methods in the same column with the same letter did not differ ($P < 0.05$).
[c] The difference (Dif) in the number of responses by pest group between control methods listed to be most frequently used and those listed to be most effective for wildlife pest control. Proportions that were significantly different are indicated with **.
[d] The proportion of responses for control methods used most frequently and those deemed most effective differed ($P < 0.05$).

regions for further analysis. We did observe a significant difference in both the frequency (exact multinomial test, $P < 0.001$) and effectiveness (exact multinomial test, $P < 0.001$) of control methods for ground squirrels. Of these methods, poison baits were used most frequently (85% of responses) and were considered the most effective method of control (77% of responses; Table 11).

We observed no regional differences for all other wildlife pests (Fisher's exact test, $P \geq 0.056$), but did observe a difference in responses for the methods used most frequently (exact multinomial test, $P < 0.001$) and those deemed most effective (exact multinomial test, $P < 0.001$) for these same pests. For gophers, poison baits were used most frequently (57% of responses; Table 11), while poison baits, traps, and fumigants were considered most effective (40%, 30%, and 19% of responses, respectively; Table 11). The use of poison bait was both the most frequently used method (68% of responses; Table 11) and considered most effective (63% of responses; Table 11) for controlling voles. For wild pigs, shooting and trapping were both the most frequently used (61% and 26% of responses for shooting and trapping, respectively; Table 11) and most effective (50% and 28% of responses for shooting and trapping, respectively; Table 11) methods of control. Shooting was also the most frequently used method (68% of responses; Table 11) for controlling coyotes. Both shooting and trapping (34% and 44% of responses, respectively; Table 11) were equally effective.

We observed no significant difference between the methods used most frequently and those deemed most effective for gophers (Fisher's exact test, $P = 0.068$), ground squirrels (Fisher's exact test, $P = 0.230$), voles (Fisher's exact test, $P = 0.939$), or wild pigs (Fisher's exact test, $P = 0.509$) (Table 11). However, we did observe a significant difference for coyotes (Fisher's exact test, $P = 0.050$). This difference was driven primarily by a lower percentage of respondents who felt that shooting was an effective control method (34%) as compared to the percentage who listed it as the most frequently used method (68%; Fisher's exact test, $P = 0.008$; Table 11).

Regional responses as to why survey participants believed that the most frequently used and most effective methods differed did not vary for any wildlife pest (Fisher's exact test, $P \geq 0.514$). There was no significant difference among any of the responses for ground squirrels or voles (exact multinomial test, $P \geq 0.132$; Table 12). However, responses did differ for birds (exact multinomial test, $P < 0.001$), gophers (exact multinomial test, $P < 0.001$), wild pigs (exact multinomial test, $P = 0.031$), and coyotes (exact multinomial test, $P = 0.044$). For these pests, the most effective method was frequently stated to be too costly (43%, 40%, 33%, and 18% for responses for birds, gophers, wild pigs, and coyotes, respectively; Table 12). Other common responses were that the most effective method often required special certification to apply or was too restrictive to use (41%, 27%, and 22% for coyotes, birds, and wild pigs, respectively; Table 12), and that there was a lack of knowledge on which control method was most effective (28% and 27% for wild pigs and gophers, respectively; Table 12). Other responses were rarely listed as important factors (Table 12).

Needed advancements

Responses for areas of needed advancement and research in control methods differed for all wildlife pests (birds: $F_{14,217} = 10.4$, $P < 0.001$; gophers: $F_{19,237} = 6.2$, $P < 0.001$; ground squirrels: $F_{19,293} = 6.0$, $P < 0.001$; voles: $F_{19,106} = 2.1$, $P = 0.010$; wild pigs: $F_{19,113} = 2.5$, $P =$

Table 12. A comparison of the number and percentage of responses (Resp) as to why survey participants believed that the most frequently used methods and the most effective methods to control the most common wildlife pests in California differed.

Reason	Bird		Gopher		Ground squirrel		Vole		Wild pig		Coyote	
	Resp	MC[a]	Resp	MC[a]	Resp	MC[ab]	Resp	MC[ab]	Resp	MC[a]	Resp	MC[a]
Too costly	16 (43%)	A	12 (40%)	A	6 (19%)		3 (30%)		6 (33%)	A	3 (18%)	AB
Timing inappropriate	1 (3%)	C	0	B	6 (19%)		1 (10%)		2 (11%)	AB	1 (6%)	AB
Lack of knowledge	3 (8%)	BC	8 (27%)	A	8 (26%)		4 (40%)		5 (28%)	AB	1 (6%)	AB
Too restrictive	10 (27%)	AB	4 (13%)	AB	6 (19%)		1 (10%)		4 (22%)	AB	7 (41%)	A
Inhumane or ecologically unsafe	1 (3%)	C	4 (13%)	AB	2 (6%)		0		1 (6%)	AB	3 (18%)	AB
Limited by endangered species	5 (14%)	BC	1 (3%)	B	1 (3%)		1 (10%)		0	B	2 (12%)	AB
Limited due to organic needs	1 (3%)	C	1 (3%)	B	2 (6%)		0		0	B	0	B

[a] MC = mulitiple comparisons. All comparisons were conducted using the exact multinomial test. Control methods with the same letter in the same column did not differ ($P < 0.05$).

[b] The proportion of responses for this species did not differ ($P > 0.05$).

0.001; coyotes: $F_{19,141} = 4.1$, $P < 0.001$). For all pests, there was a significant difference in response to the listed options (birds: $F_{4,217} = 29.7$, $P < 0.001$; gophers: $F_{4,237} = 12.0$, $P < 0.001$; ground squirrels: $F_{4,293} = 13.3$, $P < 0.001$; voles: $F_{4,106} = 6.4$, $P < 0.001$; wild pigs: $F_{4,113} = 6.9$, $P < 0.001$; coyotes: $F_{4,141} = 14.5$, $P < 0.001$). However, we observed no significant difference by region (birds: $F_{2,217} = 0.1$, $P = 0.894$; gophers: $F_{3,237} = 0.1$, $P = 0.987$; ground squirrels: $F_{3,293} = 0.03$, $P = 0.994$; voles: $F_{3,106} = 0.1$, $P = 0.986$; wild pigs: $F_{3,113} = 0.1$, $P = 0.980$; coyotes: $F_{3,141} = 0.2$, $P = 0.904$) or in any research-needs × region interaction (birds: $F_{8,217} = 1.7$, $P = 0.107$; gophers: $F_{12,237} = 1.7$, $P = 0.073$; ground squirrels: $F_{12,293} = 1.7$, $P = 0.070$; voles: $F_{12,106} = 0.9$, $P = 0.529$; wild pigs: $F_{12,113} = 1.3$, $P = 0.242$; coyotes: $F_{12,141} = 1.0$, $P = 0.435$) for any of the 6 wildlife pest groupings. For these pests, greater advancements in control methods were listed as a top research priority ($\bar{x}$ rank = 3.71–4.62; Table 13). A better understanding of the economic damage caused by wild pigs ($\bar{x}$ rank = 3.63) and the juxtaposition of crop fields and natural areas on the distribution and population dynamics of wild pigs ($\bar{x}$ rank = 3.04) and voles ($\bar{x}$ rank = 3.43) were also considered high priorities (Table 13). A greater understanding of the biology of pest species ($\bar{x}$ rank = 2.12–3.01) and greater knowledge of the impact of control methods to the environment ($\bar{x}$ rank = 2.27–3.06) were frequently the lowest scoring responses (Table 13).

Preferred control methods

We found that rankings associated with various control methods were not equivalent ($F_{39,1029} = 4.7$, $P < 0.001$). These rankings varied depending on the control method in question ($F_{9,1029} = 6.5$, $P < 0.001$). Collectively, baiting ($\bar{x}$ rank = 3.92), trapping ($\bar{x}$ rank = 3.83), and biocontrol ($\bar{x}$ rank = 3.61) were considered the most appealing methods of control (Table 14). The use of frightening ($\bar{x}$ rank = 3.19) and gas explosive devices ($\bar{x}$ rank = 2.91) were least appealing (Table 14).

Rankings did not vary by region ($F_{3,1029} = 2.1$, $P = 0.094$), but we did observe a significant control method × region interaction ($F_{27,1029} = 3.5$, $P < 0.001$). The use of baiting ($\bar{x}$ rank = 3.45–4.41), trapping ($\bar{x}$ rank = 3.32–4.09), and biocontrol ($\bar{x}$ rank = 3.00–3.98) typically scored high, although trapping scores were lower for the central and desert valley regions ($\bar{x}$ rank = 3.32), while biocontrol scored low for the statewide region ($\bar{x}$ rank = 3.00; Table 15). The appeal of chemical repellents ($\bar{x}$ rank = 3.13–3.38), frightening devices ($\bar{x}$ rank = 2.91–3.60), and gas explosive devices ($\bar{x}$ rank = 2.75–3.02) was typically quite low, although frightening devices did score somewhat higher for the statewide region ($\bar{x}$ rank = 3.60; Table 15). Other control methods exhibited variable responses. For example, exclusionary devices were the most appealing control method in the coastal region ($\bar{x}$ rank = 4.03), but were the least appealing method in the central and desert valley region ($\bar{x}$ rank = 2.58; Table 15). Likewise, the scores associated with shooting ($\bar{x}$ rank = 2.91) and fumigants ($\bar{x}$ rank = 3.18) were low for the coastal region, but were relatively high for the statewide region (shooting: $\bar{x}$ rank = 3.75, fumigants: $\bar{x}$ rank = 3.95; Table 15).

Use of IPM for wildlife pest control

Collectively, survey respondents felt that most individuals responsible for wildlife pest control in agriculture currently rely on an IPM approach (69 respondents) as opposed to a single control method (44 respondents; exact binomial test, $P = 0.024$). However, this response did vary

Table 13. Mean rank scores in areas of needed research for the 6 most frequently listed wildlife pests in California. Multiple comparisons (MC) using Fishers LSD were conducted to test for differences in rank scores within each species.

	Bird		Gopher		Ground squirrel		Vole		Wild pig		Coyote	
Response[a]	Rank[b]	MC[c]	Rank[b]	MC[c]	Rank[b]	MC[c]	Rank[b]	MC[c]	Rank[b]	MC[c]	Rank[b]	MC[c]
Biology	2.41	BC	2.68	B	2.05	C	3.01	BC	2.22	C	2.12	C
Control methods	4.62	A	4.21	A	4.28	A	4.44	A	3.71	A	4.31	A
Economic damage	2.87	B	2.99	B	3.15	B	2.38	BC	3.63	A	3.29	B
Environment	2.31	C	2.61	B	3.06	B	2.27	C	2.41	BC	2.74	BC
Juxtaposition of habitat	2.88	B	2.67	B	2.65	BC	3.43	B	3.04	AB	2.59	C

[a] Responses include: biology = greater knowledge in biology of the pest; control methods = greater advancements in control methods of this pest; economic damage = greater knowledge of the economic damage caused by this pest; environment = greater knowledge on the impact of available pest control methods to the environment; and juxtaposition of habitat = greater understanding of how the juxtaposition of crop fields and natural areas influences the distribution and population dynamics of the pest.
[b] Possible ranks ranged from 1–5 with 5 indicating most important and 1 indicating least important. Each rank could be used only once for each pest.
[c] Means in the same column with the same letter did not differ ($P < 0.05$).

Table 14. Mean rank scores indicating the appeal of each of the below-listed wildlife pest control methods throughout California. Multiple comparisons (Fishers LSD) were conducted to test for differences in rank scores across each control method.

Control method	Rank[a]	Multiple comparison[b]
Bait	3.92	A
Trap	3.83	AB
Biocontrol	3.61	ABC
Habitat modification	3.57	BCD
Fumigant	3.54	BCD
Shooting	3.46	CDE
Exclusion	3.39	CDE
Repellent	3.25	DE
Frightening device	3.19	EF
Explosive device	2.91	F

[a] Possible ranks ranged from 1–5 with 5 indicating highly desirable and 1 indicating highly undesirable.
[b] Means with the same letter did not differ ($P < 0.05$).

Table 15. Mean rank scores indicating the appeal of each of the below-listed wildlife pest control methods for Coastal, Mountain, Valley, and Statewide regions throughout California. Multiple comparisons (Fishers LSD) were conducted to test for differences in rank scores across each control method within the same regional class (Meth) and for each control method across regional classes (Reg).

	Coastal			Mountain			Valley			Statewide		
Control method	Rank[a]	Meth[b]	Reg[c]	Rank[a]	Meth[b]	Reg[c]	Rank[a]	Meth[b]	Reg[c]	Rank[a]	Meth[b]	Reg[c]
Bait	3.61	AB	Z	3.45	AB	Z	4.22	A	Y	4.41	A	Y
Trap	3.94	A	Y	4.09	A	Y	3.32	BC	Z	3.95	AB	Y
Biocontrol	3.97	A	Y	3.50	AB	YZ	3.98	AB	Y	3.00	CD	Z
Habitat modification	3.79	A	Y	3.45	AB	Y	3.41	BC	Y	3.62	BC	Y
Fumigant	3.18	BC	Z	3.44	AB	YZ	3.58	B	YZ	3.95	AB	Y
Shooting	2.91	C	Z	3.67	AB	YZ	3.53	B	Y	3.75	B	Y
Exclusion	4.03	A	Y	3.30	AB	YZ	2.58	D	Z	3.67	B	Y
Repellent	3.13	BC	Y	3.22	AB	Y	3.28	BC	Y	3.38	BCD	Y
Frightening device	2.94	C	Z	2.91	B	YZ	3.30	BC	YZ	3.60	BCD	Y
Explosive device	2.75	C	Y	2.90	B	Y	3.02	CD	Y	2.95	D	Y

[a] Possible ranks ranged from 1–5 with 5 indicating highly desirable and 1 indicating highly undesirable.
[b] Means in the same column with the same letter did not differ ($P < 0.05$).
[c] Means in the same row with the same letter did not differ ($P < 0.05$).

regionally (Fisher's exact test, $P = 0.024$; Table 16). Most respondents in the mountain (83%) and statewide (80%) regions believed that an IPM approach was typically used to control wildlife pests, while those in the central and desert valley region were split on whether an IPM approach or a single control method (47% versus 53% for each, respectively) were typically used to control such pests (Table 16). Reasons for not using an IPM approach varied (exact multinomial test, $P < 0.001$), although the primary reasons provided were a preference for using a single method that has proven effective (43% of respondents) and a lack of effective control methods for managing wildlife pests thereby eliminating the possibility of following an IPM program (30% of respondents; Table 17). There was no regional impact on this response (Fisher's exact test, $P = 0.702$).

Preferred attributes of control methods

We found that rankings associated with various attributes of control methods were not equivalent ($F_{19,545} = 33.4$, $P < 0.001$); these rankings varied depending on the attribute in question ($F_{4,545} = 105.8$, $P < 0.001$). Collectively, efficacy was the most important attribute ($\bar{x}$ rank = 4.51; Table 18). Methods that were quick and inexpensive were also highly preferred ($\bar{x}$ rank = 3.62), while the humaneness of a control method was least important ($\bar{x}$ rank = 1.76; Table 18).

Rankings did not vary by region ($F_{3,545} = 0.1$, $P = 0.977$), but we did observe a significant attribute × region interaction ($F_{12,545} = 3.5$, $P < 0.001$). Efficacy was consistently the most important attribute across regions ($\bar{x}$ rank = 4.49–4.53; Table 19). Those methods that were quick and inexpensive also scored high across all regions ($\bar{x}$ rank = 3.42–4.02), although this appeared to be more important in the central and desert valley region (Table 19). The importance of the level of safety to the environment ($\bar{x}$ rank = 2.15–2.97) and the potential hazard of a control method to the applicator ($\bar{x}$ rank = 2.23–3.14) varied regionally, with the potential of hazard to the applicator scoring higher in the central and desert valley ($\bar{x}$ rank = 2.85) and statewide regions ($\bar{x}$ rank = 3.14; Table 19). There was no statistical difference in the coastal and mountain regions between these two attributes, although environmental safety scored slightly higher in these regions (Table 19). The humaneness of a control method always scored low ($\bar{x}$ rank = 1.28–2.23; Table 19).

DISCUSSION

Ground squirrels

The California ground squirrel has long been considered to be one of the most damaging wildlife pests in California (Marsh 1998). Ground squirrels were a particularly large pest in the central and desert valleys (Table 6). This region of the state is responsible for much of the nut and tree fruit production that occurs in California, for which consumption of these food sources was the primary form of damage caused by ground squirrels (Table 9). However, ground squirrels will also girdle trees, consume green vegetation, and cause considerable damage to irrigation hose, microsprinklers, and irrigation canals (Table 9). In fact, ground squirrels were among the highest ranking pests with respect to the amount of damage caused (Table 7), with previous estimates of damage ranging from \$20–\$28 million annually (Marsh 1998).

Table 16. A comparison of the number and percentage of survey takers who believe that most individuals involved in wildlife pest control in agricultural commodities in California use either a single method or an IPM approach for controlling these pests. Survey participants were broken into Coastal, Mountain, Valley, and Statewide regions for analysis.

Region	Single method	IPM	Multiple comparison[a]
Coastal	13 (39%)	20 (61%)	AB
Mountain	2 (17%)	10 (83%)	A
Valley	25 (53%)	22 (47%)	B
Statewide	4 (20%)	16 (80%)	A

[a] MC = mulitiple comparisons. All comparisons were conducted using Fishers exact test. Regions with the same letter did not differ ($P < 0.05$).

Table 17. A comparison of the number and percentage of responses (Resp) as to why survey participants believed that some individuals do not use an IPM program for controlling wildlife pests in California.

Reasons	Resp	MC[a]
They prefer to use a single method that has proven effective.	36 (43%)	A
There is a lack of tools to control some wildlife pests; therefore, utilizing more than a single method that has proven effective may not be possible.	25 (30%)	A
They are not aware of what an IPM program is or how it is implemented.	9 (11%)	B
There is a lack of cost-benefit studies showing potential financial savings using an IPM program.	9 (11%)	B
There is a lack of research indicating the effectiveness of an IPM program.	4 (5%)	B

[a] MC = mulitiple comparisons. All comparisons were conducted using the binomial exact test. Responses with the same letter did not differ ($P < 0.05$).

Table 18. Mean rank scores indicating which attributes of a control method are most important to agricultural clientele throughout California. Multiple comparisons (Fishers LSD) were conducted to test for differences in rank scores across each attribute.

Attribute	Rank[a]	Multiple comparison[b]
Efficacy	4.51	A
Quick and inexpensive	3.62	B
Hazard to applicator	2.69	C
Environmentally safe	2.54	C
Humane	1.76	D

[a] Possible ranks ranged from 1–5 with 5 indicating most important and 1 indicating least important.
[b] Means with the same letter did not differ ($P < 0.05$).

Table 19. Mean rank scores indicating which attributes of a control method are most important to agricultural clientele for Coastal, Mountain, Valley, and Statewide regions throughout California. Multiple comparisons (Fishers LSD) were conducted to test for differences in rank scores across each attribute within the same regional class (Attr) and for each attribute across regional classes (Reg).

	Coastal			Mountain			Valley			Statewide		
Attribute	Rank[a]	Attr[b]	Reg[c]	Rank[a]	Attr[b]	Reg[c]	Rank[a]	Attr[b]	Reg[c]	Rank[a]	Attr[b]	Reg[c]
Efficacy	4.53	A	X	4.50	A	X	4.49	A	X	4.52	A	X
Quick and inexpensive	3.42	B	Y	3.62	B	XY	4.02	B	X	3.43	B	Y
Hazard to applicator	2.52	C	YZ	2.23	C	Z	2.85	C	XY	3.14	B	X
Environmentally safe	2.97	BC	X	2.69	C	XY	2.36	D	Y	2.15	C	Y
Humane	1.72	D	X	2.23	C	X	1.28	E	Y	1.81	C	X

[a] Possible ranks ranged from 1–5 with 5 indicating most important and 1 indicating least important. Each rank could be used only once.
[b] Means in the same column with the same letter did not differ ($P < 0.05$).
c Means in the same row with the same letter did not differ ($P < 0.05$).

The primary method for controlling ground squirrels was the use of poison baits (85%; Table 11); this approach was also deemed most effective (77%; Table 11). The primary toxicants used to control ground squirrels are first-generation anticoagulants (chlorophacinone and diphacinone) and zinc phosphide. These toxicants are usually delivered through a grain-based carrier such as oats or wheat. Both anticoagulant and zinc phosphide baits can be highly effective and are typically cheaper to apply than other alternatives (Salmon et al. 2000, 2007). However, burrow fumigation (primarily aluminum phosphide and gas cartridges) is also highly effective (Salmon et al. 1982, Baldwin and Holtz 2010), and is typically more effective than baiting in early spring when ground squirrels are eating primarily green foliage; this preference for green foliage limits their desire to consume grain-based baits. Burrow fumigants do have limitations as well, most notably the time and labor cost required to treat each burrow system, and the need for relatively high soil moisture to hold toxic gases within the burrow system. Still, burrow fumigants were clearly considered to be the second most effective option for ground squirrel control (Table 11).

Even with the availability of several effective options for ground squirrel control, there was still a strong belief among survey participants that greater advancements in control efforts were needed (Table 13). Although tools like baiting and burrow fumigation are effective in many situations, they do not solve all ground squirrel problems. For example, ground squirrels can cause substantial damage in almond orchards. However, baiting is not effective in these orchards during the summer given the abundance of a more preferred food (i.e., almonds). Burrow fumigation is also not effective at this time given relatively dry soil conditions, and most other options are less effective or too costly and time-consuming to implement (e.g., trapping: Horn and Fitch 1946; explosive device: Sullins and Sullivan 1992). The development of a control method that could effectively reduce ground squirrel populations in this situation would be highly useful to many growers throughout the state.

Pocket gophers

Like ground squirrels, pocket gophers cause extensive damage to a wide variety of crops (Table 8). However, in contrast to ground squirrels, primary gopher damage is attributed to a loss in vigor or direct mortality of plants (Table 9). Other common forms of damage include consumption of crops and damage to irrigation infrastructure. Although gopher damage is fairly consistent across most crops, damage was highest in alfalfa (8.8% loss; Table 8), where they have been reported to cause a 43–46% reduction in alfalfa production over the course of one year (Luce et al. 1981). Similar investigations in Nevada and Utah noted that gophers caused either the greatest or the second greatest level of damage to alfalfa of all wildlife pests considered (Lewis and O'Brien 1990, Messmer and Schroeder 1996).

The primary method for controlling gophers in California was poison baiting (57%), followed by trapping (28%) and burrow fumigants (7%; Table 11). Baiting (i.e., strychnine, zinc phosphide, and first-generation anticoagulants [chlorophacinone and diphacinone]) is generally considered to be the quickest and cheapest form of control for pocket gophers, particularly if the bait is applied via an artificial burrow builder machine (Marsh 1992). The use of burrow fumigation (primarily aluminum phosphide) and trapping are generally considered to be more labor intensive, time-consuming, and costly (Marsh 1992, Summers 1998, Engeman and Witmer 2000). As such, these approaches are used less frequently in agricultural fields.

Although baiting was frequently used (57%), we observed a noticeably lower percentage of respondents who listed it as the most effective method (40%), while we saw a substantial increase in the percentage of respondents who named fumigation as the most effective approach (frequency = 7%, effective = 19%); trapping remained consistent (frequency = 28%, effective = 30%). The efficacy of baiting has varied tremendously across studies (e.g., 0–100%; Tickes et al. 1982, Evans et al. 1990) likely due to a variety of factors including bait type and bait-applicator experience (Baldwin et al. 2011). Alternatively, trapping and burrow fumigation provide more consistent results and are often considered more effective than baiting for gopher control (Lewis and O'Brien 1990, Proulx 1997, Baker 2004). Unfortunately, the cost of trapping and burrow fumigation to control gophers is often considered too high by most growers (Table 12). Additionally, survey participants felt that many individuals who deal with gopher damage do not realize that trapping and burrow fumigation can be more effective than baiting (Table 12); this should be considered more thoroughly as greater awareness could increase the effectiveness of gopher control throughout California. Regardless, most survey respondents listed advancements in control methods as the primary area of need with respect to gopher management (Table 13). Gopher control can be quite challenging given their almost exclusive use of underground burrow systems which makes targeting this pest difficult. Currently, we have techniques that are either quick to apply (i.e., bait application via burrow builder) or consistently efficacious (trapping and burrow fumigation), but not both. The development of such a tool would greatly increase an individual's ability to control this damaging pest.

Birds

Primary bird pests included crows (*Corvus brachyrhynchos*), blackbirds (*Agelaius* spp.), and starlings (*Sturnus vulgaris*; Table 4). Individually, none of these bird species were considered as great a pest as pocket gophers, ground squirrels, voles, wild pigs, or coyotes (Table 4), although collectively, birds were considered substantial pests, particularly by those who managed agricultural commodities or wildlife pests statewide (Table 6). This strong statewide response is most likely representative of the respondent's employer, as 63% (10 of 16 total bird responses) of the individuals who listed birds as one of the most frequent pests in the statewide region worked for governmental agencies (either CDFG or Wildlife Services). These individuals are responsible for much of the bird control that occurs in California. As such, they likely had a stronger opinion on the impact caused by these pests. We did not observe this same regional effect when assessing the need for improved methods of control. In fact, we observed significantly higher mean rank scores for needed advancements in control methods ($\bar{x}$ rank = 1.07) compared to the frequency of complaints ($\bar{x}$ rank = 0.67) indicating that bird control is a substantial area of concern throughout California.

As with gophers and ground squirrels, birds cause extensive and quite varied forms of damage, although the consumption of nuts, fruits, seeds, and vegetation was the primary form of damage reported in our study (Table 9). This was further illustrated by the large losses estimated in nut (9.6%) and grape (9.0%) crops where previous estimates of damage have ranged from 0–30% and 0–77%, respectively, for a variety of bird pests (Gebhardt et al. 2011). Primary methods employed to control this damage varied regionally, with exclusionary devices used most frequently in the coastal region (75% of responses), while frightening devices were frequently used in all other regions (84% of responses; Table 10). These differences were likely driven by the type and value of crops grown in the coastal region, as many of the highest value crops found in California (e.g., artichokes, cole crops, leafy greens, and wine grapes) are grown in this region. Physical exclusionary devices such as bird netting are widely considered to be one of the most effective methods for reducing bird damage to many crops, yet netting is also very expensive (Fuller-Perrine and Tobin 1993). Given the high value of many of the crops grown in the coastal region, netting was often a cost effective strategy. As such, growers in the coastal region were able to use the method they felt was most effective.

Frightening devices were clearly not the preferred method for bird control in all other regions, while shooting, trapping, baiting, and exclusionary devices all showed substantial increases in preference (Table 10). Frightening devices such as propane cannons and reflective tape are relatively cheap to use but are generally only effective for a few days to a few weeks (Gilsdorf et al. 2002). However, although shooting, trapping, and baiting may be deemed more effective, there are many restrictions involved in the take of most bird species through these approaches. For example, most bird species require a depredation permit if they are to be trapped or shot, while no avicides are currently available for use by anyone other than Wildlife Services. It is these greater costs and restrictions that appear to limit the use of lethal approaches for bird control in many portions of California and likely the rest of the U.S. Given the high cost of exclusion, the dissatisfactory efficacy associated with frightening devices, and substantial restrictions associated with lethal removal approaches, it is not surprising that most respondents identified a desire for better control methods as the primary area of advancement needed for this pest.

Coyotes

The frequency with which coyotes were reported as pests also differed regionally, as coyote-human conflict was highest in the mountain region (Table 6) where much of the rangeland exists in California. The need for advancements in control methods was consistent with the frequency of complaints for this pest (Table 5). The primary concern with coyotes was depredation of livestock, with losses by coyotes predictably the greatest in rangelands (8.9% loss), and to a lesser extent, dairies and feedlots (3.9%; Table 8). Similar losses have been reported throughout the U.S. (e.g., reported losses to Animal Damage Control offices = $9.9 million; Connolly 1992). Damage to irrigation infrastructure through chewing was also a large concern, particularly in the central and desert valleys where irrigation through drip lines and microsprinklers was common (Table 9). The reported value of coyote damage to irrigation infrastructure was $132,000 in 1990 (Connolly 1992), but actual values are believed to be substantially higher than this amount. Nonetheless, greater information on economic damage caused by coyotes is needed to gain a better grasp of the impact of this pest on agricultural commodities as illustrated by the high rank of this research need (Table 13).

Throughout California, coyotes were most frequently controlled through shooting. However, we observed a significantly lower proportion of individuals who felt that shooting was the most effective form of control (Table 11). Although not significantly different from shooting, trapping was considered the most effective control method for coyotes (Table 11). Primary traps used to capture coyotes throughout most of the U.S. include foothold traps and snares. However, these traps are not currently legal for use in most cases in California. This restriction serves as the likely explanation why survey particpants felt that the most frequently used and most effective methods for coyote control differed (Table 12). The loss of this valuable management tool, along with the loss of sodium cyanide in 1998 (Connolly 2002), has resulted in few options for coyote control in California. Not surprisingly, development of new and more effective control methods, or perhaps a relaxation of current trapping regulations in California, was the primary area of needed advancement selected in our survey (Table 13).

Wild pigs

We observed no regional difference in the ranking for frequency of complaints for wild pigs. However, rankings for needed advancements in control were significantly higher than the frequency of complaints (Table 5) indicating a strong belief that alternative or more efficient methods of control are needed for this pest (Table 13). Currently, trapping and shooting are the most frequently used methods of control and are considered to be the most effective as well (Table 11). These methods can effectively reduce wild pig populations, but require much effort (West et al. 2009). Additionally, they are only effective long-term if adjacent property owners work in a collaborative method to reduce population size. Otherwise, populations quickly rebound and reinvade (West et al. 2009). A better understanding of the influence of the juxtaposition of adjacent habitats would likely increase control efforts as well, as wild pigs are likely to use areas with dense riparian vegetation for resting and escape cover, while areas with agricultural crops or oaks will likely be used for foraging (Schauss et al. 1990, Choquenot and Ruscoe 2003). Areas that contain both of these habitat requirements are more likely to house wild pig populations. A better understanding of this relationship, as well as extension of this knowledge to landowners, would likely increase control of this pest.

Greater knowledge on these issues is becoming increasingly important in California, as wild pig populations have expanded dramatically over the last 20 years (West et al. 2009). The impact of this increase is reflected in the large estimate of damage to a variety of agricultural commodities including nuts, grapes, and rangelands (Table 8). In fact, the collective damage estimate from wild pigs was as high as or higher than that of the other wildlife pests included in this survey (6.8% loss compared to 3.4–5.9% for other wildlife pests; Table 7), with nationwide estimates of damage reported around $1.5 billion annually (Pimentel 2007). Consumption of crops, disease transmission, and contamination of livestock and human foods are typically the primary forms of damage caused by wild pigs to agricultural commodities (West et al. 2009). Although we observed no significant difference between any of the reported forms of damage for wild pigs (Table 9), these were the components that scored highest and are likely the primary forms of damage caused by wild pigs in California as well.

Voles

Of the 6 pest groupings we focused our efforts on, voles were reported as the least frequent pest and scored lowest on the need for advancements in control methods; this did not vary regionally (Table 5). However, when voles were present, they were responsible for substantial economic losses (Table 7), particularly in alfalfa where they resulted in the greatest amount of damage of any pest in any crop (11.3%; Table 9). We observed no significant difference in the primary forms of damage caused by voles. However, 83% of all responses were either for loss of crop production or direct mortality of the plant (Table 9) which are typically the primary forms of damage caused by voles (Messmer and Schroeder 1996).

Voles are a common pest of alfalfa, although damage appears to vary substantially across species and region. For example, in Europe, the common vole (*Microtus arvalis*) resulted in 8.7%, 35.6%, and 60.2% reduction in biomass for subsequent cuttings (Babińska-Werka 1979). However, surveys conducted in Nevada and Utah indicated a relative cost of damage for voles (*Microtus* spp.) of 0.4 and 0.9, respectively, based on a scale of 0–5 (0 = no cost through 5 = high cost; Lewis and O'Brien 1990, Messmer and Schroeder 1996). These scores were substantially lower than those of other pests such as pocket gophers (3.0 and 2.4 for Nevada and Utah, respectively), deer (2.9 for Utah), and ground squirrels (1.4 for both Nevada and Utah). Based on our findings, vole damage in alfalfa in California appears to be more in line with that of Babińska-Werka (1979).

The primary method for control of voles was the use of poison baits (68% of respondents; Table 11). Poison baits were also considered to be the most effective method of control for voles which is similar to survey findings in Utah (55% of respondents; Messmer and Schroeder 1996). However, this same question in Nevada indicated cultural practices as the most effective control method (cultural practices = 47% of respondents, baiting = 35% of respondents; Lewis and O'Brien 1990). Voles are cover dependent; a reduction in cover results in increased predation which can help regulate vole populations (e.g., Getz et al. 2005). The use of habitat modification/cultural practices was the second highest scoring response for voles in our study (Table 11), and should also be considered an effective approach for controlling this pest species in some cropping systems.

The primary area in need of additional research for voles was for greater advancements in control methods (Table 13). This likely stems from a paucity of methods available to control voles in most crops during the active growing season. As already stated, the only two methods typically practical for vole control in agricultural fields are poison baits and habitat modification. Unfortunately, in many crops, one or neither of these approaches may be available. For example, in alfalfa the only poison bait that can be used is zinc phosphide and it can only be applied once every 6 months. However, rodents such as voles often exhibit bait shyness with respect to zinc phosphide (Marsh 1987), thereby rendering this approach ineffective in some situations. Additionally, habitat modification is not practical, as cover is an inherent characteristic of alfalfa. Similarly, application of most poison baits is not allowable in vineyards or orchards during the growing season when they are often most needed. In these cases, growers are left with few if any control options. The development of an alternative strategy to control voles in these situations is greatly needed.

Less frequent pests

There were other less common pests that were reported in this survey including deer (*Odocoileus hemionus*), rats (*Rattus* spp., and *Neotoma* spp.), rabbits and hares (*Lepus californicus* and *Sylvilagus* spp.), black bears (*Ursus americanus*), and beaver (*Castor canadensis*; Table 4). There are certainly scenarios where these wildlife pests cause significant damage to agricultural commodities. For example, deer and rabbits can cause substantial losses in alfalfa (Messmer and Schroeder 1996), while deer mice (*Peromyscus* spp.) can cause extensive damage to almonds in some orchards (Pearson et al. 2000). Developing effective management tools to control these pests will continue to be an important area of research, particularly as populations of invasive species such as roof rats (*Rattus rattus*) and eastern fox squirrels (*Sciurus niger*) continue to expand. However, based on the results of our survey, greater effort should be placed on research and extension efforts that target ground squirrels, gophers, birds, wild pigs, coyotes, and voles to maximize benefits associated with this effort.

Preferred control methods

Collectively, the use of poison baits ($\bar{x}$ rank = 3.92), trapping ($\bar{x}$ rank = 3.83), and biocontrol ($\bar{x}$ rank = 3.61) were the most preferred methods of control for wildlife pests, while frightening ($\bar{x}$ rank = 3.19) and gas explosive devices ($\bar{x}$ rank = 2.91) were least preferred (Table 14). However, these rankings varied regionally (Table 15). For example, rankings for exclusionary devices were much higher in the coastal region ($\bar{x}$ rank = 4.03) than in the central and desert valley region ($\bar{x}$ rank = 2.58), shooting was much higher in the mountain ($\bar{x}$ rank = 3.67) and statewide regions ($\bar{x}$ rank = 3.75) than in the coastal region ($\bar{x}$ rank = 2.91), while biocontrol ranked much higher in the coastal ($\bar{x}$ rank = 3.97) and central and desert valley regions ($\bar{x}$ rank = 3.98) than for the statewide region ($\bar{x}$ rank = 3.00). Generally speaking, the coastal region was most different, with a stronger preference for non-lethal control methods such as exclusionary devices ($\bar{x}$ rank = 4.03) and habitat modification ($\bar{x}$ rank = 3.79; Table 15). The central and desert valley region exhibited the opposite trend with a strong preference for lethal removal approaches such as baiting ($\bar{x}$ rank = 4.22), burrow fumigants ($\bar{x}$ rank = 3.58), and shooting ($\bar{x}$ rank = 3.53). These differences should not be unexpected given the more urban composition of the coastal region as opposed to the more rural make-up of the central and desert valleys. The only clear difference for the mountain region was a preference for trapping ($\bar{x}$ rank = 4.09) and a selection against frightening ($\bar{x}$ rank = 2.91) and gas explosive devices ($\bar{x}$ rank = 2.90).

Interestingly, the statewide region trended toward approaches that have proven more effective yet practical (poison baits [$\bar{x}$ rank = 4.41]—Salmon et al. 2000, 2007, Sterner et al. 1996; burrow fumigation [$\bar{x}$ rank = 3.95]—Baker 2004, Baldwin and Holtz 2010; trapping [$\bar{x}$ rank = 3.95]—Choquenot et al. 1993, Proulx 1997), while avoiding those that have not been proven effective (e.g., biocontrol [$\bar{x}$ rank = 3.00]—Marsh 1992, 1994, Witmer 2007; gas explosive devices [$\bar{x}$ rank = 2.95]—Sullins and Sullivan 1992, 1993). Given the low efficacy of biocontrol, it is curious why it scored so high in all other regions. Possible explanations for this high ranking are a lack of knowledge on the low efficacy associated with this approach, or perhaps a strong desire to find a biocontrol method that is efficacious. Certainly the reliance on natural predation would lower the costs and environmental risks associated with other alternative control methods. Regardless, the strong regional differences we observed clearly illustrate the importance of considering varying perspectives on the appropriateness of wildlife pest control methods. What may be economically and politically appropriate in one region, may not be met with the same enthusiasm elsewhere.

Use of IPM for wildlife pest control

Most individuals surveyed (61% of respondents) indicated a preference for an IPM approach for controlling wildlife pests, although this did vary regionally, as individuals in the central and desert valleys did not exhibit this preference (Table 16). We are unsure why there was such a dramatic difference in the central and desert valleys but could be due to their desire to use a single approach that has proven effective (Table 17). The two primary pests in this region were ground squirrels and pocket gophers (Table 6), for which baiting was the primary control method for both species (Table 11). These individuals may have felt that baiting alone was enough to provide satisfactory results. It seems unlikely that it is due to a lack of proven control methods, as we have more tools to control ground squirrels and gophers than most other wildlife pests.

For all other regions, IPM methods were preferred (Table 16). Following an IPM program is typically provides the best results (Engeman and Witmer 2000, Sterner 2008); such programs have been steadily incorporated into many wildlife control programs. Much time and effort has been spent on advocating the utility of this approach. It is reassuring to note that most survey respondents (89%) did not feel that a lack of knowledge on the IPM concept was a limiting factor to its implementation. Likely the greatest step that can be taken to further increase its incorporation into wildlife pest control programs is to develop alternative methods of control for those pests where options are limited (e.g., voles and coyotes). This would likely increase the level of control for most of these pests while reducing the possibility of behavioral (e.g., avoidance of strychnine baits; Marsh 1992) or physiological (resistance of voles to anticoagulants; Salmon and Lawrence 2006) resistance to the currently available control methods.

Preferred attributes of control methods

A perfect control method would be highly efficacious, quick and inexpensive to apply, safe to the environment and the applicator, and humane. However, developing control methods that achieve high scores for all of these attributes is a difficult task, so oftentimes we are forced to focus our efforts on achieving high levels of success for the most important attributes while attaining acceptable levels for less important attributes. Based on our survey, the development of a technique that is efficacious is the most important attribute ($\bar{x}$ rank = 4.51); methods that are quick and inexpensive to apply are next in importance ($\bar{x}$ rank = 3.62; Table 18). This is somewhat counter to our previous findings as we often observed differences in the frequency of use and perceived effectiveness of various control methods (Tables 11 and 12). For most pests, cost was the primary reason provided as to why the more efficacious methods were not used more frequently (Table 12). Certainly, there will be some threshold where cost overrides efficacy. For example, in 1993, almond growers were not willing to spend more than $24/acre to reduce crow damage by 50% (Hasey and Salmon 1993). It is likely that costs of more efficacious control methods exceeded this undefined level for many of the proposed human-wildlife pest conflicts in this study which resulted in the more frequent use of less efficacious methods.

While efficacy and cost effectiveness were the two most important attributes listed in our survey, humaneness scored the lowest ($\bar{x}$ rank = 1.76; Table 18). Clearly, humaneness of control methods is an important consideration as there have been many advancements and changes in many control techniques to reduce stress and injury to target species (e.g., development of padded foothold traps; Gruver et al. 1996). Additionally, there is currently a push by some to prioritize the humaneness of control methods over other desired attributes (Schmidt and Brunner 1981, Meerburg et al. 2008). Nonetheless, even with this push, other desirable attributes appear to override the importance of humaneness, at least as long as some minimal level is achieved.

The primary regional differences we observed were between the impact of control methods on the environment and potential hazard to the applicator (Table 19). Survey participants in the central and desert valley and statewide regions considered the hazard to the applicator to be the higher priority, while those individuals in the coastal and mountain regions felt environmental safety was a greater concern (Table 19). Primary concerns with environmental safety likely apply to non-target exposure to pesticides, and to a lesser extent to lead poisoning from shooting activities. For example, much research has recently been conducted on methods to reduce non-target exposure to poison baits (e.g., Whisson 1999, Whisson and Salmon 2002), while new laws have been enacted to reduce the distribution of lead bullets and shot in the environment (Kelly et al. 2011). The survey participants in the coastal and mountain regions are often considered more sensitive to these environmental concerns, which likely played a role in its higher ranking than applicator safety. However, individuals in other regions likely did not share the same level of environmental concern, and thus rated applicator safety as a greater attribute. This information should be useful when prioritizing the relevance of various control methods regionally throughout California.

MANAGEMENT IMPLICATIONS

Wildlife pests cause extensive damage to a number of agricultural commodities throughout California. However, given a finite number of resources to deal with human-wildlife conflicts, we need to most effectively utilize our available resources to combat these situations. Our findings suggest that research and extension efforts should focus on the development of better control methods for ground squirrels, pocket gophers, birds, wild pigs, coyotes, and voles. These control methods should be woven into an IPM program to maximize efficacy while minimizing negative effects to the environment. Special emphasis should be placed on control methods that are both efficacious and quick and inexpensive to apply. That being said, we did observe significant differences regionally for many of the factors we addressed in this study. It is important managers of wildlife consider these regional differences when developing an appropriate control strategy.

Although our study provides general guidance on areas to focus research and extension efforts, specialized situations with extensive or impending damage may occasionally occur that require research efforts that fall outside the areas of emphasis we have reported. For example, western gray squirrel (*Sciurus griseus*) and eastern fox squirrel populations have been expanding in California (Palmer et al. 2007, Matson et al. 2010). The possibility exists that these species could become more significant pests, thereby requiring greater research to develop effective management strategies for these pests. As such, wildlife pest control professionals need to be flexible enough to adapt to these scenarios to develop effective protocols to manage these situations.

The wildlife pests, control methods, current beliefs, and areas of needed research we have identified as most important to agricultural producers and wildlife pest managers are likely to change over time as agricultural commodities, cultivation and irrigation practices, wildlife species composition, and public opinion change. However, our survey provides the framework with which to reassess these important factors at a later date. We strongly encourage such a reassessment at least every 10–15 years as such changes are likely to occur.

ACKNOWLEDGMENTS

This project was funded by the Vertebrate Pest Control Research Advisory Committee. We would like to thank D. Bulls, M. Lopez, N. Quinn, D. Stetson, and M. Tibbets for assistance in developing and distributing this survey, to M. Remmenga for valuable statistical assistance, and to S. Shwiff for providing very useful comments on survey design. Lastly, we would like to thank all survey participants for volunteering their valuable time to complete this survey.

LITERATURE CITED

Abhat, D. 2010. A poisonous dilemma: when rodenticides move beyond their target species. The Wildlife Professional 4:28–29.

Babińska-Werke, J. 1979. Effects of common vole on alfalfa crop. Acta Theriologica 24:281–297.

Baker, R. O. 2004. Field efficacy of Fumitoxin® (55% aluminum phosphide) tablets for controlling valley pocket gopher. Proceedings of the Vertebrate Pest Conference 21:253–257.

Baldwin, R. A., and B. A. Holtz. 2010. Fumigation of California ground squirrels revisited: are fumigants an effective method for controlling ground squirrels? Proceedings of the Vertebrate Pest Conference 24:129–132.

Baldwin, R. A., J. Roncoroni, R. J. Smith, and S. Swain. 2011. Determining and demonstrating the importance of training and experience in trapping and baiting programs for controlling pocket gophers. University of California, Davis, CA. Unpublished Final Report.

Baldwin, R. A., and T. P. Salmon. 2011. The facts about rodenticides. The Wildlife Professional 5:50–53.

California Department of Food and Agriculture. 2011. Agricultural Statistical Review. http://www.cdfa.ca.gov/Statistics/PDFs/AgResourceDirectory_2010-2011/2AgOvStat10_WEB.pdf (accessed 16 July, 2011).

Choquenot, D. J., R. J. Kilgour, and B. S. Lukins. 1993. An evaluation of feral pig trapping. Wildlife Research 20:15–22.

Choquenot, D., and W. A. Ruscoe. 2003. Landscape complementation and food limitation of large herbivores: habitat-related constraints on the foraging efficiency of wild pigs. Journal of Animal Ecology 72:14–26.

Connolly, G. E. 1992. Coyote damage to livestock and other resources. Pages 161–169 *in* A. H. Boer, editor. Ecology and Management of the Eastern Coyote. Wildlife Research Unit, University of New Brunswick, Fredericton, New Brunswick, Canada.

Connolly, G. E. 2002. A history of toxicant ejectors in coyote control. Proceedings of the Vertebrate Pest Conference 20:201–218.

Engeman, R. M., and G. W. Witmer. 2000. Integrated management tactics for predicting and alleviating pocket gopher (*Thomomys* spp.) damage to conifer reforestation plantings. Integrated Pest Management Reviews 5:41–55.

Evans, J., G. H. Matschke, D. L. Campbell, P. L. Hegdal, and R. M. Engeman. 1990. Efficacy data for registration of strychnine grain baits to control pocket gophers (*Thomomys* spp.). Proceedings of the Vertebrate Pest Conference 14:82–86.

Fuller-Perrine, L. D., and M. E. Tobin. 1993. A method for applying and removing bird-exclusion netting in commercial vineyards. Wildlife Society Bulletin 21:47–51.

Gebhardt, K., A. M. Anderson, K. N. Kirkpatrick, and S. A. Shwiff. 2011. A review and synthesis of bird and rodent damage estimates to select California crops. Crop Protection 30:1109–1116.

Getz, L. L., M. K. Oli, J. E. Hofmann, and B. McGuire. 2005. Habitat-specific demography of sympatric vole populations over 25 years. Journal of Mammalogy 86:561–568.

Gilsdorf, J. M., S. E. Hygnstrom, and K. C. VerCauteren. 2002. Use of frightening devices in wildlife damage management. Integrated Pest Management Reviews 7:29–45.

Gruver, K. S., R. L. Phillips, and E. S. Williams. 1996. Leg injuries to coyotes captured in standard and modified Soft Catch traps. Proceedings of the Vertebrate Pest Conference 17:91–93.

Hasey, J., and T. P. Salmon. 1993. Crow damage to almonds increasing; no foolproof solution in sight. California Agriculture 47:21–23.

Horn, E. E., and H. S. Fitch. 1946. Trapping the California ground squirrel. Journal of Mammalogy 27:220–224.

Kelly, T. R., P. H. Bloom, S. G. Torres, Y. Z Hernandez, R. H. Poppenga, W. M. Boyce, and C. K. Johnson. 2011. Impact of the California lead ammunition ban on reducing lead exposure in golden eagles and turkey vultures. PLoS ONE 6: e17656. doi:10.1371/journal.pone.0017656.

Lewis, S. R., and J. M. O'Brien. 1990. Survey of rodent and rabbit damage to alfalfa hay in Nevada. Proceedings of the Vertebrate Pest Conference 14:116–117.

Luce, D. G., and R. M. Case. 1981. Damage to alfalfa fields by plains pocket gophers. Journal of Wildlife Management 45:258–260.

Marsh, R. E. 1987. Relevant characteristics of zinc phosphide as a rodenticide. Proceedings of the Great Plains Wildlife Damage Control Workshop 8:70–74.

Marsh, R. E. 1992. Reflections on current (1992) pocket gopher control in California. Proceedings of the Vertebrate Pest Conference 15:289–295.

Marsh, R. E. 1994. Current (1994) ground squirrel control practices in California. Proceedings of the Vertebrate Pest Conference 16:61–65.

Marsh, R. E. 1998. Historical review of ground squirrel crop damage in California. International Biodeterioration and Biodegradation 42:93–99.

Matson, J. O., W. F. Laudenslayer, Jr., S. A. Trewhitt, and M. Flores. 2010. Range expansion of the western gray squirrel (*Sciurus griseus*) in northeastern California. Western North American Naturalist 70:266–269.

McDonald, J. H. 2009. Handbook of Biological Statistics (2nd ed.). Sparky House Publishing, Baltimore, Maryland, USA.

Meerburg, B. G., F. W. A. Brom, and A. Kijlstra. 2008. The ethics of rodent control. Pest Management Science 64:1205–1211.

Messmer, T. A., and S. Schroeder. 1996. Perceptions of Utah alfalfa growers about wildlife damage to their hay crops: implications for managing wildlife on private land. Great Basin Naturalist 56:254–260.

Palmer, G. H., J. Koprowski, and T. Pernas. 2007. Tree squirrels as invasive species: conservation and management implications. Pages 273–282 *in* G. W. Witmer, W. C. Pitt, and K. A. Fagerstone, editors. Managing vertebrate invasive species: proceedings of an international symposium. USDA APHIS Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado, USA.

Pearson, A. B., W. P. Gorenzel, and T. P. Salmon. 2000. Lesser-known vertebrate pests of almonds in California. Proceedings of the Vertebrate Pest Conference 19:365–376.

Pimentel, D. 2007. Environmental and economic costs of vertebrate species invasions into the United States. Pages 2–8 *in* G. W. Witmer, W. C. Pitt, and K. A. Fagerstone, editors. Managing vertebrate invasive species: proceedings of an international symposium. USDA APHIS Wildlife Services, National Wildlife Research Center, Fort Collins, Colorado, USA.

Proulx, G. 1997. A northern pocket gopher (*Thomomys talpoides*) border control strategy: promising approach. Crop Protection 16:279–284.

Ramsey, D. S. L., and J. C. Wilson. 2000. Towards ecologically based baiting strategies for rodents in agricultural systems. International Biodeterioration and Biodegradation 45:183–197.

Salmon, T. P., W. P. Gorenzel, and W. J. Bentley. 1982. Aluminum phosphide (Phostoxin) as a burrow fumigant for ground squirrel control. Proceedings of the Vertebrate Pest Conference 10:143–146.

Salmon, T. P., and S. J. Lawrence. 2006. Anticoagulant resistance in meadow voles (*Microtus californicus*). Proceedings of the Vertebrate Pest Conference 22:156–160.

Salmon, T. P., D. A. Whisson, and W. P. Gorenzel. 2000. Use of zinc phosphide for California ground squirrel control. Proceedings of the Vertebrate Pest Conference 19:346–357.

Salmon, T. P., D. A. Whisson, A. R. Berentsen, and W. P. Gorenzel. 2007. Comparison of 0.005% and 0.01% diphacinone and chlorophacinone baits for controlling California ground squirrels (*Spermophilus beecheyi*). Wildlife Research 34:14–18.

Schauss, M. E., H. J. Coletto, and M. J. Kutilek. 1990. Population characteristics of wild pigs, *Sus scrofa*, in eastern Santa Clara County, California. California Fish and Game 48:68–77.

Schmidt, R. H., and J. G. Brunner. 1981. A professional attitude toward humaneness. Wildlife Society Bulletin 9:289–291.

Shwiff, S. A., K. Gebhardt, and K. N. Kirkpatrick. 2009. The economic impact of bird and rodent damage to California crops: an economic evaluation of the losses caused by bird and rodent damage and selected benefits of pest control expenditures. Report prepared for the California Department of Food and Agriculture, Vertebrate Pest Control Research Advisory Committee, 35pp.

Smith, R. F. R., and R. van den Bosch. 1967. Integrated control. Pages 295–340 *in* W. W. Kilgore and R. L. Doutt, editors. Pest control: biological, physical, and selected chemical methods. Academic Press, New York, USA.

Sterner, R. T. 2008. The IPM paradigm: vertebrates, economics, and uncertainty. Proceedings of the Vertebrate Pest Conference 23:194–200.

Sterner, R. T., C. A. Ramey, W. D. Edge, T. Manning, J. O. Wolff, and K. A. Fagerstone. 1996. Efficacy of zinc phosphide baits to control voles in alfalfa – an enclosure study. Crop Protection 15:727–734.

Sullins, M., and D. Sullivan. 1992. Observations of a gas exploding device for controlling burrowing rodents. Proceedings of the Vertebrate Pest Conference 15:308–311.

Sullins, M., and D. Sullivan. 1993. Observations of a gas exploding device for controlling pocket gophers. Montana Department of Agriculture Technical Report 93-01, Helena, Montana, USA.

Summers, C. G. 1998. Integrated pest management in forage alfalfa. Integrated Pest Management Reviews 3:127–154.

Tickes, B. R., L. K. Cheathem, and J. L. Stair. 1982. A comparison of selected rodenticides for the control of the common valley pocket gopher (*Thomomys bottae*). Proceedings of the Vertebrate Pest Conference 10:201–204.

West, B. C., A. L. Cooper, and J. B. Armstrong. 2009. Managing wild pigs: a technical guide. Human-Wildlife Interactions Monograph 1:1–55.

Whisson, D. A. 1999. Modified bait stations for California ground squirrel control in endangered kangaroo rat habitat. Wildlife Society Bulletin 27:172–177.

Whisson, D. A., and T. P. Salmon. 2002. Effect of the timing of applications and amount of 0.01% diphacinone consumed on mortality of California ground squirrels (*Spermophilus beecheyi*). Crop Protection 21:885–889.

Witmer, G. 2007. The ecology of vertebrate pests and integrated pest management (IPM). Pages 393–410 *in* M. Kogan and P. Jepson, editors. Perspectives in ecological theory and integrated pest management. Cambridge University Press, Cambridge, UK.

Zar, J. H. 1999. Biostatistical analysis. Prentice-Hall, Inc., Upper Saddle River, New Jersey, USA.

APPENDIX

The following is reformatted version of the electronic survey that was distributed for our study.

PURPOSE

California's wildlife is an important natural resource that is highly valued by the citizens of our state. However, at certain times and locations, some species of wildlife come into conflict with human activities. In particular, mammals and birds may negatively affect crop and livestock production. Research can help define the roles and impacts of wildlife in relation to agriculture and natural systems which in turn will help guide the development of better methods to prevent and solve human-wildlife conflicts. Unfortunately, sufficient resources are not available to adequately address all situations nor are all conflicts of equal importance. Therefore, we have developed this survey to ask individuals involved with or impacted by wildlife damage to help guide us.

Your participation is vital, as your responses will determine the most important research needs concerning wildlife damage in California and will guide future research efforts for years to come. Only through your input can we adequately assess which research needs are most important and subsequently provide needed management strategies to deal with these problems.

This survey is being distributed by Roger Baldwin, University of California Cooperative Extension.

If you have any questions, contact:

Roger A. Baldwin, Ph.D.
IPM Wildlife Pest Management Advisor
U.C. Kearney Ag. Center
9240 S. Riverbend Ave.
Parlier, CA 93648
Phone: 559-646-6583
E-mail: rbaldwin@uckac.edu

DIRECTIONS

Please answer the following questions to the best of your ability, and unless otherwise stated, provide only one answer per question. If more than one answer appears appropriate, respond with the answer that is most appropriate. Questions that allow for more than one answer will explicitly state so.

GENERAL INFORMATION

1) Who do you work for?

____County Agricultural Commissioner's office
____University of California Cooperative Extension (UCCE)
____University affiliation other than UCCE
____USDA Wildlife Services
____Commodity board
____California Department of Fish and Game

2) How would you define your position (include all that apply)?

____Work with agricultural crops
____Work with wildlife pests associated with agricultural crops
____Work with livestock on rangelands
____Work with wildlife pests associated with livestock and rangelands
____Work with dairy cattle or livestock in feedlots
____Work with wildlife pests associated with dairy cattle or livestock in feedlots
____Work with landscapers and landscape horticulturalists
____Work with wildlife pests associated landscape and garden-type settings
____Conduct research associated with wildlife
____Manage wildlife resources

3) What counties do you primarily work in (including all that apply or list statewide if work occurs throughout the state)?

____Statewide
____Alameda
____Alpine
____Amador
____Butte
____Calaveras
____Colusa
____Contra Costa
____Del Norte
____El Dorado
____Fresno
____Glenn
____Humboldt
____Imperial
____Inyo
____Kern
____Kings
____Lake
____Lassen
____Los Angeles
____Madera
____Marin
____Mariposa
____Mendocino
____Merced
____Modoc
____Mono
____Monterey
____Napa
____Nevada
____Orange
____Placer
____Plumas
____Riverside
____Sacramento
____San Benito
____San Bernardino
____San Diego
____San Francisco
____San Joaquin
____San Luis Obispo
____San Mateo
____Santa Barbara
____Santa Clara
____Santa Cruz
____Shasta
____Sierra
____Siskiyou
____Solano
____Sonoma
____Stanislaus
____Sutter
____Tehama
____Trinity
____Tulare
____Tuolumne
____Ventura
____Yolo
____Yuba

DIRECTIONS

The next series of questions will ask you for your opinion on what you feel are the three most damaging agricultural wildlife pests in California. Questions 4a–g, 5a–g, and 6a–g will pertain to the most damaging, second most damaging, and third most damaging pests, respectively. When we ask for your opinion on these questions, consider not only what you have heard directly from your clientele, but also consider indirect comments and observations from others. However, for questions that pertain to specific commodity groupings, please answer only for those that you have interaction or experience with.

(Authors note: Questions 4a–g, 5a–g, and 6a–g were presented separately in the actual survey, but are combined in this appendix to avoid repetition and save space)

4–6a) In your opinion, which wildlife pest results in the GREATEST, SECOND GREATEST, and THIRD GREATEST number of complaints each year?

____Crows

____Ravens

____Blackbirds

____Starlings

____Magpies

____Scrub jays

____Horned larks

____House finches

____Pocket gophers

____Ground Squirrels

____Tree Squirrels

____Meadow voles (meadow mice)

____House and deer mice

____Norway, roof, and wood rats

____Rabbits and hares

____Deer

____Wild pigs

____Coyote

____Other (please list) ____

All of the following questions on this page (4–6b through 4–6g) refer to the pest species you just listed in question 4–6a.

4–6b) To the best of your ability, estimate the loss in net profit caused by these pests for the agricultural commodity groupings listed below. This loss in profit could be from a variety of pest related costs including reduction in crop yield, damage to infrastructure (e.g., damage to drip lines, damage to farm equipment from burrows, etc.), and costs spent on controlling these pests. If you do not have any experience or interaction with a specific commodity group, please mark "I don't know" rather than provide an estimate of damage.

	No Damage	Slight damage (<5% loss in profit)	Moderate damage (5–15% loss in profit)	Heavy damage (>15% loss in profit)	I don't know
Nuts[a]	________	__________	__________	__________	_________
Tree Fruit[b]	________	__________	__________	__________	_________
Berries[c]	________	__________	__________	__________	_________
Grapes[d]	________	__________	__________	__________	_________
Vegetables and Row Crops[e]	________	__________	__________	__________	_________
Alfalfa	________	__________	__________	__________	_________
Rangelands	________	__________	__________	__________	_________
Dairy and Feedlots	________	__________	__________	__________	_________
Other (please list):	____				

[a]Nuts = almonds, pistachios, walnuts, and pecans
[b]Tree Fruit = apples, pears, pomegranates, olives, avocados, stone fruit, etc.
[c]Berries = strawberries, blackberries, raspberries, blueberries
[d]Grapes = wine, raisin, and table grapes
[e]Vegetable and row crops = tomatoes, cole crops, lettuce, egg plant, squash, cucurbits, artichokes, carrots, potatoes, corn, rice, etc.

4–6c) In your opinion, what is the most economically costly form of damage caused by these pests?

____Loss of crop production through direct consumption of fruit, nut, seed, or vegetation
____Loss of vigor or direct mortality of plant (e.g., chewing of roots, girdling, removal of seedlings, etc.)
____Loss of irrigation water down burrow systems
____Damage to irrigation infrastructure (e.g., drip lines, sprinklers, irrigation canals, etc.)
____Consumption or contamination of feed in dairies and feedlots
____Depredation of livestock
____Transmission of disease to crop or livestock (e.g., salmonella contamination of leafy greens, leptospirosis in livestock, etc.)
____Other form of damage (please specify)

4–6d) In your opinion, which one control method is MOST FREQUENTLY USED to control these pests?

____Poison baits (e.g., anticoagulants, strychnine, and zinc phosphide)
____Fumigants (e.g., gas cartridges, aluminum phosphide)
____Traps (both live and kill traps)
____Habitat modification/cultural practices
____Biocontrol (e.g., encouraging predators through owl boxes, raptor perches, etc.)
____Physical exclusionary devices (e.g., fencing, tree guards, etc.)
____Chemical repellents
____Frightening devices (e.g., propane cannons, electronic distress calls, etc.)
____Gas explosive devices (e.g., Rodenator, Rodex®)
____Shooting
____Other method (please list): ____

4–6e) In your opinion, which one control method is MOST EFFECTIVE for the three pests?

____Poison baits (e.g., anticoagulants, strychnine, and zinc phosphide)
____Fumigants (e.g., gas cartridges, aluminum phosphide)
____Traps (both live and kill traps)
____Habitat modification/cultural practices
____Biocontrol (e.g., encouraging predators through owl boxes, raptor perches, etc.)
____Physical exclusionary devices (e.g., fencing, tree guards, etc.)
____Chemical repellents
____Frightening devices (e.g., propane cannons, electronic distress calls, etc.)
____Gas explosive devices (e.g., Rodenator, Rodex®)
____Shooting
____Other method (please list): ____

4–6f) In your opinion, if the MOST FREQUENTLY USED and MOST EFFECTIVE method for controlling this species differ, why? Mark all answers that apply.

____These methods do not differ
____The most effective method is too costly and/or takes too long to apply
____The most effective method is not as effective at certain times of the year when most needed
____There is a lack of knowledge among users on which control method is most effective
____The most effective method requires special certification to apply or is too restrictive to use
____Users do not feel the most effective method is as humane or ecologically safe as alternatives
____The presence of endangered species often reduces or eliminates the use of the most effective method
____Damage frequently occurs in an organic setting for which use of the most effective method is not allowable
____Other (please list): ____

4–6g) For these same pests, in your opinion, rank where you feel the greatest advancements and research are needed and would be most beneficial for each of the following wildlife pest issues with 1 being least important and 5 being most important. Each ranking can be used only once per pest.

	1	2	3	4	5
Greater knowledge on the biology of this pest	_____	_____	_____	_____	_____
Greater knowledge on the impact of available pest control methods to the environment	_____	_____	_____	_____	_____
Greater knowledge of the economic damage caused by this pest	_____	_____	_____	_____	_____
Greater advancements in control methods for this pest	_____	_____	_____	_____	_____
Greater understanding of how the juxtaposition of crop fields and natural areas influences their distribution and population dynamics	_____	_____	_____	_____	_____

7) The following is a list of common wildlife pests of a variety of agricultural commodities. Please examine this list and rank the three wildlife pests for which we most critically need new and/or improved control methods. A rank of 1 = the highest ranked pest for which we need advancements in control, 2 = the second highest ranked pest for which we need advancements in control, and 3 = the third highest ranked pest for which we need advancements in control. Each ranking can be used only once resulting in a total of 3 wildlife pests selected.

____Crows
____Ravens
____Blackbirds
____Starlings
____Magpies
____Scrub jays
____Horned larks
____House finches
____Pocket gophers
____Ground Squirrels
____Tree Squirrels
____Meadow voles (meadow mice)
____House and deer mice
____Norway, roof, and wood rats
____Rabbits and hares
____Deer
____Wild pigs
____Coyote
____Other (please list) _______________

8) Many people have differing perspectives on what are appropriate methods for controlling wildlife pests. Based on your interaction with most growers, ranchers, pest control advisors, and other individuals responsible for wildlife pest control in agriculture in your area, provide a score ranging from 1–5 (1 = highly undesirable, 2 = undesirable, 3 = neutral, 4 = desirable, and 5 = highly undesirable) for the following potential methods of wildlife pest control given their appeal to these individuals.

	1	2	3	4	5
-Poison baits (e.g., anticoagulants, strychnine, and zinc phosphide)	____	____	____	____	____
-Fumigants (e.g., gas cartridges, aluminum phosphide)	____	____	____	____	____
-Traps (both live and kill traps)	____	____	____	____	____
-Habitat modification/cultural practices	____	____	____	____	____
-Biocontrol (e.g., encouraging predators through owl boxes, etc.)	____	____	____	____	____
-Physical exclusionary devices (e.g., fencing, tree guards, etc.)	____	____	____	____	____
-Chemical repellents	____	____	____	____	____
-Frightening devices (e.g., propane cannons, electronic distress calls, etc.)	____	____	____	____	____
-Gas explosive devices (e.g., Rodenator, Rodex®)	____	____	____	____	____
-Shooting	____	____	____	____	____

9a) Integrated Pest Management (IPM) is a concept that focuses on the utilization of multiple management approaches (e.g., habitat modification, baiting, trapping, fumigation, etc.) to more effectively control target pests while reducing risks to the environment. In your opinion, do most growers, ranchers, pest control advisors, or other individuals responsible for wildlife pest control in agriculture rely primarily on one method for control or do they use an IPM approach?

_____ Single method

_____ IPM approach

9b) In your opinion, why do individuals who utilize a single control method not utilize an IPM program?

____Most individuals do use an IPM program for controlling wildlife pests
____They prefer to use a single method that has proven effective
____They are not aware of what an IPM program is or how it is implemented
____There are a lack of effective tools to control some wildlife pests; therefore, utilizing more than a single method that has proven effective may not be possible
____There is a lack of research indicating the effectiveness of an IPM program
____There is a lack of cost-benefit studies showing potential financial savings using an IPM program
____Other reason (please list): ____

10) Although the best control measures will ideally be effective, quick and inexpensive to apply, humane, environmentally safe, and present minimal hazard to the applicator, this is not always possible. Rank these attributes as they apply to wildlife pest control methods in order of importance to your agricultural clientele with 1 being least important and 5 most important. Each ranking should be used only once.

	1	2	3	4	5
Efficacy	______	______	______	______	______
Quick and inexpensive to apply	______	______	______	______	______
Environmentally safe	______	______	______	______	______
Humane	______	______	______	______	______
Present minimal hazard to applicator	______	______	______	______	______

11) Please provide any comments you would like here. Include any specific wildlife pest issues you feel are important but were not addressed in this survey.

____