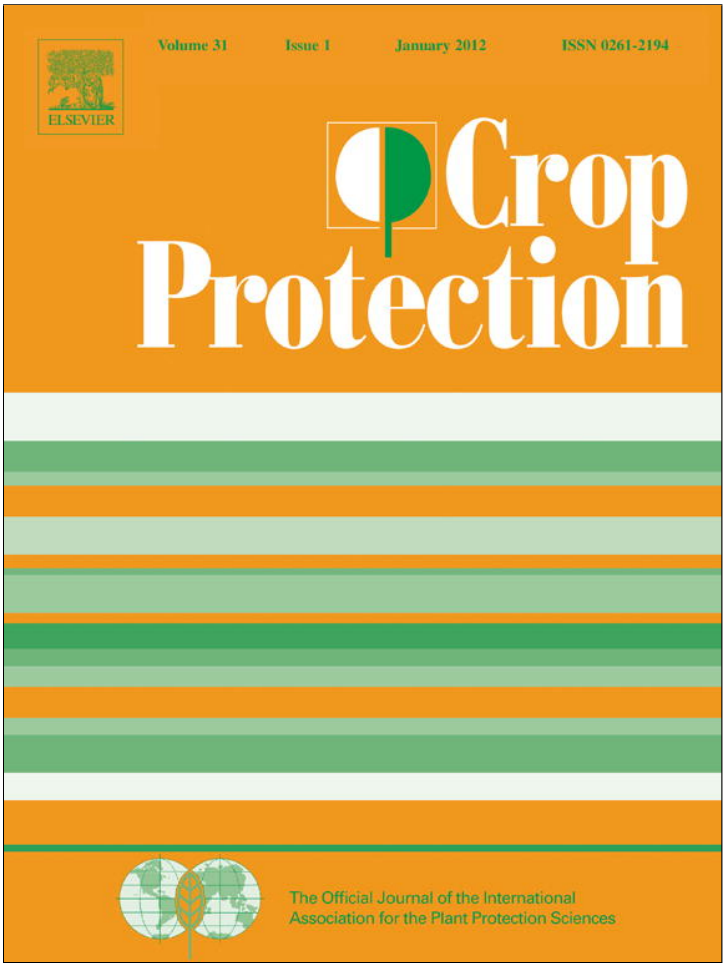
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Wildlife pests of California agriculture: Regional variability and subsequent impacts on management

Roger A. Baldwin [a,*], Terrell P. Salmon [b], Robert H. Schmidt [c], Robert M. Timm [d]

[a] University of California, Kearney Agricultural Research and Extension Center, 9240 South Riverbend Avenue, Parlier, CA 93648, United States
[b] University of California Cooperative Extension, 9335 Hazard Way, Suite 201, San Diego, CA 92123, United States
[c] Utah State University, Department of Environment and Society, Logan, UT 84322, United States
[d] University of California, Hopland Research and Extension Center, 4070 University Road, Hopland, CA 95449, United States

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ABSTRACT

Numerous wildlife species are known pests of California agriculture. Effective management of these pests is required to maximize agricultural production, yet it is unclear how the importance of various wildlife pest species and associated management strategies may vary regionally throughout California. Accounting for these regional differences should yield management programs that are specifically tailored to the regions constituents and should be considered when managing wildlife pests at a more localized level. Therefore, we developed a survey to provide quantitative data on regional differences in research and management needs to better guide future research efforts in developing more effective, practical, and appropriate methods for managing wildlife pests. We found that coyotes were a more common pest in the mountain region, ground squirrels were a greater concern in the central and desert valley region, while birds were most commonly listed as pests by individuals working in multiple regions of California. Coyote damage varied regionally, with livestock depredation the greatest concern throughout most of California, although damage to irrigation tubing and sprinklers was of equal concern in the central and desert valley region. For bird pests, exclusionary devices were the most common and most effective methods of control in the coastal region. Frightening devices were the most commonly used method for bird control in all other regions, although the efficacy associated with frightening devices was considered far lower than their level of use, suggesting that better management options are needed for bird control in these regions. For all wildlife pests, nonlethal control options (e.g., exclusionary devices, habitat modification) were generally preferred in the coastal region while lethal removal options ranked higher in the central and desert valley region (e.g., baiting, burrow fumigation). Efficacy was considered the most important attribute of a control method for all regions, while Integrated Pest Management programs were considered the most effective method for controlling wildlife pests in all regions except for the central and desert valley region. Collectively, the importance of wildlife pests and the perception of associated control methods varied throughout California and reflects the need to consider these regional differences in order to optimize damage management strategies at the regional level.

1. Introduction

Although wildlife species often provide many positive intrinsic values, they can also cause damage when present in large numbers or in undesirable areas (Conover, 2002). For example, in a recent study that addressed the economic impact of rodent and bird pests to 22 commodities across 10 counties in California, this loss was determined to be US$168–$504 million dollars annually (Shwiff et al., 2009). Likewise, nationwide estimates of economic damage caused by rats (*Rattus* spp.; US$27 billion) and wild pigs (*Sus scrofa*; US$1.5 billion) are great (Pimentel, 2007). Controlling these pest species is imperative if damage to crops is to be minimized. Likewise, wildlife are often responsible for transmitting disease (e.g., plague [*Yersinia pestis*] transmission; Smith et al., 2010), and are a major concern for food safety (e.g., *Escherichia coli* in leafy greens; Jay et al., 2007). Given the differing composition of wildlife species throughout large geographical areas (e.g., California), the importance of differing pest species is likely to vary across geographic regions and is worth considering when developing management priorities.

* Corresponding author. Tel.: +1 559 646 6583; fax: +1 559 646 6593.
E-mail address: rabaldwin@ucanr.edu (R.A. Baldwin).

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Common control options for many wildlife pests include habitat modification, exclusion, frightening devices, trapping, baiting, burrow fumigation, etc. (e.g., Bruggers et al., 1998; Engeman and Witmer, 2000; Conover, 2002). However, the efficacy, cost effectiveness, environmental impact, safety to applicator, and humaneness of these approaches varies across these different treatment options. Developing the most appropriate management program will depend on all of these factors although preference will likely be given to those control efforts that maximize the benefits of the preferred attributes. The importance of these attributes is likely to vary regionally and warrants consideration when allocating resources to develop new techniques for wildlife pest control.

One approach to maximize the positive attributes associated with control methods is to use an Integrated Pest Management (IPM) program for wildlife pest control. This approach utilizes multiple control techniques (Sterner, 2008) and usually results in less cost and greater efficacy than when relying on any single approach (e.g., Ramsey and Wilson, 2000). IPM also reduces negative risks to the environment and applicator by reducing the use of pesticides whenever practical. However, we are unaware to what extent IPM programs are used to control wildlife pests and if greater efforts are needed to increase its incorporation into wildlife pest management programs.

Determining which wildlife species are the most common pests and developing programs that effectively and efficiently manage these pest species is imperative to maximize production of crops and livestock. However, we have limited resources to adequately address all wildlife pest problems that are encountered in agriculture. As such, it is imperative that we focus our efforts on activities that will provide the greatest benefit. Needs assessment surveys are often employed to ascertain what the most important research and management needs are for the selected audience (e.g., Bruggers et al., 2002; Stuart et al., 2011) and are an excellent tool in determining these needs for wildlife pest management.

Individuals often have varying viewpoints on preferred attributes of management techniques depending on a variety of factors including local agricultural systems and wildlife species, personal upbringing, social status, and political beliefs. These viewpoints are often represented by regional differences in responses (Irby et al., 1997; Conover, 2002). Accounting for these regional differences should yield management programs that are specifically tailored to its constituents and should be considered when managing wildlife pests at a more localized level. 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 at a regional level. More specifically, our 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 identify the most costly form of damage caused by each pest, 3) to identify which methods are used most frequently and which are most effective for controlling these pests, 4) to identify which control methods are most appealing to individuals involved in wildlife pest control, 5) to identify the most important attributes for wildlife pest control methods, and 6) to determine if individuals involved in wildlife pest control in agriculture follow an IPM approach for managing these pests. These objectives are focused on regional differences in responses and represent a subset of a larger survey on research and management needs for wildlife pests of agriculture in California. See Baldwin et al. (2011) for a complete report on the entire survey.

2. Methods

We developed a 10-question electronic survey with multiple parts to some questions via SurveyMonkey (http://www.surveymonkey.com/). This survey was disbursed via e-mail in 2010 to California County Agricultural Commissioner's offices, members of the University of California Cooperative Extension (UCCE), University affiliates other than UCCE, Commodity Boards, California Department of Fish and Game (CDFG), and United States Department of Agriculture (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).

Before survey distribution, we divided all counties into 1 of 3 regions (coastal, mountain, and central and desert valley) based on prevailing agricultural commodities, geological construct (e.g., mountains, coastline, valleys), rainfall, and socio-political composition (Fig. 1). Wine grapes, vegetables, berries, ornamental flowers, and nursery products were common commodities within the coastal region; dairies, nuts, tree fruits, table and raisin grapes, and rice are primary commodities in the central and desert valleys; the mountain region was dominated by livestock, hay, and timber production (CDFA, 2012). We also developed a fourth category to include those individuals who worked largely in multiple regions of the state (multi-region). This category was included in all regional analyses.

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. See Baldwin et al. (2011) for complete survey.

2.1. Survey design

For Objective 1, a score of 1–3 (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) 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. 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 2–3 corresponded to the pests selected by each individual in Objective 1. Objective 2 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. Options 3–4 and 5–6 were combined for analysis due to a low number of responses for options 3 ($n = 5$) and 6 ($n = 5$) and because of the similarity in the combined responses.

For Objective 3, 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,

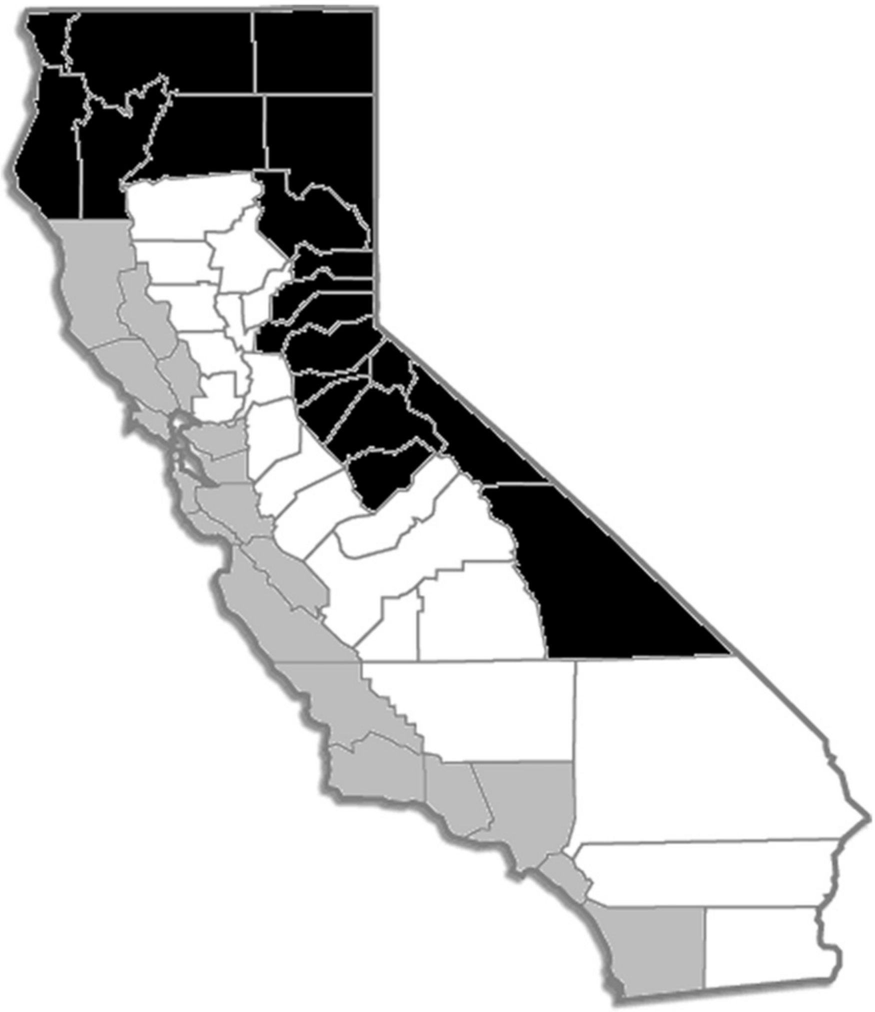

Fig. 1. Delineation of coastal (gray), mountain (black), and central and desert valley regions (white) of California used in this study.

3) traps, 4) habitat modification/cultural practices, 5) biocontrol (i.e., relying on natural predation), 6) physical exclusionary devices, 7) chemical repellents, 8) frightening devices, 9) gas explosive devices (devices that explode tunnel systems; e.g., Rodenator, Emmett, ID), 10) shooting, and 11) other methods.

We were also interested in the appeal of various control methods to individuals involved in wildlife pest control (Objective 4). The proposed control methods are the same as those listed for Objective 3. Potential scores ranged from 1 to 5 (5 = highly desirable, 1 = highly undesirable).

For Objective 5, we wanted to determine the most important attributes for wildlife pest control methods. Survey participants were allowed to rank possible attributes from 1 to 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.

Objective 6 inquired as to whether or not survey respondents felt that most individuals involved in wildlife pest control in agriculture followed an IPM approach for controlling wildlife pests. All objectives were tested for regional differences in responses.

2.2. Statistical analysis

We used multiple techniques for analysis depending on the data format. For continuous rank data (Objectives 1, 4–5), we used two way analysis of variance (ANOVA) to test for the influence of the two explanatory variables (Objective 1: pest and region; Objective 4: control method and region; Objective 5: 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).

For nominal responses (Objectives 2–3, 6), 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.

3. 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. The majority of the responses came from UCCE (41%) and California Agricultural Commissioner's offices (31%). Every county in the state was represented by at least one survey participant (see Baldwin et al., 2011 for complete summary of survey respondent demographics). Regionally, the breakdown of respondents was as follows: central and desert valley region = 57, coastal region = 43, mountain region = 16, and multi-region category = 27. This breakdown is consistent with where most agricultural production occurs in California (CDFA, 2012) and should be reflective of the state as a whole.

3.1. Common wildlife pests

The wildlife species listed most frequently as pests included ground squirrels (*Spermophilus* spp.), pocket gophers (*Thomomys* spp.), birds, voles (*Microtus* spp.), wild pigs, and coyotes (*Canis latrans*) (see Baldwin et al., 2011 for complete detail). Comparison of these pests 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 ($F_{3,810} = 0.69$, $P = 0.556$). 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 1). For regional comparisons within each pest, mean ranks for birds were higher for the multi-region category ($\bar{x} = 1.19$) than for all other regions ($\bar{x} = 0.19$–0.64), while ranks for ground squirrels were highest for the central and desert valley region ($\bar{x}$ valley region = 1.64, $\bar{x}$ for all other regions = 0.81–1.19; Table 1). Coyote ranks were highest for the mountain region ($\bar{x} = 1.25$) and lowest for the coastal ($\bar{x} = 0.50$) and valley ($\bar{x} = 0.51$) regions. Regional ranks for other pests did not differ (Table 1). For pest comparisons within the same region, ground squirrels and pocket gophers were the most consistent high-ranking pests (Table 1), although coyotes were the highest ranking in the mountain region ($\bar{x} = 1.25$) while birds were the highest ranking for the multi-region category ($\bar{x} = 1.19$; Table 1).

3.2. Costly forms of damage

We observed a significant difference in the regional response of survey participants to the most costly 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 region (Fisher's exact test, $P = 0.016$) and the multi-region category (Fisher's exact test, $P = 0.048$). As such, we analyzed differences in responses separately among the coastal, valley, and mountain and multi-region category combined (Table 2). We found that in the coastal (exact multinomial test, $P = 0.022$) and combined mountain and multi-region category (exact multinomial test, $P < 0.001$), depredation of livestock was the primary form of damage (70% and 93%, respectively; Table 2). 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 2), although there was no significant difference in the 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, $P \geq 0.073$).

Table 2
The number (Num) and percent (%) of responses and results from multiple comparisons (MC) of the most common forms of damage for the coastal, valley, and mountain plus multi-region (Mt + Multi) category for coyotes.

Form of damage[a]	Coastal			Valley			Mt + Multi		
	Num	%	MC[b]	Num	%	MC[c]	Num	%	MC[b]
Direct consumption	0		B	1	7		0		B
Damage to irrigation	3	30	AB	8	57		1	7	B
Depredation of livestock	7	70	A	5	36		14	93	A

[a] Forms of damage were as follows: direct consumption = loss of crop production through direct consumption of fruit, nut, seed, or vegetation; damage to irrigation = damage to irrigation infrastructure or loss of water down burrow system; depredation of livestock = depredation of livestock.
[b] Values in the same column with the same letter did not differ ($P < 0.05$).
[c] There was no significant difference ($P > 0.05$) in the reported forms of damage for this region.

3.3. 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 3); 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 combined, there was a significant difference in the methods used most frequently (exact multinomial test, $P < 0.001$), as well as for the methods used most effectively (exact multinomial test, $P < 0.001$) 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%; Table 3). 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 3).

For all other regions, frightening devices were used most frequently (84% of responses) to control bird pests, while frightening devices (37%) and shooting (22%) were considered to be the most effective methods of control (Table 3). 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

Table 1
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 (Fisher's 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).

Region	Bird			Pocket gopher			Ground squirrel			Vole			Wild pig			Coyote		
	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
Multiple[d]	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 ($P < 0.05$).
[d] Includes responses from survey participants who work in more than one region.

Table 3
A comparison of control methods used most frequently (Freq) and those considered most effective (Eff) 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.

Control method	Coastal							Combined[e]						
	Freq[a]	%[b]	MC[c]	Eff[a]	%[b]	MC[c]	Dif[d]	Freq[a]	%[b]	MC[c]	Eff[a]	%[b]	MC[c]	Dif[d]
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
Exclusion	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 that region.
[b] Percentage (%) of responses for that region.
[c] MC = multiple comparisons. All comparisons were conducted using the exact multinomial test. Control methods in the same column with the same letter did not differ ($P < 0.05$).
[d] 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 **.
[e] The proportion of responses for control methods used most frequently and those deemed most effective differed ($P < 0.05$).

participants who identified frightening devices as the most frequently used method (84%) compared to those individuals who thought these devices were the most effective method of control (37%; Fisher's exact test, $P < 0.001$; Table 3). Additionally, we saw a significantly larger number 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%; Table 3). 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 3).

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, $P \geq 0.480$). Unfortunately, we only had 4 responses for this region for ground squirrel control. Because of this low number of responses 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 not to further analyze regional differences for this pest species. We observed no regional differences for all other wildlife pests (Fisher's exact test, $P \geq 0.056$).

3.4. 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 ($F_{9,1029} = 6.5$, $P < 0.001$). Rankings did not vary across 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 ($\bar{x} = 3.45–4.41$), trapping ($\bar{x} = 3.32–4.09$), and biocontrol ($\bar{x} = 3.00–3.98$) typically scored high, although trapping scores were lower for the central and desert valley regions ($\bar{x} = 3.32$), while biocontrol scored low for respondents working in multiple regions ($\bar{x} = 3.00$; Table 4). The appeal of chemical repellents ($\bar{x} = 3.13–3.38$), frightening devices ($\bar{x} = 2.91–3.60$), and gas explosive devices ($\bar{x} = 2.75–3.02$) was typically quite low, although frightening devices did score somewhat higher for the multi-region category ($\bar{x} = 3.60$; Table 4). Other control methods exhibited variable responses. For example, exclusionary devices were the most appealing control method in the coastal region ($\bar{x} = 4.03$), but were the least appealing method in the central and desert valley region ($\bar{x} = 2.58$; Table 4). Likewise, the scores associated with shooting ($\bar{x} = 2.91$) and fumigants ($\bar{x} = 3.18$) were low for the coastal region, but were relatively high for the multi-region category (shooting: $\bar{x} = 3.75$, fumigants: $\bar{x} = 3.95$; Table 4).

Table 4
Mean rank scores indicating the appeal of each of the below-listed wildlife pest control methods for coastal, mountain, valley, and multi-region categories throughout California. Multiple comparisons (Fisher's 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).

Control method	Coastal			Mountain			Valley			Multi-region		
	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 to 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 ($P < 0.05$).

Table 5
Mean rank scores indicating which attributes of a control method are most important to agricultural clientele for coastal, mountain, valley, and multi-region categories throughout California. Multiple comparisons (Fisher's LSD) tested for differences in rank scores across each attribute within the same regional class (Attr) and for each attribute across regional classes (Reg).

Attribute	Coastal			Mountain			Valley			Multi-region		
	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 to 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 ($P < 0.05$).

3.5. *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 ($F_{4,545} = 105.8$, $P < 0.001$); 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 ($\bar{x} = 4.49–4.53$; Table 5). Those methods that were quick and inexpensive also scored high across all regions ($\bar{x} = 3.42–4.02$), although this appeared to be more important in the central and desert valley region (Table 5). The importance of safety to the environment ($\bar{x} = 2.15–2.97$) and the potential hazard of a control method to the applicator ($\bar{x} = 2.23–3.14$) varied regionally, with hazard potential scoring higher in the central and desert valley ($\bar{x} = 2.85$) and multi-region category ($\bar{x} = 3.14$; Table 5). 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 5). The humaneness of a control method always scored low, although the respective scores were quite a bit different between the regions ($\bar{x} = 1.28–2.23$; Table 5).

3.6. *Use of IPM for wildlife pest control*

We observed a regional difference in whether or not respondents believed that most individuals responsible for wildlife pest control in agriculture currently rely on an IPM approach as opposed to a single control method (Fisher's exact test, $P = 0.024$; Table 6). Most respondents in the mountain (83%) and multi-region category (80%) 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% vs. 53% for each, respectively) were typically used to control such pests (Table 6).

Table 6
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 multi-region categories for analysis.

Region	Single method		IPM		MC[a]
	Number	%	Number	%	
Coastal	13	39	20	61	AB
Mountain	2	17	10	83	A
Valley	25	53	22	47	B
Multi-region	4	20	16	80	A

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

4. Discussion

California is a large, diverse state with respect to the distribution of agricultural commodities and geophysical construct. As such, it was not surprising that the importance of wildlife pests varied regionally. Ground squirrels were a particularly important pest in the central and desert valleys, coyotes were listed far more regularly in the mountain region, while bird pests were most commonly listed by multi-region respondents. The California ground squirrel (*Spermophilus beecheyi*) is quite common throughout the valley regions of California and is a common pest of nut crops, tree fruits, and rangelands (Baldwin et al., 2011). These commodities are frequently found throughout the central and desert valleys of California, but nut crops and tree fruits are less common in other regions of the state (CDFA, 2012). Their lower prevalence is likely the primary reason why ground squirrels are considered less of a pest in other regions of California.

Coyotes are well known predators of livestock, with nationwide estimates of damage to cattle and calves of US$52.3 million in 2010 (USDA, 2011) and >$11 million for sheep, lambs, and goats in 1999 (USDA, 2000). Livestock are the primary commodity in the mountain region, with coyote predation the most costly form of damage in this region (Table 2). However, in the central and desert valley region, damage to irrigation equipment and subsequent water loss were of equal concern (Table 2). Coyotes frequently chew on irrigation tubing and microsprinklers, resulting in extensive damage throughout the state each year (Connolly, 1992). Control methods used to curtail this damage may be different than those used to reduce depredations of livestock and highlight the need to consider regional variability in wildlife damage when developing an effective management plan.

A variety of bird species cause problems throughout the state of California including the European starling (*Sturnus vulgaris*), various black bird species (*Agelaius* spp.), and the American crow (*Corvus brachyrhynchos*) (Baldwin et al., 2011). This damage was particularly noted by those who managed agricultural commodities or wildlife pests across two or more regions (Table 1). This strong multi-region 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 multi-region category 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.

Birds often cause extensive and quite varied forms of damage, although the consumption of nuts, fruits, seeds, and vegetation is the primary form of damage reported in California (Baldwin et al., 2011) with estimates of damage for nut and grape crops ranging from 0 to 30% and 0 to 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%; Table 3). 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 afford 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 3). 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). Although shooting, trapping, and baiting may be deemed more effective, there are many restrictions involved in the take of most bird species. 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. This dissatisfaction with available control options in other regions of the state is apparent and highlights the need for more efficacious and/or cost effective methods of control for managing bird pests in California agriculture.

Pocket gophers, wild pigs, and voles were also significant pests of agricultural commodities in California (Baldwin et al., 2011) but did not exhibit substantial regional differences. Likewise, techniques used to control pocket gophers, wild pigs, and voles did not vary regionally. These pests are found throughout most of California (Baker et al., 2003; Pugh et al., 2003; West et al., 2009), and cause similar damage throughout the state (Baldwin et al., 2011). For example, the primary form of damage caused by pocket gophers is a loss of vigor or direct mortality to plants (Baldwin et al., 2011). This does not vary depending on the commodity; therefore, even though commodity distribution does vary regionally, the impact of pocket gophers does not. Likewise, because their prevalence and the impact they have on varying commodities does not differ regionally, it stands to reason that available and preferred control techniques will not differ regionally as well.

It should be pointed out that even though we did not detect regional differences for pocket gophers, wild pigs, and voles in this study, this may be an artifact of the scale of the regions we assessed. For example, wild pigs are not typically found east of the Sierra Nevada Mountains (West et al., 2009). Studies that utilized smaller regions would likely have found regional differences in the importance of wild pigs as a wildlife pest in California. Therefore, it is worthwhile to always initially test for regional differences in similar studies where the surveyor's goal is to tailor wildlife pest management to more localized clientele needs.

Techniques used to control wildlife pests can be controversial, particularly when they involve lethal actions (Conover, 2002). This is particularly true in residential and urban areas where nonlethal approaches are preferred. There is typically less resistance to lethal control methods in rural areas given their more utilitarian approach toward wildlife (Conover, 2002). As such, it was not surprising that the rankings provided for various wildlife control techniques varied regionally in California (Table 4). For example, rankings for exclusionary devices were much higher in the coastal region ($\bar{x} = 4.03$) than in the central and desert valley region ($\bar{x} = 2.58$), shooting was much higher in the mountain ($\bar{x} = 3.67$) and multi-region category ($\bar{x} = 3.75$) than in the coastal region ($\bar{x} = 2.91$), while biocontrol ranked much higher in the coastal ($\bar{x} = 3.97$) and central and desert valley regions ($\bar{x} = 3.98$) than for those who worked in multiple regions ($\bar{x} = 3.00$). Generally speaking, the coastal region was most different, with a stronger preference for nonlethal control methods such as exclusionary devices ($\bar{x} = 4.03$) and habitat modification $\bar{x} = 3.79$; Table 4). The central and desert valley region exhibited the opposite trend with a strong preference for lethal removal approaches such as baiting ($\bar{x} = 4.22$), burrow fumigants ($\bar{x} = 3.58$), and shooting ($\bar{x} = 3.53$). These differences were not surprising given the more urban composition of the coastal region as opposed to the more rural make-up of the central and desert valleys.

Interestingly, the multi-region respondents preferred approaches that have proven more effective and practical (poison baits [$\bar{x} = 4.41$]—Salmon et al., 2000, 2007; Sterner et al., 1996; burrow fumigation [$\bar{x} = 3.95$]—Baker, 2004; Baldwin and Holtz, 2010; trapping [$\bar{x} = 3.95$]—Choquenot et al., 1993; Proulx, 1997), while avoiding those that have not been proven effective (e.g., biocontrol [$\bar{x} = 3.00$]—Marsh, 1992, 1994; Witmer, 2007; gas explosive devices [$\bar{x} = 2.95$]—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, strong advocacy by environmental or animal welfare organizations, 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, but unless efficacy of biocontrol methods can be substantially increased, it does not appear to be a reliable technique for wildlife pest control. 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.

There are many attributes that comprise an ideal control method including high efficacy, short times for application, minimal environmental risks, minimal risk to the applicator, and maximizing the humaneness of the control method. However, the importance of these attributes is likely to differ from person to person and subsequently across regions if the socio-political environment is substantially different across these regions. In our study, regardless of the region surveyed, efficacy was always the highest priority (Table 5). Those methods that were quick and inexpensive to apply were also consistently important across all regions. The primary regional differences we observed were between the impact of control methods on the environment and potential hazard to the applicator (Table 5). Survey participants in the central and desert valley and multi-region categories 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 5). Primary concerns with environmental safety likely apply to nontarget 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 nontarget 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 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.

Integrated Pest Management is typically referenced as the most effective method for controlling wildlife pests (Engeman and Witmer, 2000; Sterner, 2008). However, individuals in the central and desert valleys did not exhibit this preference (Table 6). We are unsure why there was such a dramatic difference in the central and desert valleys, but it could be due to their desire to use a single approach that has proven effective (Baldwin et al., 2011). The two primary pests in this region were ground squirrels and pocket gophers (Table 1), for which baiting was the primary control method for both species (Baldwin et al., 2011). 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 pocket gophers than most other wildlife pests. Increasing the efficacy and cost effectiveness of existing control options may reduce the reliance on a single control method, thereby increasing overall efficacy of wildlife pest control programs in the central and desert valley region.

5. Conclusions

This survey allowed us to ascertain the impact that wildlife pests have on agriculture throughout different regions of California. We were also able to discern regional opinions on how these wildlife pests should be managed. This regional variability was great for some pests (e.g., birds), while essentially nonexistent for others (e.g., voles). These differences indicate the need to consider many different factors that might impact responses to wildlife management surveys if management practices are to be conducted in a manner that minimizes human–wildlife conflict while adhering to local socio-political views. This survey provides a basic framework for similar studies in other states or countries who are interested in managing agricultural pest species.

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