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Review

A review and synthesis of bird and rodent damage estimates to select California crops

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ABSTRACT

A comprehensive literature review was conducted to identify the magnitude of bird and rodent damage to 19 economically important crops in California. Interviews with agriculture experts provided additional information about damages. Monte Carlo simulations were used to derive summary estimates of damages to each crop. A meta-analysis indicated that summary damage estimates from expert interviews were higher than estimates from field studies and surveys. It was also found that there has been a downward trend over time in damages to almonds and grapes. The results of our study indicate that damages from bird and rodents remain high for many crops and are likely to be economically significant within the state of California.

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1. Introduction

The negative impacts (e.g., bird, rodent, and insect damage and drought) to agricultural production in California can have a major effect on the state's economy and consumers throughout the U.S. and around the world. Understanding the level of damage caused by birds and rodents is crucial to effective implementation of management strategies and techniques to mitigate the negative impact and thereby minimize the effect on the greater economy.

Damage caused by birds and rodents can be severe, diverse, and vary across time and geography. Examples include crows consuming grapes and almonds as well as ground squirrels girdling trees and feeding on alfalfa. Growers employ a variety of strategies and techniques to combat crop loss including the use of rodenticides and avicides, trapping, exclusion, and chemical aversion (Sexton et al., 2007). Although these techniques are generally effective at limiting crop loss, damage due to birds and rodents remains a problem in California.

Research on bird and rodent damage consists predominantly of individual studies on either a single species or multiple species impacting a single crop's final product (see Crase et al., 1976; Hothem et al., 1981; Gadd, 1996; Cummings et al., 2005; Berge et al., 2007; Delwiche et al., 2007) or a single species impacting multiple crops' final product (see DeHaven, 1974; Marsh, 1998). A shortcoming of these studies is their limited focus. A multi-crop, multi-region analysis would allow investigation of the broader impact that birds and rodents have on California agriculture and the California economy, and would allow a more comprehensive assessment of the benefits of employing various pest control methods.

A limited amount of research has attempted to incorporate multiple pest species' damage to multiple crops (see Razee, 1976; NASS, 1999; NASS, 2002; Hueth et al., 1997). One of the most comprehensive studies was Hueth et al. (1997), which undertook an analysis of the economic impact of vertebrate pest damage to select California crops. Although the study was a multi-crop, multi-region analysis, the estimates of damage were obtained from a very limited number of interviews and published studies.

Our study builds on previous research by compiling the estimates of bird and rodent damage to 19 economically important crops in select regions within California. The crops studied were alfalfa, almonds, artichokes, broccoli, carrots, cherries, grapes, lettuce, lemons, melons, nursery products, oranges, pistachios, peaches, rice, spinach, strawberries, tomatoes, and walnuts. Damage estimates were gathered from several types of sources, including previously published estimates, unpublished studies, and interviews with

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Table 1
Review of bird and rodent damage estimates and sources.

Damage per Acre (%)			Pest	Region	Year of Study	Type	Source
Low	Mid	High					
Almonds							
3	4	15	Vertebrate pests	California	2008	Interview	Marsh, 2008
1.52	2.07	5.05	Vertebrate pests	Fresno County	2008	Interview	Sagardia and Sagardia, 2008
–	15	–	Vertebrate pests	Fresno County	2008	Interview	Taber, 2008
–	0.0065	–	Birds, crows	Fresno County	2003	Field Study	Delwiche et al., 2007
–	0.0335	–	Birds, crows	Fresno County	2003	Field Study	Delwiche et al., 2007
–	0.33525	–	Birds, crows	Yuba County	2003	Field Study	Delwiche et al., 2007
–	0.004	–	Birds, crows	Fresno County	2003	Field Study	Delwiche et al., 2007
–	0.058	–	Birds, crows	Fresno County	2003	Field Study	Delwiche et al., 2007
–	0.0315	–	Birds, crows	Yuba County	2003	Field Study	Delwiche et al., 2007
–	0.0065	–	Birds, crows	Fresno County	2002	Field Study	Delwiche et al., 2007
–	0.242	–	Birds, crows	Fresno County	2002	Field Study	Delwiche et al., 2007
–	0.94	–	Birds, crows	Yuba County	2002	Field Study	Delwiche et al., 2007
–	0.006	–	Birds, crows	Fresno County	2002	Field Study	Delwiche et al., 2007
–	0.0755	–	Birds, crows	Fresno County	2002	Field Study	Delwiche et al., 2007
–	0.06675	–	Birds, crows	Yuba County	2002	Field Study	Delwiche et al., 2007
–	0.0989	–	Crows	Sacramento Valley	1999	Field Study	Salmon et al., 2000
–	2.03	–	Crows	Sacramento Valley	1999	Field Study	Salmon et al., 2000
–	0.0465	–	Crows	Sacramento Valley	1999	Field Study	Salmon et al., 2000
–	0.0407	–	Crows	Sacramento Valley	1999	Field Study	Salmon et al., 2000
–	0.023	–	Crows	Sacramento Valley	1999	Field Study	Salmon et al., 2000
–	0.71	–	Crows	San Joaquin Valley	1999	Field Study	Salmon et al., 2000
–	7.05	–	Crows	Sacramento Valley	1999	Field Study	Salmon et al., 2000
–	0.97	–	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Field Study	Salmon et al., 1999
–	1.39	–	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Field Study	Salmon et al., 1999
–	6.1	–	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Field Study	Salmon et al., 1999
–	2.44	–	Crow, Magpie, Scrub Jay	Sacramento Valley	1998	Field Study	Salmon et al., 1999
–	0.128	–	Crows	Sacramento Valley	1998	Field Study	Salmon et al., 1999
0.03	–	0.04	Deer mice	Central Valley and Sacramento Valley	1997–99	Field Study	Pearson et al., 2000
0.07	–	0.10	Deer mice	Central Valley and Sacramento Valley	1997–99	Field Study	Pearson et al., 2000
0.10	–	0.16	Birds, crows, magpies	Central Valley and Sacramento Valley	1997–99	Field Study	Pearson et al., 2000
0.06	–	0.09	Western gray squirrel	Central Valley and Sacramento Valley	1997–99	Field Study	Pearson et al., 2000
–	2.34	–	Crows	Yolo County	1997	Field Study	Salmon et al., 1997
–	1.32	–	Crows	Yolo County	1997	Field Study	Salmon et al., 1997
–	29.53	–	Crows	Sutter County	1997	Field Study	Salmon et al., 1997
–	10.57	–	Crows	Sutter County	1997	Field Study	Salmon et al., 1997
–	4.22	–	Crows	Sutter County	1997	Field Study	Salmon et al., 1997
–	3.5	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
3		4	Crows	Yuba and Sutter Counties	1988	Field Study	Hasey and Salmon, 1993
–	4.1	–	Crow, Scrub Jay, Magpie	Merced County	1984	Survey	CDFA, 1984
–	3	–	Crow, Scrub Jay, Magpie	San Joaquin County	1984	Survey	CDFA, 1984
–	1.5	–	Crow, Scrub Jay, Magpie	Butte County	1984	Survey	CDFA, 1984
–	30	–	Crow, Scrub Jay, Magpie	Fresno County	1984	Survey	CDFA, 1984
–	6	–	Crow, Scrub Jay, Magpie	Colusa County	1984	Survey	CDFA, 1984
–	1	–	Crow, Scrub Jay, Magpie	Kings County	1984	Survey	CDFA 1984
–	1.8	–	Crow, Scrub Jay, Magpie	Glenn County	1984	Survey	CDFA, 1984
–	16	–	Crow, Scrub Jay, Magpie	Tulare County	1984	Survey	CDFA 1984
–	0.12	–	Crow, Scrub Jay, Magpie	Solano County	1984	Survey	CDFA, 1984
–	5	–	Crow, Scrub Jay, Magpie	Contra Costa County	1984	Survey	CDFA, 1984
6	–	18	Crows	Tulare County	1966	Interview	Simpson, 1972
–	7	–	Birds, linnets, crows, jays, etc.	Sacramento Valley	1935–36	Field Study	Emlen, 1937
–	21	–	Birds, linnets, crows, jays, etc.	Sacramento Valley	1935–36	Field Study	Emlen, 1937
–	28	–	Birds, linnets, crows, jays, etc.	Sacramento Valley	1935–36	Field Study	Emlen, 1937
Artichokes							
20	–	30	Voles, gophers	California	2008	Interview	Roach, 2008
1.5	3	–	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	15	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Broccoli							
–	0.6	–	Birds and rodents	Fresno County	2008	Interview	Strmiska, 2008
–	0.1	–	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	100	–	Ground squirrels	Santa Cruz County	2003–04	Field Study	Muramoto et al., 2005
Carrots							
–	0.1	–	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	0.62	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Cherries							
5	–	6	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	–	50	Birds	Fresno County	2008	Interview	Taber, 2008
7.62	–	10	Birds	California	1975–76	Field Study	DeHaven et al., 1979

Table 1 (*continued*)

Damage per Acre (%)			Pest	Region	Year of Study	Type	Source
Low	Mid	High					
Citrus							
–	3.5	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
–	0.5	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Table Grapes							
0.76	–	0.95	Birds	Fresno County	2008	Interview	Pitts, 2008
0.07	–	0.14	Rodents	Fresno County	2008	Interview	Pitts, 2008
–	25	35	Birds	Fresno County	2008	Interview	Vasquez, 2008
0.5	–	1	Rodents	Fresno County	2008	Interview	Vasquez, 2008
–	0.87	–	Wildlife damage	California	1998	Survey	NASS, 1999
–	3.5	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
0.43	–	0.71	Birds	California	1976	Survey	Razee, 1976
–	1	–	Birds	California	1973	Survey	Stone, 1973
0.1	9.6	30	Birds	California	1973	Survey	Crase et al., 1976
Wine Grapes							
–	25	35	Birds	Fresno County	2008	Interview	Vasquez, 2008
0.5	–	1	Rodents	Fresno County	2008	Interview	Vasquez, 2008
–	3	35	Birds	Napa County	2008	Interview	Goymerac, 2008
3	5	–	Birds	Napa County	2008	Interview	Goymerac, 2008
0.5	–	2	Birds	Fresno and Napa Counties	2008	Interview	Taber, 2008
50	–	60	Birds	Fresno and Napa Counties	2008	Interview	Taber, 2008
1	13	20	Birds	Napa County	2008	Interview	Witmer, 2008
–	11.1	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	14.9	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	7.7	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	2.8	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	6.5	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	3.8	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	0.7	–	Birds	Napa and Sonoma Counties	2005	Field Study	Berge et al., 2007
–	7.7	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	11.6	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	5.3	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	8.5	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	8.4	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	2	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	1.2	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	0.5	–	Birds	Napa and Sonoma Counties	2004	Field Study	Berge et al., 2007
–	0.87	–	Wildlife damage	California	1998	Survey	NASS, 1999
–	1.02	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
–	11	–	House finch	Sonoma County	1996	Field Study	Gadd, 1996.
–	2.5	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	1.5	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	4.75	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	2	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	2.5	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	2	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	1.25	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	1	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	7.75	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	5.5	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	3.25	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	13.3	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	7.75	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	4	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	2.5	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981
–	2.5	–	Robin, house finches, quail, and goldfinches	Napa and Sonoma Counties	1978	Field Study	Hothem et al., 1981

(*continued on next page*)

Table 1 (*continued*)

Damage per Acre (%)			Pest	Region	Year of Study	Type	Source
Low	Mid	High					
–	1.4	–	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977–78	Field Study	DeHaven and Hothem, 1980
–	2.6	–	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977–78	Field Study	DeHaven and Hothem, 1980
–	6.3	–	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977–78	Field Study	DeHaven and Hothem, 1980
–	9.8	–	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977–78	Field Study	DeHaven and Hothem, 1980
–	15.1	–	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977–78	Field Study	DeHaven and Hothem 1980
–	76.8	–	House finches, quail, and robins	Napa, Sonoma, and San Joaquin Counties	1977–78	Field Study	DeHaven and Hothem, 1980
0.43	–	0.71	Birds	California	1976	Survey	Razee, 1976
–	1	–	Birds	California	1973	Survey	Stone, 1973
0.1	9.6	30	Birds	California	1973	Survey	Crase et al., 1976.
–	10	–	Birds	Alameda County	1973	Survey	DeHaven, 1974
–	3.7	–	Birds	Mendocino County	1973	Survey	DeHaven, 1974
–	11.4	–	Birds	Monterey County	1973	Survey	DeHaven, 1974
–	16.9	–	Birds	Napa County	1973	Survey	DeHaven 1974
–	17.8	–	Birds	San Benito County	1973	Survey	DeHaven, 1974
–	54.7	–	Birds	Santa Clara County	1973	Survey	DeHaven, 1974
–	11.7	–	Birds	Solano County	1973	Survey	DeHaven, 1974
–	14.7	–	Birds	Sonoma County	1973	Survey	DeHaven, 1974
Alfalfa							
–	7.6	–	Belding's ground squirrel	Surprise Valley	1999	Field Study	Whisson et al., 2000
–	6.97	–	Belding's ground squirrel	Butte Valley	1999	Field Study	Whisson et al., 2000
–	9.5	–	Belding's ground squirrel	Butte Valley	1998	Field Study	Whisson et al., 2000
–	10.76	–	Belding's ground squirrel	Surprise Valley	1998	Field Study	Whisson et al., 2000
–	7.6	–	Belding's ground squirrel	Butte Valley	1997	Field Study	Whisson et al., 2000
–	7.83	–	Vertebrate pests	California	1996–97	Field Study	Hueth et al., 1997
–	37	–	Belding's ground squirrel	Siskiyou County, Butte Valley	1996	Field Study	Whisson et al., 1999
–	45.9	–	Belding's ground squirrel	Siskiyou County, Butte Valley	1996	Field Study	Whisson et al., 1999
–	34.6	–	Belding's ground squirrel	Siskiyou County, Butte Valley	1996	Field Study	Whisson et al., 1999
–	18.3	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1995	Field Study	Whisson et al., 1999
–	48	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1995	Field Study	Whisson et al., 1999
–	36.1	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	53.8	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	42.8	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	40	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	28.8	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	28.8	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	29.8	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	17.6	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	17.9	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	17.6	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	20.3	–	Belding's ground squirrel	South central Oregon	1977	Field Study	Kalinowski and deCalesta, 1981
–	17.5	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
–	28.4	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
–	19.5	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
–	21.1	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
–	19.5	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
–	38.5	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
–	17.1	–	Belding's ground squirrel	Siskiyou and Modoc Counties	1975–78	Field Study	Sauer, 1984
Lettuce							
–	1	–	Birds	Santa Cruz and Monterey Counties	2008	Interview	Bolda, 2008
3	–	4	Birds	Fresno County	2008	Interview	Maya, 2008
0	–	–	Rodents	Fresno County	2008	Interview	Maya, 2008
–	–	50	Birds	Fresno County	2008	Interview	Maya, 2008
1	–	2	Rodents	Fresno County	2008	Interview	Maya, 2008
30	–	100	Birds and rodents	Fresno County	2008	Interview	Strmiska, 2008
–	20	–	Rodents	Fresno County	2008	Interview	Strmiska, 2008
2	–	3	Vertebrate pests	California	2008	Interview	Marsh 2008
–	30	–	Birds	Fresno County	2008	Interview	Taber, 2008
–	0.6	–	Horned lark	San Joaquin Valley	1999	Field Study	York et al., 2000
–	3.75	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Melon							
10	–	20	Rodents	Fresno County	2008	Interview	Strmiska, 2008
–	1	–	Rodents	Fresno County	2008	Interview	Strmiska, 2008
–	1.38	–	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	0.1	–	Birds	Fresno County	2008	Interview	Taber, 2008
–	1.38	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997

Table 1 (*continued*)

Damage per Acre (%)			Pest	Region	Year of Study	Type	Source
Low	Mid	High					
Nursery							
–	–	5	Cottontail rabbit	Orange, San Diego, and Los Angeles Counties	2008	Interview	Wilen, 2008
4	–	6	Cottontail rabbit	Orange, San Diego, and Los Angeles Counties	2008	Interview	Wilen, 2008
Peaches							
–	0.1	–	Birds	Fresno County	2008	Interview	Taber, 2008
1	–	2	Vertebrate pests	California	2008	Interview	Marsh, 2008
3	–	4	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	0.68	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Pistachio							
3	4	15	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	15	–	Birds	Fresno County	2008	Interview	Taber, 2008
–	5.75	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
–	0.91	–	Crows	California	1993	Field Study	Hasey and Salmon, 1993
–	4	–	Birds	Tulare County	1985	Field Study	Crabb et al., 1986
–	7.87	–	Birds	Tulare County	1985	Field Study	Crabb et al., 1986
–	12.2	–	Birds	Tulare County	1985	Field Study	Crabb et al., 1986
2	4	10	Crow, Raven, Jay, Starling, Magpies	California	1984	Field Study	Crabb et al., 1986
–	24	–	Crow, Scrub Jay, Magpie	Tulare County	1984	Survey	CDFA, 1984
Rice							
–	1	–	Blackbirds	California	2001	Field Study	Cummings et al., 2005
0.1	0.2	3	Birds	Sacramento Valley	1972	Survey	Stone, 1973
–	0.1	–	Birds	Sacramento Valley	1971	Interview	DeHaven, 1971
Rice (Wild)							
1	–	10	Blackbirds	Sacramento Valley	1993	Survey	Marcum and Gorenzel, 1994
Strawberry							
–	0.1	–	Vertebrate pests	Santa Cruz and Monterey Counties	2008	Interview	Bolda, 2008
–	0.1	10	Vertebrate pests	Santa Cruz and Monterey Counties	2008	Interview	Moinar, 2008
–	1.28	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Tomatoes							
0.1	1	–	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	1.38	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
–	0.5		Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
Walnuts							
–	0	–	Vertebrate pests	California	2008	Interview	Marsh, 2008
–	3	5	Birds	Fresno County	2008	Interview	Taber, 2008
–	2.8	–	Vertebrate pests	California	1996–97	Mixed	Hueth et al., 1997
–	4	–	Crow, Scrub Jay, Magpie	Tulare County	1984	Survey	CDFA, 1984
–	0.9	–	Crow, Scrub Jay, Magpie	Butte County	1984	Survey	CDFA, 1984
–	6	–	Crow, Scrub Jay, Magpie	Merced County	1984	Survey	CDFA, 1984
6	–	18	Crows	Tulare County	1966	Interview	Simpson, 1972

experts. A limited meta-analysis was performed to examine the impact that the data source has on the reported level of damage and examine any trend in damage over time. These damage estimates are reported by crop, and summary estimates based on the results of a Monte Carlo simulation of damages are then provided.

2. Materials and methods

To compile the bird and rodent damage data, a comprehensive search for published studies, surveys, and unpublished reports was conducted. Additional estimates were gathered in 2007 through personal interviews of agricultural extension specialists, County Agricultural Commissioners, crop growers, and knowledgeable wildlife damage specialists from across California. These experts were asked to estimate the amount of damage per acre caused by birds and rodents in either percent or monetary terms using current control methods for a particular crop. If estimates were given in monetary terms, they were converted to percent yield loss based on 3-year average price and yield data from California. In general, experts identified one or two major species that cause the majority of the damage to a particular crop. The data was compiled by crop and separated between field studies and interviews/surveys. All data used for the analysis from the various sources are provided in Table 1. Many studies provided a range of damage estimates for a single crop. If a minimum and maximum damage estimate was provided, these are listed in the “low” and “high” columns in the table. When only a single estimate was provided, the estimate was listed in the “mid” column. Therefore, the distinction between low, mid, and high was derived directly from the estimates provided by each specific data source and was not our interpretation of the relative size of the estimates.

To obtain a summary estimate of damage for each crop, two Monte Carlo simulations were performed. The first Monte Carlo simulation relied on data from field studies; the second on data from surveys and interviews. This distinction was made because of the difference in methodology between field studies and surveys and interviews. For the simulations, damage estimates from sources that provide a minimum and maximum damage were assumed to be uniformly distributed. Those studies that provide a minimum and maximum, as well as a most likely value, were assumed to have a triangular distribution where the most likely value is the mode. No distribution was assigned to studies that provide a single number; this number was assumed to occur with certainty. The simulation proceeds by randomly drawing a damage estimate from all of the individual estimates and assigning that estimate to some acre of land. This was done repeatedly for 1000 acres of land and the mean damage across those 1000 acres was calculated. To obtain a single summary result for each crop, the Monte Carlo simulation using field study data was given a 70% weight, while the other Monte Carlo simulation was given a 30% weight. This weighting assumed that field study data is more reliable than survey or interview data.

The expected yield loss per damaged acre was weighted by the fraction of planted acres of the crop that were affected by pests and then averaged (see Table 2). Because not all acres suffer damage, multiplying the percent yield loss per damaged acre by the percent of acres damaged gives the expected damage from bird and rodent pests for each crop. It should be noted that the method of weighting used here provides a conservative estimate of damages. Some studies that provided an estimate of the fraction of planted acres affected by a pest had already taken that into account when reporting yield loss. The yield loss estimates from such studies were used in the Monte Carlo simulation to derive the yield loss per acre affected by pest. Therefore, weighting this result again by the fraction of acres damaged puts a downward bias on the expected yield loss. However, failure to weight the results of the Monte Carlo simulation in this way would put upward bias on the damage estimates.

The extensive collection of damage estimates assembled allowed for a limited meta-analysis. Meta-analysis uses a statistical approach to review and summarize literature and previously obtained research results (Florax et al., 2002; Egger and Smith, 1997). One function of a meta-analysis is to determine how different research methods affect the results of the study (Stanley, 2001). The type of meta-analysis performed here is more specifically called a meta-regression analysis (Stanley and Jarrell, 1989). Given the purpose of our study is, in part, a synthesis of previous damage estimates, a meta-analysis can provide several useful insights. First, the impact of the source of the damage estimate (e.g. field study, interview) on the magnitude of the reported damage can be investigated. For example, experts may only become aware of damage when it is abnormally high, and the data from interviews with these experts may reflect this. Second, there may be a trend in damages over time. Perhaps damage has decreased over time as producers gain damage management experience, or conversely, regulations may have reduced the ability of producers to use certain control methods. In either case, the meta-analysis can examine any resulting trend in the data.

Table 2
Expected yield loss per damaged acre, percent of total acreage that suffers damage, and percent of total yield that is lost to bird and rodent pests.

Crop	Expected Yield Loss Per Damaged Acre (%)	Acres Damaged (% of total)	Expected Damage (% yield loss)
Almond	5.1	50.8	2.6
Artichoke	11.8	70.0	8.3
Broccoli	9.5	42.1	4.0
Carrots	0.4	40.0	0.2
Cherries	11.1	34.0	3.8
Citrus, oranges	1.0	30.0	0.3
Citrus, lemons	3.5	30.0	1.1
Grapes, table	5.4	67.5	3.6
Grapes, wine	10.7	67.5	7.2
Hay, alfalfa	24.0	17.0	4.1
Lettuce	6.1	42.1	2.6
Melons	4.2	17.5	0.7
Nursery, flower	3.0	20.0	0.6
Nursery, container	5.0	100.0	5.0
Peaches	1.6	40.0	0.6
Pistachios	8.4	53.0	4.5
Rice	0.7	39.0	0.3
Rice, wild	5.4	93.0	5.0
Spinach	6.1	42.1	2.6
Strawberry	2.6	30.0	0.8
Tomato	0.8	30.0	0.2
Walnut	5.0	40.0	2.0

Our study included many different crops and these crops do not suffer equal damage. This necessitated controlling for the type of crop in the meta-analysis. Unfortunately, there was an insufficient number of damage estimates available for most crops to make this statistically feasible. We were therefore forced to limit our sample to the four crops with the most observations: almonds, grapes, alfalfa, and lettuce.

The model we used for the meta-analysis assumes the damage estimate depends on the year of the study or expert interview, the type of crop, and whether the damage estimate was obtained from an interview with an expert. The model can therefore be written as

$$\begin{aligned} damage_i = \; & \beta_1 + \beta_2(year_i) + \beta_3(almonds_i) + \beta_4(grapes_i) \\ & + \beta_5(alfalfa_i) + \beta_6(expert_i) + u_i \end{aligned} \tag{1}$$

In this equation, i indicates the particular damage estimate observation (e.g., a 5% estimate of lettuce damage from an expert). The *year* variable represents the year that the study or expert interview was performed. The estimated coefficient $\hat{\beta}_2$ can be interpreted as the change in the expected damage estimate when the year is increased by one. Stated differently, as all other factors are held constant, a one year movement closer to the present will change the expected damage by $\hat{\beta}_2$

The crop variables (*almonds*, *grapes*, *alfalfa*) are dummy variables that equal one if an observation came from that particular crop and zero otherwise. To avoid perfect collinearity among the variables, no dummy variable is specified for lettuce (Greene, 2003). Therefore, the estimated coefficients $(\hat{\beta}_3, \hat{\beta}_4, \hat{\beta}_5)$ reflect how much expected damage to the other crops differ from expected damage to lettuce. Similarly, *expert* is a dummy variable that equals one if the observation came from an interview with an expert and zero otherwise. No dummy variable was specified for other types of data sources to avoid perfect collinearity. The coefficient $\hat{\beta}_6$ indicates the difference in expected damage when the damage estimate comes from an interview with an expert instead of some other data source.

The model was estimated using ordinary least squares (OLS) (Greene, 2003). However, to account for both heterskedasticity and autocorrelation, the Newey–West estimator was used to obtain the covariance matrix of the OLS estimator (Newey and West, 1987). This insures hypothesis tests on the estimated coefficients are statistically valid. Hypothesis tests on the estimated coefficients were the standard two-tailed t-tests (Greene, 2003).

3. Results

The results of the Monte Carlo simulation and weighting method are given in Table 2. Expected (the weighted mean) yield loss per damaged acre is the direct result of the Monte Carlo simulation, while expected damage is the weighted result. Assessment of relative pest damage should be based on the expected damage rather than the expected damage per damaged acre. These summary estimates may be interpreted as the expected crop damage given the range of estimates provided by the various sources. While it is tempting to simply take the mean of the individual estimates for each crop, such an approach may lead to a biased result because many of the estimates from individual sources are not a single number. Referring back to Table 1, it is clear that some estimates were reported as a range or with some value within that range being reported as most likely. The expected damage estimates do not reveal any obvious ranking of damages according to crop categories, but they do indicate considerable differences in damage among the crops. Average artichoke damage, for example, is 8.3%, but average damage to carrot acreage is only 0.2%.

The results of the meta-analysis are presented in Table 3. The constant term (equal to one for all observations) accounts for the fact that there is no dummy variable for lettuce and non-expert interview data sources and serves as a baseline from which we can interpret the coefficients on the dummy variables that were included. Thus, the coefficient on *expert* (7.714) means that the expected damage estimate from an expert interview is approximately 7.7% higher than the expected damage estimate from some other data sources. The corresponding t-stat (2.16) and *p*-value (0.033) indicate that for this variable, the data source matters and expert interviews yield larger damage estimates than other sources.

The other key variable of interest was *year*. The estimate of the coefficient (0.008) was statistically significant at the 1% level (*p*-value of 0.002). This can be interpreted as a small upward trend in the damage estimates over time. The coefficients on the crop-specific dummy variables can be interpreted as the difference in the expected damage to those crops relative to expected lettuce damage when all other factors are held constant. Thus, almonds are expected to suffer about 5% less damage than lettuce, grapes about the same level of damage as lettuce, and alfalfa about 15% greater damage. The alfalfa coefficient indicated statistical significance at commonly accepted levels (*p*-value of 0.009). Although the other two are not statistically significant at the 5% or 10% level, the estimates are the best indication of the relative difference in damages between these crops and lettuce.

4. Discussion

U.S. agricultural production plays a crucial role in the domestic and world economy. California leads the nation in the production of agricultural goods, producing roughly $38 billion worth of agricultural commodities annually (CDFA, 2010). Damage to these crops can be severe and lead to impacts that extend beyond the producer, resulting in losses to the state and national economies. To successfully combat bird and rodent damage to crops, producers, agricultural extension experts, and researchers must have an understanding of the level of damage to these economically important crops.

This review and synthesis provides the most comprehensive and current compilation of bird and rodent damage to select California crops available from scientific literature and expert knowledge. While numerous sources contain components of the data presented in this study, collating this data into one study allowed for a Monte Carlo analysis and a synthesis of the data that provided new information including the influence of the data source on damage estimates, trends in damage estimates over time, and how estimates differ among crops.

Table 3
Meta-analysis results.

Variable	Coefficient	Standard Error	*t*-statistic	*p*-value
Constant	−6.008	6.318	−0.951	0.343
year	0.008	0.002	3.161	0.002
almonds	−5.486	4.321	−1.270	0.206
grapes	−0.971	4.300	−0.226	0.822
alfalfa	15.559	5.871	2.650	0.009
expert	7.714	3.572	2.160	0.033

The magnitude of the results of the Monte Carlo simulation and an examination of the assembled damage estimates indicate that damage remains significant despite the use of a variety of methods (e.g. rodenticides and avicides, trapping, exclusion, and chemical aversion) to control bird and rodent pests. Crops such as artichokes, wine grapes, and wild rice were damaged heavily, and it is likely that the economic impact of this damage is very large. Thus, there are significant benefits to be had by developing and implementing more effective pest control methods. It is also possible that effective means of control are available but are too costly to use. Therefore, efforts to lower the costs of currently available methods are likely warranted. Estimates of damage used in our study were pest-related primary damages to the final fruit, nut, grain, vegetable, nursery, or forest product. For example, primary bird damage to grapes occurs when the bird plucks whole fruit or pecks at the fruit resulting in decreased yield (Tobin, 1984). Pocket gophers may cause secondary damage by tunnelling near a grape vine, but this is not damage to the final fruit and is not reflected in our damage estimate. Inclusion of this secondary damage would increase the estimated damages to agricultural crops.

Unfortunately, the effect of bird and rodent pests on many of the crops has not been studied and documented sufficiently. Some damage estimates had limited availability of sources, and many were based on expert opinion rather than actual field studies. Additionally, it is also important to note that the nature of vertebrate pests has changed over time and invasive species have become an increasing concern. Our study provides a baseline from which future examinations of invasive species impacts to these crops can be measured.

In conclusion, our study indicates that damage to select California crops can be significant. The summary estimates calculated in the analysis are valuable because they condense the wide-ranging individual estimates into a single, perhaps more usable, estimate for each crop. This enables targeted and efficient application of current pest control methods and can serve as a guide for the development of new methods. There are numerous extensions to the analysis that could be fruitful areas for future research. First, it would be advantageous to translate the yield loss due to pests into economic damages. When yield is reduced, producer revenue falls, impacting the regional economy as well as the producer as less is spent on wages and other goods. Additionally, the results may be incorporated into a wider examination of the benefits and costs of pest control methods. Our results indicate remaining damages with current pest control methods. Given that the presence of pests necessitate the use of pest control, the remaining damages could be combined with the cost of the pest control to develop an estimate of the total negative impact of bird and rodent pests on California growers.

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