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Abbreviations:
MGL: most (bordering) grazing land; MWH: most (bordering) wildlife habitat; SGL: some (bordering) grazing land; SWH: some (bordering) wildlife habitat

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Pre-harvest food safety and conservation challenges facing US produce growers: results from a national survey

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Abstract

Fruit and vegetable growers in the US face tradeoffs and synergies between on-farm conservation and pre-harvest food safety as a result of economic considerations, regulatory concerns, and external pressure from other stakeholders. However, detailed data on the frequency and extent of these tradeoffs across US regions remain sparse. We designed and implemented a national grower survey for the 2018 crop year to address this gap. Based on 209 responses, we examined usage of pre-harvest food safety and conservation practices with a particular emphasis on managing animal intrusion into growing areas and maintaining wildlife habitat. We also analyzed associations between farm characteristics and the probability that growers used different on-farm food safety and conservation practices. We did not find a simple bio-physical or socio-economic explanation for why some farms adopted specific practices over others. Instead, our findings suggest that the adoption of particular food safety practices is influenced by a complex assemblage of factors that include environmental context, supply chain pressures, cost considerations, and growers' perceptions of risk. A better understanding of the diverse tradeoffs and synergies that US produce growers face between on-farm conservation and pre-harvest food safety is critical for effective policy design.

Introduction

Growers generally manage agroecosystems with both human and environmental health in mind, but external regulatory, economic, and cultural forces can pressure growers to forfeit on-farm conservation in the name of food safety (Baur, 2020). For example, after investigations concluded that a 2006 outbreak of *Escherichia coli* 157:H7 linked to California-grown spinach *might* have been caused by wild boar intrusion into spinach fields (Jay *et al.*, 2007), multiple interview and survey-based studies found that customer concerns over wildlife led growers to remove vegetated buffers (e.g., filter strips and hedgerows), set out poison bait, remove irrigation or drainage ponds, and adopt other wildlife deterrents (Beretti and Stuart, 2008; Stuart, 2009; Gennet *et al.*, 2013; Baur *et al.*, 2016). Today, after investigations linked more recent, nationwide *E. coli* outbreaks to water sources used for irrigation and mixing agrichemical sprays (Marshall *et al.*, 2020), growers have come under further scrutiny to test and chemically treat agricultural water. Over a decade after the 2006 outbreak, research among California growers still found that 'food safety requirements can conflict with growers' management philosophies and environmental sustainability goals' (Olimpi *et al.*, 2019).

Failure to adopt or maintain practices intended to conserve soil, water, and biodiversity in agroecosystems can result in the loss of ecosystem services that enhance farm productivity and, in some cases, mitigate the risk that human pathogens will contaminate farm products (Karp *et al.*, 2015; Olimpi *et al.*, 2019; Weller *et al.*, 2020; Smith *et al.*, 2022). Non-crop vegetation on farms (e.g., hedgerows, constructed wetlands) can reduce erosion and provide biodiversity-enhancing habitat, which promotes native pollinators and insect predators that help control pests (Sweeney *et al.*, 2004; Ponisio, M'Gonigle and Kremen, 2015; Sellers *et al.*, 2018). A recent meta-analysis found that including higher amounts of non-crop habitat in the farm environment increased pest control and pollination services (Tamburini *et al.*, 2020). Another meta-analysis found that flower strips enhanced pest control (Albrecht *et al.*, 2020). Vegetated buffers between agricultural production areas and waterbodies also help protect water quality by capturing nutrient, agrichemical, and microbial pollutants in agricultural runoff before they enter waterways (Douglas-Mankin, Helmers and Harmel, 2021; Díaz, O'Geen and Dahlgren, 2012; Reichenberger *et al.* 2007). When growers remove that vegetation, they forego those benefits and increase the risk of harm to local ecosystems, community health, and rural economies.

Nevertheless, research suggests that growers face increasing pressure from external groups (e.g., buyers, regulators) to meet more stringent expectations for managing pre-harvest food safety hazards (Esquivel *et al.*, 2021; Becot *et al.*, 2021; Baur, 2020; Astill, Minor and Thornsbury, 2019a; Astill *et al.*, 2019b; Minor *et al.*, 2019). Such expectations generally do not account for potential costs to the grower or conservation trade-offs in the farm environment. From a biodiversity conservation perspective, the amount of natural habitat remaining in the landscape is the most important determinant of species persistence (Watling *et al.*, 2020). A potential tradeoff between conservation and food safety may occur when farmers weigh the risk and benefit of adoption/maintenance of on-farm practices that represent natural habitat. While the ecological and socio-economic effects of these pressures on growers in California's Central Coast have been extensively studied since the 2006 outbreak (Beretti and Stuart, 2008; Lowell, Langholz and Stuart, 2010; Olimpi *et al.*, 2019), data on the frequency with which growers in other regions face and act on such pressures, and whether that results in concrete trade-offs between food safety and environmental conservation, remain sparse. Interview-based and survey studies outside California have tended to focus on rates of food safety practice adoption, compliance costs, and other barriers to complying with applicable food safety regulations. Consistently, this research shows that smaller-scale farms exhibit lower rates of adoption compared to their larger-scale counterparts—including adoption of practices which are likely to interact with on-farm conservation practices, such as managing hazards associated with wildlife intrusion and agricultural water. These studies also found that smaller-scale farms also pay relatively more to comply with food safety requirements than do their larger-scale counterparts (Astill *et al.*, 2018; Adalja and Lichtenberg, 2018a, 2018b; Schmit *et al.*, 2020; Becot *et al.*, 2021). At the same time, pressure to implement food safety practices appears to be driven largely by the demands of buyers: growers adopt some food safety practices out of intrinsic desire to 'do better', but adoption is also strongly motivated by the desire to maintain or expand access to wholesale markets and corporate buyers by passing food safety audits and securing third-party Good Agricultural Practices (GAP) certification (Astill *et al.*, 2019b; Schmit *et al.*, 2020; Olimpi *et al.*, 2019; Minor *et al.*, 2019). This suggests that market channel—the types of markets through which growers sell their products—is an important factor mediating grower decisions about trade-offs between food safety and on-farm conservation. However, no surveys outside of California have asked whether (1) farms actually experience tradeoffs between food safety practices and on-farm conservation or (2) whether and how that experience differs among farms, for example, by farm size, certified organic status, or market channel.

Understanding how often, to what extent, and under what conditions growers find themselves making trade-offs between food safety and on-farm conservation is critical for developing adaptive strategies to better co-manage agricultural environments for both objectives. With climatic, economic, and regulatory stresses on growers likely to increase for the foreseeable future, systems-based perspectives are needed to help find the right balance among the many societal demands on agriculture and ensure the short- and long-term safety, sustainability, and economic resiliency of agricultural systems (Baur, 2020; Vågsholm, Arzoomand and Boqvist, 2020). For this reason, we designed a national grower survey specifically to address this gap in understanding how growers differentially experience trade-offs between food safety and sustainability.

Materials and methods

Survey design

We designed the grower survey to provide data with which to address five research questions: (1) what are the animal intrusion risk factors on farms; (2) what practices do farmers use to prevent animal intrusion; (3) to what extent do farmers perceive that these practices reduce food safety risk; (4) to what extent do these practices impact environment/conservation; and (5) how do farm characteristics affect all of the above? The survey focused on the 2018 crop year and was designed to characterize pre-harvest food safety and conservation practices used by US fruit and vegetable growers, their perceptions of the benefits and trade-offs between food safety and conservation practices, and the internal and external factors that motivated growers to adopt specific practices. Since food safety practices for deterring wildlife intrusion into farm environments—including the maintenance or removal of on-farm non-crop vegetation—were of particular interest, the survey included questions about animal intrusion risk factors and the presence of potential wildlife habitat on or near farms. The survey also collected information for the 2018 crop year on farm size (annual sales and acreage), non-agricultural land uses, farm product portfolio, marketing channels, geographic location (state level), and whether the farm grew certified organic[1] products. Where possible, specific questions and response choices were aligned with similar questions from previous related surveys of on-farm food safety practices, including Beretti and Stuart (2008), Baur *et al.* (2016), Adalja and Lichtenberg (2018a, 2018b), and Astill *et al.* (2018). The survey instrument is provided in the online supplementary material Appendix D.

We created an online draft of the survey instrument using Qualtrics (https://www.qualtrics.com). To ensure questions and vocabulary aligned with on-farm practices, we piloted the survey in two rounds. First, we shared an alpha version with produce safety extension agents, who submitted feedback to the authors via email. We incorporated this feedback into a beta version, which was distributed to eight growers who had worked with the authors on previous projects. Based on beta responses and feedback, the survey instrument was revised and finalized. All research activities were reviewed by Cornell's Human Research Protection Program and determined exempt as the activities do not meet the IRB definition of human subjects research.

Survey implementation

Due to the breadth of the survey's target population (all US fruit and vegetable growers) and lack of any centralized means to contact this population, an open-ended, network recruitment strategy was chosen to maximize exposure. Starting 15 January 2020, a live Qualtrics link to the survey was distributed digitally through email

[1]Hereafter, all references to 'organic' always mean 'certified organic' unless stated otherwise.

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listservs, websites, and newsletters by 21 state and national extension programs, 22 regional trade organizations, six national trade organizations, five trade journals, and one commercial seed company. Distribution extended through word of mouth as well. A monetary incentive (a $15 e-gift card) was offered to respondents who completed the survey. The survey was closed to further responses on 21 April 2020.

Data analysis

All statistical analysis was conducted using R v. 4.1.2 (R Foundation). We considered a detailed analysis of differences in responses based on US Environmental Protection Agency (EPA) regions (US EPA, 2022), but the survey sample underrepresented several regions such that this was not feasible (Fig. 1). We provide a basic summary of regional differences in the online supplementary material Appendix C. A response rate cannot be calculated when using an open-ended recruitment strategy, thus limiting the extent to which we can extrapolate our findings to broader populations of US growers. For that reason, our analyses and subsequent discussion focus mainly on relevant associations identified within the sample among farm characteristics and farming practice outcomes.

We constructed several variables based on survey responses to facilitate analysis. First, we calculated the proportion of each operation's acreage used for fruit and vegetable production in 2018 as well as two variations of a Herfindahl–Hirschman Index (HHI) for each grower to characterize operational diversity in production and distribution. We calculated acreage HHI based on each grower's percent of farm area under each of nine land uses: in-field or high tunnel vegetable or herb production; orchards, cane, bush berry, or other fruit production; feed, grain, oilseeds, and dry beans; fruits, vegetables, or herbs in a greenhouse or controlled; pasture land; grassland (not for grazing); woodland, wetlands, and other non-grass vegetation; bare ground, fallowed, and idled land; and other uses. Similarly, we calculated distribution HHI based on each grower's percent of farm sales through each of seven distribution channels: produce wholesalers; grocery retailers; mass merchandisers; processors; foodservice operations; direct to consumers; and other channels. HHI is a measure of concentration and can range from 0 to 10,000, where 10,000 indicates that the entirety of an operation's acreage or sales revenue, respectively, falls into a single land use or marketing channel. Values closer to zero indicate more widespread distribution of land uses or marketing channels, respectively, within a given operation.

To assess how food safety management may vary by cropping system and market channel, we created quartiles for the share of each operation's acreage used for fruit and vegetable production in 2018 and for the share of each operation's total sales made through direct-to-consumer (DTC) channels.

Descriptive statistics were calculated for all survey questions. First, we constructed two-way cross-tabulations between revenue category and production method, geographic region, proximity to wildlife habitat, and proximity to grazing land. To summarize grower responses to binary response questions, separate cross-tabulations between binary responses and categorical groupings for farm revenue, production method, fruit and vegetable acreage proportion, direct sales proportion, proximity to wildlife habitat, and proximity to grazing land were also calculated. Prior research indicates that these are important factors in growers' decisions to use food safety and conservation practices (Baur *et al.*, 2016; Adalja and Lichtenberg, 2018a; Astill *et al.*, 2018). For these cross-tabs, we also conducted Pearson's χ^2 tests of independence to compare response frequencies across groups and identify trends. Correlations reported as statistically significant in the text reflect a *P*-value of $P \leq 0.05$ unless noted otherwise.

Cross-tabulations allow us to examine observable trends in the prevalence of use of on-farm operating practices, but they do not allow us to control for correlation among farm characteristics, so probit regression is often used with survey data to analyze qualitative binomial responses in a multivariable framework with the cumulative normal probability distribution (Finney, 1971). To systematically explain how the likelihood of using different operating practices changes across farm characteristics while controlling for confounding factors, we estimated a series of 35 probit regression models to examine the effects of farm characteristics on the probability of using different on-farm food safety practices, vegetative buffers, wildlife habitat control, wildlife direct deterrence, and conservation practices. For ease of exposition, we provide directional signs (±) of the estimated coefficients for statistically significant results ($P \leq 0.05$) within the text and table. The full set of estimated regression coefficients for each of the probit models are also provided in the online supplementary material Appendix A.

The dependent variable in each probit model was a binary response (0/1) indicating use of a particular practice. The explanatory variables consisted of revenue category, an indicator for any organic production, produce acreage share, DTC sales share, and an indicator for proximity to wildlife habitat. Each of the explanatory variables is defined as follows. For revenue category, we grouped farms into three categories based on their reported average annual revenue between 2016 and 2018 to align with US Food Safety Modernization Act (FSMA) farm size classifications: less than $25,000 (exempt from FSMA), $25,000–$500,000 (very small and small farms), and greater than $500,000 (large farms). For the organic production indicator, we created a binary indicator of *any* organic production by combining wholly organic farms with those that reported managing both conventional and organic production (i.e., 'split operations'). For produce acreage share, we calculated produce (fruit and vegetable) acreage as a proportion of total farm acreage for each grower. For DTC sales share, we used each grower's reported percentage of farm sales through DTC channels. For the proximity to wildlife habitat indicator, we created a categorical variable for the share of an operation's production area that bordered wildlife habit in 2018, with three levels: none (0%), some (<50%), and most (>50%); all results for the proximity indicator are interpreted relative to the excluded category, none.

Results

In total, 2142 respondents completed the survey. After applying filtering criteria to ensure that responses represent current fruit and vegetable growers, our final dataset comprised 209 responses (see online supplementary material Appendix B). As is standard with survey data, response rates vary because not every respondent chose to answer every question. The cross-tabulation results and the associated Pearson's χ^2 tests of independence are presented first to analyze trends in the prevalence of use of on-farm food safety and conservation practices. The probit regression results are then presented in section 'Probit regression analyses' to explain associations among farm characteristics and the likelihood of using these same operating practices.

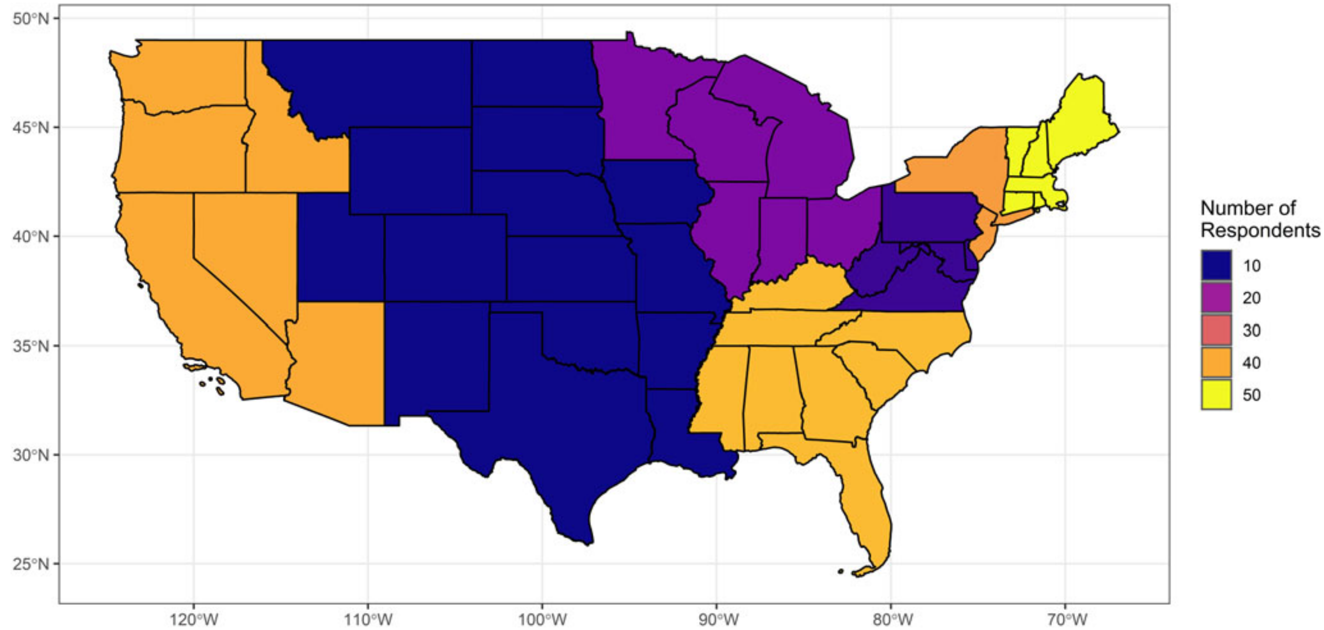

Figure 1. Geographic distribution of survey respondents.

Farm characteristics, production, and marketing

The survey asked respondents to estimate their average annual revenue for all farm production between 2016 and 2018. We grouped farms with revenue information ($N = 199$) into six revenue categories based on FSMA farm size classifications but with more granularity for large farms (Table 1): less than \$25,000 (exempt from FSMA; 10%), \$25,000–\$250,000 (very small farms; 29%), \$250,000–\$500,000 (small farms, 15%), \$500,000 to \$1 million (large farms, 14%), \$1–\$5 million (large farms; 24%), and greater than \$5 million (large farms; 9%).

Overall, nearly half of all respondents grew both conventional and organic products (i.e., 'split operations', 47%, $N = 193$), while 36% grew only conventional ($N = 193$), and 17% grew only organic ($N = 193$). Only 7% of farms with revenue above \$500,000 ($N = 92$) grew solely organic products.

On average, about 42% (95% CI 38–46%) of each operation's acreage was dedicated to fruit and vegetable production. This estimate is fairly consistent across revenue categories. Based on our calculated HHI measures, a clear trend emerges of increasing diversity of land uses by operations with higher revenue: average acreage HHI for the largest revenue group is about half that of the smallest group. Similarly, we observe a strong trend of increased diversity of distribution channels used by operations with higher revenue: average distribution HHI for the largest revenue group is less than half that of the smallest group.

Respondents were asked whether most (>50%, 'MWH'), some (>0 and <50%, 'SWH'), or none (0%) of their fruit, vegetable, or other specialty crop production area (e.g., fields, orchards, etc.), bordered hedgerows, woodlands, wetlands, or other terrestrial wild lands and wildlife habitat in 2018. Overall ($N = 196$), 34% reported MWH, 45% SWH, and 20% none.

Respondents were also asked how much of their fruit, vegetable, or other specialty crop production area bordered lands used for grazing or raising livestock (including hobby farms) in 2018 using the same classification scheme as the wildlife habitat question. In this case ($N = 196$), only 14% of growers reported that most (>50%, 'MGL') of their production area bordered grazing land, while 49% reported that some (>0 and <50%, 'SGL') of the production area bordered grazing land, and 37% reported that none of the production area bordered grazing land.

The survey also asked growers about the water sources their operation used for pre-harvest applications that touched the harvested portion of the crop in 2018. Most growers ($N = 202$) used some type of surface water (e.g., ponds, reservoirs, streams, or canals) for applications that touched the harvested portion of produce (63%), while 37% did not use surface water for these applications.

Programmatic level of food safety management and oversight

The survey assessed each farm's programmatic level of food safety management and oversight by asking growers if they: (1) or any staff members attended any food safety training on in-field food safety practices in the past five years (e.g., FSMA training, GAPs); (2) currently had a food safety plan with a pre-harvest component; (3) hired a food safety consultant in the past five years; (4) carried any form of insurance policy for food safety liability; and (5) were covered by any third-party food safety audits (e.g., PrimusGFS, GlobalGAP, USDA GAP) in 2018 (Table 2). For context, the survey also asked whether the respondent's operation had incurred any financial losses due to food safety concerns in the past five years. Across all farms ($N = 209$), 50% had growers or staff that attended training on in-field food safety practices in the past five years, but fewer than half carried food safety insurance (44%), had a food safety plan (40%), had undergone a third-party food safety audit (28%), or hired a food safety consultant (21%). One in four (26%) incurred financial losses related to food safety in the past five years.

Farm revenue was significantly associated with three of the five food safety management and oversight activities. We observed positive associations between increasing farm revenue and having a food safety plan, hiring a food safety consultant, and using

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Table 1. Farm characteristics by revenue category

Classification[a]	Responses by revenue category (in US$)							
	<25k	25–250k	250–500k	500k–1M	1–5M	5M+	Not reported	Total
All farms ($N = 209$)	19	57	30	28	47	18	10	209
Production method ($N = 193$)								
Organic and conventional	1	16	12	20	32	8	2	91 (47%)
Organic only	3	16	8	0	2	4	0	33 (17%)
Conventional only	12	21	10	8	13	5	0	69 (36%)
Operational diversity								
Prop. FV acreage ($N = 200$)	0.403	0.396	0.446	0.517	0.400	0.365	0.269	0.417
Avg. acreage HHI[b] ($N = 195$)	5698	4465	3258	3726	3702	3055	4503	3981
Avg. distr. HHI[c] ($N = 201$)	8640	5312	4077	3637	3707	3438	8717	4700
Wildlife habitat ($N = 196$)								
Most (MWH)	13	24	4	5	13	5	3	67 (34%)
Some (SWH)	3	23	16	12	24	11	0	89 (45%)
None	1	9	10	11	9	0	0	40 (20%)
Grazing land ($N = 196$)								
Most (MGL)	1	10	5	0	5	6	0	27 (14%)
Some (SGL)	3	27	14	13	30	8	2	97 (49%)
None	13	19	11	15	11	2	1	72 (37%)
Production water (touching produce) ($N = 202$)								
Surface water used	1	28	23	24	38	12	1	127 (63%)
No surface water used	17	27	7	4	9	6	5	75 (37%)

[a](No. of respondents).
[b]Average acreage HHI is the average of grower acreage HHIs calculated based on each grower's percent of farm area under each of nine land uses.
[c]Average distribution HHI is the average of grower distribution HHIs calculated based on each grower's percent of farm sales through each of seven distribution channels.
Note: Not all respondents chose to report classification information. Response rates for each classification are reported in parentheses. In the 'Total' column, percentages of total responses are reported in parentheses for each classification group.

third-party audits. For instance, 15% of farms with annual revenue between \$25k and \$500k ($N = 87$) had undergone an audit, compared to 58% of farms with annual revenue over \$1M ($N = 65$). Meanwhile, the proportion incurring financial losses due to food safety incidents also rose steadily with farm revenue, from 11% ($N = 57$) for farms with annual revenues between \$25k and \$250k to 50% ($N = 18$) for farms with annual revenues exceeding \$5M.

Use of organic production practices ($N = 193$) is also significantly, positively correlated with multiple aspects of food safety program organization. Compared to conventional growers, greater proportions of organic growers reported having a food safety plan (48 *vs* 32%), hiring a food safety consultant (30 *vs* 9%), using third-party audits (37 *vs* 19%), and having incurred financial losses (33 *vs* 17%).

Growers with less than 50% of their farm's acreage in fruits and vegetables were significantly more likely than growers with more than 50% to attend food safety training (61 *vs* 39%, $N = 200$), use food safety insurance (53 *vs* 32%), and experience financial loss due to food safety events (34 *vs* 17%).

The trends by DTC quartile ($N = 201$) are fairly clear, with lower shares of DTC sales correlated with higher degrees of formal food safety organization: we found statistically significant associations with having a food safety plan, hiring a food safety consultant, and undergoing third-party audits. The highest DTC sales quartile consistently reported very low use of these three food safety management and oversight activities (17, 0, and 2%, respectively), while the lowest quartile reported markedly higher use (52, 30, and 44%, respectively). Likewise, the quartile with the most DTC sales experienced significantly lower rates of financial loss due to a food safety event than did the quartile with least DTC sales (10 *vs* 37%).

Food safety practices

The survey also asked growers about the types of pre-harvest food safety risk mitigation strategies they employed in their operation in 2018 (Table 3). The strategies included food safety operational practices defined in the FDA Produce Rule: monitoring agricultural water, treating biological soil amendments (e.g., through a validated composting method), monitoring for wildlife intrusion, managing and deterring domestic or wild animal intrusion, using hygienic handling practices, employee food safety training, sanitizing tools and equipment, and recordkeeping. Across all farms ($N = 209$), majorities of growers reported monitoring agricultural water (56%), monitoring animal intrusion (54%), deterring or managing animal intrusion (63%), using hygienic handling practices (58%), and training employees in food safety

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Table 2. Food safety program organization

Classification[a]	N	Proportion of respondents that reported use: Attended external training	Food safety plan	Consulting services	Food safety insurance	Third-party audits	Financial losses
All farms	209	0.502	0.402	0.214	0.438	0.282	0.263
Revenue in US$ ($N = 199$)			*	*		*	*
<25k	19	0.684	0.158	0.000	0.500	0.000	0.211
25–250k	57	0.456	0.316	0.091	0.382	0.105	0.105
250–500k	30	0.467	0.500	0.233	0.400	0.233	0.267
500k–1M	28	0.357	0.357	0.179	0.321	0.286	0.286
1–5M	47	0.638	0.638	0.447	0.553	0.574	0.383
5M+	18	0.611	0.444	0.278	0.611	0.611	0.500
Organic prod. ($N = 193$)			*	*		*	*
Any	124	0.548	0.476	0.303	0.451	0.371	0.331
None	69	0.478	0.319	0.090	0.433	0.188	0.174
FV acreage % ($N = 200$)		*			*		*
[0, 25%]	61	0.656	0.443	0.220	0.492	0.230	0.279
[25, 50%]	59	0.559	0.525	0.328	0.569	0.424	0.407
[50, 75%]	49	0.327	0.347	0.167	0.292	0.224	0.204
[75, 100%]	31	0.484	0.290	0.097	0.355	0.290	0.129
Direct sales % ($N = 201$)			*	*		*	*
[0, 25%]	124	0.532	0.516	0.298	0.468	0.435	0.371
[25, 50%]	26	0.346	0.308	0.192	0.231	0.115	0.077
[50, 75%]	10	0.500	0.500	0.100	0.500	0.100	0.300
[75, 100%]	41	0.610	0.171	0.000	0.514	0.024	0.098

[a](No. of respondents).

Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

(51%). Less than half of respondents reported treating biological soil amendments (48%), sanitizing tools (46%), or maintaining written records (23%).

Farm revenue was significantly associated with water monitoring and testing, hygienic handling practices, and recordkeeping. Farms with \$1–\$5 million in annual sales ($N = 47$) and those with over \$5 million in annual sales ($N = 18$) reported greater use of water testing (79 and 67%, respectively), while farms with less than \$25,000 in annual sales reported much lower use of water testing (26%, $N = 19$). Conversely, use of hygienic handling practices was highest (90%) among farms with less than \$25,000 in annual sales ($N = 19$) and lowest (36%) among operations with \$500,000 to \$1 million in annual sales ($N = 28$). Recordkeeping varied considerably across revenue categories with no clear monotonic relationship, though in all categories still fell short of a majority.

We also observed significant correlation between a farm's organic status and monitoring for animal intrusion or using hygienic handling practices. Conventional farms ($N = 69$) reported greater use of both wildlife monitoring practices (65 *vs* 49%, respectively) and hygiene practices (71 *vs* 52%, respectively) than operations with organic production ($N = 124$).

Proximity to wildlife habitat was significantly associated with water testing, monitoring wildlife, wildlife deterrence, hygiene practices, employee training, and tool sanitization, but not water testing. For all six significantly correlated practices, only a minority of operations with no reported bordering wildlife habitat ($N = 40$) used them (ranging from 25 to 45%), whereas majorities of those with MWH ($N = 67$) did so (ranging from 57 to 85%).

Lastly, proximity to grazing land is significantly associated with the use of water monitoring/testing, treating soil amendments, and deterring animal intrusion, although the relationships are not all clear. For example, operations with SGL ($N = 97$) reported the highest usage of water testing (69%) and wildlife deterrence (78%), whereas operations with MGL ($N = 27$) reported the most treatment of biological soil amendments (74%). While operations with no bordering grazing land ($N = 72$) reported the lowest usage of water testing (43%) and treating biological soil amendments (33%), those with MGL reported the lowest usage of animal deterrence (48%).

Mitigation of risk from wildlife

The survey asked growers about how their operation managed food safety risks related to animal intrusion over the previous five years. This section presents results for management practices used to mitigate food safety risks from animal intrusion, including

Table 3. Food safety practices

Classification[a]	N	Proportion of respondents that reported use							
		Water testing	Treat soil amendments	Monitor wildlife	Deter wildlife	Hygiene practices	Employee training	Sanitize tools	Record keeping
All farms	209	0.560	0.478	0.536	0.627	0.579	0.507	0.459	0.234
Revenue in US$ ($N = 199$)		*				*			*
<25k	19	0.263	0.368	0.684	0.632	0.895	0.421	0.579	0.263
25–250k	57	0.614	0.456	0.491	0.614	0.649	0.456	0.526	0.140
250–500k	30	0.533	0.467	0.567	0.600	0.600	0.533	0.267	0.200
500k–1M	28	0.429	0.393	0.393	0.607	0.357	0.464	0.464	0.179
1–5M	47	0.787	0.617	0.617	0.766	0.553	0.617	0.489	0.426
5M+	18	0.667	0.611	0.611	0.611	0.611	0.667	0.500	0.278
Organic prod. ($N = 193$)				*		*			
Any	124	0.565	0.532	0.492	0.637	0.516	0.548	0.427	0.250
None	69	0.623	0.449	0.652	0.667	0.710	0.507	0.522	0.261
Wildlife habitat ($N = 196$)		*		*	*	*	*	*	
Most (MWH)	67	0.567	0.522	0.642	0.791	0.851	0.657	0.716	0.284
Some (SWH)	89	0.685	0.539	0.584	0.640	0.483	0.483	0.416	0.247
None	40	0.375	0.350	0.375	0.450	0.450	0.400	0.250	0.175
Grazing land ($N = 196$)		*	*		*				
Most (MGL)	27	0.593	0.741	0.444	0.481	0.630	0.593	0.333	0.185
Some (SGL)	97	0.691	0.546	0.629	0.784	0.588	0.536	0.485	0.258
None	72	0.431	0.333	0.514	0.542	0.611	0.486	0.542	0.250

[a](No. of respondents).

Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

maintaining buffers to separate fields from adjacent lands, controlling wildlife habitat to reduce the potential for animal intrusion, and direct deterrence methods such as trapping or fencing used to keep animals out of crop production areas. We distinguish practices to control wildlife habitat from those used to directly deter animal intrusion, which include non-lethal measures such as fencing and bird deterrents (Mylar strips, sound cannons), and lethal measures, i.e., those practices that intentionally kill the target animal (traps, poison bait, hunting/shooting) but may also cause collateral damage to other species (e.g., poison bait killing raptors or dogs). Lethal and non-lethal categories correspond to the language used by the US Fish and Wildlife Services (see, e.g., https://www.fws.gov/service/3-200-13-migratory-bird-depredation).

Buffers between fields and adjacent land

Over 93% of growers ($N = 209$) reported using buffers between fields and adjacent lands, but the type of buffer used varied widely (Table 4). Many growers reported using mowed grass (38%) or low-risk crops such as hay or root vegetables (37%) as buffers, with fewer using bare ground or dirt (31%) or other non-crop vegetation (26%).

Buffer type appears to vary by farm size. Increasing annual farm revenue was significantly associated with use of bare ground or dirt buffers, and low-risk crops as buffers. Notably, 44% of farms with annual revenue over \$500,000 ($N = 93$) used bare ground buffers between fields and adjacent lands compared to 23% of farms with annual revenue under \$500,000 ($N = 106$). No clear trend was observed for mowed grass or non-crop vegetation buffers.

Proximity to wildlife habitat was significantly associated with buffer type. Farms with SWH were significantly more likely to use bare ground or dirt buffers (44%, $N = 89$) than were farms with MWH (24%, $N = 67$) or no bordering habitat (25%, $N = 40$), while farms with MWH were significantly more likely to use mowed grass than those with SWH or no bordering habitat (51 *vs* 44% and 18%, respectively). Meanwhile, growers with SGL or MGL ($N = 124$) were significantly more likely to use bare ground (43%) or mowed grass buffers (48%) than growers with no bordering grazing land (17 and 29%, respectively; $N = 72$).

Activities to control wildlife habitat

The survey asked growers which practices they used within the last five years for controlling wildlife habitat to reduce the potential for animal intrusion during the growing season. These included two co-management practices—planting low-risk crops on fields at risk of animal intrusion and using wildlife corridors to route animals around or away from fields—that seek to manage food safety concerns with minimal environmental or economic impact; two economically impactful practices—taking acreage out of production to expand buffers and fallowing fields at risk for animal intrusion; and four environmentally impactful practices—clearing vegetation around fields, draining/filling or

Table 4. Use of vegetative buffers

Classification[a]	N	Proportion of respondents that reported use				
		Bare ground or dirt	Mowed grass	Low-risk crops	Non-crop vegetation	No buffer use
All farms	209	0.311	0.383	0.368	0.258	0.067
Revenue in US$ ($N = 199$)		*		*		*
<25k	19	0.053	0.368	0.158	0.211	0.053
25–250k	57	0.211	0.421	0.281	0.386	0.035
250–500k	30	0.367	0.367	0.433	0.367	0.033
500k–1M	28	0.464	0.357	0.571	0.214	0.036
1–5M	47	0.426	0.426	0.447	0.149	0.191
5M+	18	0.444	0.389	0.444	0.222	0.000
Organic prod. ($N = 193$)						
Any	124	0.371	0.411	0.435	0.315	0.065
None	69	0.261	0.391	0.304	0.188	0.087
Wildlife habitat ($N = 196$)		*	*	*		
Most (MWH)	67	0.239	0.507	0.269	0.328	0.060
Some (SWH)	89	0.438	0.438	0.461	0.236	0.101
None	40	0.250	0.175	0.450	0.275	0.025
Grazing land ($N = 196$)		*	*			*
Most (MGL)	27	0.444	0.556	0.444	0.259	0.037
Some (SGL)	97	0.423	0.454	0.423	0.299	0.124
None	72	0.167	0.292	0.333	0.250	0.014

[a](No. of respondents).
Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

treating farm ponds, clearing vegetation from ditches or ponds, and removing on-farm non-crop vegetation including trees and shrubs near field edges (Table 5). Co-management practices aim to 'minimize microbiological hazards associated with food production while simultaneously conserving soil, water, air, wildlife, and other natural resources' (Lowell, Langholz and Stuart, 2010; see also Karp *et al.*, 2015, 2016, and Olimpi *et al.*, 2019).

Generally, a sizeable minority of growers reported using any given technique, with one exception: most growers (52%, $N = 209$) reported clearing a buffer zone around their fields or orchards so that they could better detect animal intrusion. Across all eight practices, organic farms ($N = 124$, significant at 0.05 level for four of eight practices) and farms with SGL ($N = 124$, significant for five of eight practices) reported higher use of wildlife control measures than did conventional farms or those with no bordering grazing lands.

For co-management practices, use of wildlife corridors differed significantly among farms along all dimensions. Generally, farms with higher annual sales were more likely to use wildlife corridors, except for growers with annual sales of $250–500k who reported highest use of wildlife corridors (67%, $N = 30$). Organic farms ($N = 124$) were significantly more likely to use wildlife corridors (47%) than purely conventional farms (29%, $N = 69$), as were farms with SGL (51%, $N = 97$) or MGL (48%, $N = 27$) compared to those with no bordering grazing land (26%, $N = 72$). However, farms with only SWH were significantly more likely to use wildlife corridors (51%, $N = 89$) than either those with MWH (36%, $N = 67$) or no bordering habitat (30%, $N = 40$). Planting low-risk crops on at-risk fields, however, only showed significant difference among farms with no bordering grazing lands (28%) compared to both farms with SGL (47%) and MGL (48%).

For economically impactful practices, a significant association was observed with annual farm revenue: as annual sales went up, farms were generally more likely to report taking acreage out of production to expand buffers and fallowing fields at risk for animal intrusion. For example, 48% of farms with annual sales above $500,000 ($N = 93$) reported fallowing at-risk fields while only 25% of those with annual sales below $500,000 reported doing so ($N = 106$). Organic farms ($N = 124$) were also significantly more likely than their conventional counterparts ($N = 69$) to take acreage out of production (44 *vs* 25%) or fallow at-risk fields (40 *vs* 30%). Proximity to wildlife habitat appeared to have an opposite relationship—farms with MWH ($N = 67$) were significantly less likely to take acreage out of production to expand buffers (21%) or fallow fields (25%) compared to farms with SWH (48 and 47%, respectively, $N = 89$) or no bordering habitat (45 and 33%, respectively, $N = 40$). At the same time, farms reporting no bordering grazing land were less likely to use either practice (33 and 24%) compared to those with SGL (41 and 44%) or MGL (40 and 44%), though this trend was significant only for fallowing at-risk fields.

A sizeable minority of growers reported using environmentally impactful techniques to directly control wildlife habitat to reduce the potential for animal intrusion during the growing season. Among all growers ($N = 209$), 27% reported draining, filling, or

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Table 5. Controlling wildlife access to fields from vegetated habitat

		Proportion of respondents that reported use							
		Environmental impact				Economic impact		Co-management	
Classification[a]	*N*	Clear buffers	Drain or fill ponds	Clear veg. near water	Clear veg. near fields	Expand buffers	Fallow fields	Low-risk crops	Wildlife corridors
All farms	209	0.522	0.273	0.383	0.364	0.359	0.344	0.378	0.388
Revenue in US$ (*N* = 199)			*	*		*	*		*
<25k	19	0.368	0.053	0.105	0.526	0.158	0.105	0.316	0.211
25–250k	57	0.456	0.193	0.351	0.298	0.281	0.228	0.281	0.298
250–500k	30	0.500	0.233	0.500	0.300	0.467	0.367	0.400	0.667
500k–1M	28	0.643	0.464	0.429	0.357	0.429	0.464	0.607	0.357
1–5M	47	0.681	0.362	0.532	0.426	0.383	0.511	0.404	0.426
5M+	18	0.500	0.389	0.278	0.444	0.611	0.444	0.444	0.444
Organic prod. (*N* = 193)			*	*		*			*
Any	124	0.589	0.371	0.468	0.387	0.444	0.395	0.427	0.468
None	69	0.478	0.145	0.290	0.377	0.246	0.304	0.333	0.290
Wildlife habitat (*N* = 196)		*	*	*		*	*		*
Most (MWH)	67	0.507	0.179	0.254	0.418	0.209	0.254	0.343	0.358
Some (SWH)	89	0.663	0.348	0.483	0.438	0.483	0.472	0.449	0.506
None	40	0.400	0.350	0.500	0.225	0.450	0.325	0.400	0.300
Grazing land (N = 196)		*	*				*	*	*
Most (MGL)	27	0.556	0.296	0.407	0.370	0.407	0.444	0.481	0.481
Some (SGL)	97	0.680	0.371	0.454	0.433	0.412	0.443	0.474	0.505
None	72	0.389	0.181	0.347	0.333	0.333	0.236	0.278	0.264

[a](No. of respondents).

Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

treating farm ponds (e.g., sediment or storage pond), 38% reported clearing vegetation from irrigation/drainage ditches or farm ponds, 36% reported removing on-farm non-crop vegetation including trees or shrubs near field edges (beyond that needed for buffers), and 52% reported clearing a buffer zone around fields or orchards. Notably, draining, filling, or treating farm ponds was significantly correlated with increasing annual sales, organic status (37 *vs* 15%), and proximity to grazing land (18% for no bordering grazing land *vs* 37% for SGL and 30% for MGL). Likewise, clearing vegetation from ditches or farm ponds was significantly correlated with increasing annual sales and organic status (47 *vs* 29%). Conversely, farms with MWH were significantly *less* likely to use either practice (18 and 25%, respectively) than those with SWH (35 and 48%) or no (35 and 50%) bordering habitat. Proximity to grazing land and wildlife habitat correlated only with clearing buffer zones around fields, while no associations were observed with removing on-farm non-crop vegetation at field edges.

Activities to directly deter wildlife from intruding into fields

The survey asked growers which of seven practices they had used within the last five years to directly prevent animal intrusion into crop production areas during the growing season (Table 6). These are divided into lethal deterrents that intentionally kill the target animal (trapping, poison bait, hunting/shooting) and non-lethal deterrents (fencing, harassment via noise or similar). Among the four non-lethal animal deterrents queried, a majority of growers (52%) used deer fencing around fields, while fewer used silt or plastic fences around fields (44%) or any kind of fencing around surface waterways (e.g., ponds, ditches; 34%). About one-third of growers (34%) used bird deterrents such as reflective Mylar strips, sound cannons, or other noise-making devices. For lethal deterrents, 44% of growers reported using mechanical traps, 39% reported hunting or shooting pest animals, and 29% reported using poison bait.

Farm revenue appeared to have no significant correlation with use of direct animal deterrence practices except for plastic silt fencing, which was more likely to be used on farms with annual revenue over $250k. Farms with some organic production ($N = 124$) were significantly more likely to use silt or plastic fences (56%) or fencing around waterways (43%) than conventional farms (33 and 25%, respectively, $N = 69$).

Proximity to wildlife habitat correlated significantly with use of all three lethal deterrents. Most farms with MWH ($N = 67$) used mechanical traps (57%) and hunting/shooting pest animals (61%) and 42% used poison bait, compared to 28% for mechanical traps, 20% for hunting/shooting, and 15% for poison bait among farms with no bordering habitat ($N = 40$). For non-lethal deterrents, the correlation was split. Farms with MWH were

Table 6. Wildlife direct deterrence

		Proportion of respondents that reported use						
		Sub-lethal deterrents				Lethal deterrents		
Classification[a]	N	Deer fencing	Plastic fencing	Fencing around water	Mylar strips or cannons	Mechanical traps	Poison bait	Hunt or shoot animals
All farms	209	0.522	0.440	0.335	0.340	0.435	0.287	0.392
Revenue in US$ ($N = 199$)			*					
<25k	19	0.632	0.158	0.158	0.316	0.526	0.158	0.579
25–250k	57	0.491	0.386	0.246	0.246	0.404	0.228	0.316
250–500k	30	0.467	0.500	0.467	0.300	0.467	0.233	0.333
500k–1M	28	0.464	0.643	0.464	0.464	0.464	0.429	0.357
1–5M	47	0.681	0.532	0.383	0.447	0.447	0.362	0.489
5M+	18	0.444	0.500	0.444	0.389	0.444	0.389	0.444
Organic prod. ($N = 193$)			*	*				
Any	124	0.532	0.556	0.427	0.347	0.460	0.250	0.371
None	69	0.565	0.333	0.246	0.391	0.435	0.391	0.507
Wildlife habitat ($N = 196$)		*	*	*	*	*	*	*
Most (MWH)	67	0.746	0.269	0.239	0.522	0.567	0.418	0.612
Some (SWH)	89	0.551	0.640	0.416	0.337	0.472	0.292	0.371
None	40	0.250	0.425	0.425	0.150	0.275	0.150	0.200
Grazing land ($N = 196$)		*	*	*		*		
Most (MGL)	27	0.630	0.667	0.370	0.296	0.407	0.370	0.444
Some (SGL)	97	0.649	0.536	0.454	0.381	0.567	0.361	0.423
None	72	0.403	0.306	0.222	0.361	0.347	0.208	0.403

[a](No. of respondents).

Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

significantly more likely to use both deer fencing (75%) and Mylar strips or bird cannons (52%) than were farms with SWH (55 and 34%, respectively, $N = 89$) or no bordering habitat (25 and 15%, respectively). Conversely, farms with MWH were significantly *less* likely to use silt or plastic fencing (27%) or fencing around water bodies (24%) than were farms with SWH (64 and 42%, respectively) or no bordering habitat (43 and 43%, respectively).

Proximity to grazing land was significantly correlated with reported use of deer fencing (MGL: 63%, SGL: 65%, none: 49%), silt or plastic fencing (high: 67%, low: 54%, no: 31%), fencing around water bodies (MGL: 37%, SGL: 45%, none: 22%), and mechanical traps (MGL: 41%, SGL: 57%, none: 35%), but no significant correlation was observed for poison bait, hunting/shooting pest animals, or Mylar strips/bird cannons.

Risk perceptions related to mitigation practices

Self-reported assessment of food safety risks associated with wild and domestic animals

The survey asked each respondent to indicate whether they believed various types of animals posed a food safety risk to their farm operation (online supplementary Table B2). The most common types of animals that growers indicated as 'high risk' were rodents (26%, $N = 209$) and deer or other large mammals (25%), followed by birds (17%) and reptiles or amphibians (9%). Among domestic animals, 15% of growers believed livestock to be 'high risk', compared to only 8% for dogs and other pets, and 4% for draft animals.

No statistically significant relationships were observed between perceived risk and farm revenue, organic status, proximity to wildlife habitat, or proximity to grazing land. Since fruits and vegetables may be considered at higher risk of contamination by animals, we compared self-reported proportion of acreage in fruits and vegetables to perceived risk. However, fruit and vegetable acreage was only significantly associated with concern over risks from birds and draft animals. Specifically, 30 and 7.5% of farms with more than 50% of their acreage used for fruit/vegetable production ($N = 80$) were concerned about birds and draft animals, respectively, compared to 10 and 1.7% of respective farms with less than 50% of their acreage used for fruit and vegetable production ($N = 120$).

External food safety concerns related to wildlife, livestock, or vegetated habitat

Growers were asked if anyone external to the farm operation—including buyers and customers, private auditors and government inspectors, or farm advisors, consultants, or extension agents—had raised a food safety concern related to risk of animal intrusion (Table 7). This included concerns raised about *animals* (including

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Table 7. External input to risk assessment for wildlife or non-crop vegetation

		Proportion of respondents that reported input from			
Classification[a]	N	Buyer	Auditor or inspector	Farm advisor	None
All farms	209	0.297	0.445	0.455	0.335
Revenue in US$ ($N = 199$)		*	*	*	*
<25k	19	0.000	0.000	0.053	0.842
25–250k	57	0.175	0.246	0.298	0.439
250–500k	30	0.267	0.533	0.633	0.300
500k–1M	28	0.357	0.500	0.536	0.393
1–5M	47	0.511	0.787	0.617	0.128
5M+	18	0.556	0.667	0.778	0.056
Organic prod. ($N = 193$)			*	*	*
Any	124	0.347	0.540	0.581	0.242
None	69	0.261	0.362	0.304	0.507
FV acreage ($N = 200$)		*	*	*	
[0, 25%]	61	0.148	0.295	0.328	0.459
[25, 50%]	59	0.407	0.610	0.678	0.237
[50, 75%]	49	0.367	0.571	0.490	0.306
[75, 100%]	31	0.355	0.355	0.355	0.387
Direct sales ($N = 201$)		*	*	*	*
[0, 25%]	124	0.452	0.718	0.669	0.113
[25, 50%]	26	0.231	0.154	0.385	0.577
[50, 75%]	10	0.000	0.000	0.000	0.800
[75, 100%]	41	0.000	0.000	0.049	0.805

[a](No. of respondents).

Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

wildlife and livestock) in or near crop production areas and about the presence of *non-crop vegetation* (including wildlife habitat) near crop production areas. For the 139 farms (66%, $N = 209$) that reported someone external raising a concern, the most common sources were farm advisors (including extension agents, consultants, and trainers; 68%) and food safety auditors or government inspectors (67%), followed by buyers or customers (47%).

Only one-third of farms (34%) had not received any external signal of concern over animal intrusion. However, this figure was significantly and inversely correlated with farm revenue: only 13% of farms with \$1–\$5 million in annual sales ($N = 47$) and 6% of farms with over \$5 million in annual sales ($N = 18$) reported no external concerns related to animal intrusion risk, compared to 44% ($N = 57$) of farms with annual sales of \$25k–\$250k and 84% ($N = 19$) of those with annual sales under \$25k.

Likewise, organic farms and farms with low DTC sales were significantly more likely to experience external concerns over animal intrusion or presence of non-crop vegetation. Conventional farms were twice as likely to report no external signals of concern (51%, $N = 69$) compared to organic farms (24%, $N = 124$). Meanwhile, 11% of farms with less than 25% direct sales ($N = 124$) reported no external signals of concern compared to 72% of farms with more than 25% in direct sales ($N = 77$).

Conservation activities and practices

The survey asked respondents about their participation in self-funded or externally sponsored conservation programs and whether concerns with food safety had impaired their conservation efforts within the past five years (Table 8). Separately, respondents were also asked which specific conservation practices they utilized on their farms (Table 9).

Conservation participation and friction with food safety

About one-third of growers reported participating in on-farm conservation programs sponsored by government or third-party organizations (34%) or engaging in independent, self-funded conservation efforts on their farm (37%). Participation in on-farm conservation activities did not appear to correlate with farm size but did significantly correlate with proximity to wildlife habitat and grazing lands. Farms with more bordering wildlife habitat were more likely to engage in both sponsored conservation activities (MWH: 54%, SWH: 34%, none: 15%) and independently funded conservation (MWH: 52%, SWH: 40%, none: 15%). Farms bordering grazing land were also more likely to engage in both sponsored conservation activities (MGL: 48%, SGL: 45%, none: 20%) and independently funded conservation (MGL: 59%, SGL: 40%, none: 31%).

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Table 8. On-farm conservation activities

Classification[a]	N	Proportion of respondents that reported use		
		Gov't or third-party programs	Independent efforts	Impaired by food safety
All farms	209	0.344	0.368	0.254
Revenue in US$ ($N = 199$)				
<25k	19	0.263	0.526	0.105
25–250k	57	0.333	0.439	0.175
250–500k	30	0.267	0.300	0.300
500k–1M	28	0.286	0.286	0.250
1–5M	47	0.489	0.383	0.404
5M+	18	0.444	0.389	0.278
Organic prod. ($N = 193$)				
Any	91	0.396	0.330	0.319
None	33	0.455	0.455	0.242
Wildlife habitat ($N = 196$)		*	*	
Most (MWH)	67	0.537	0.522	0.284
Some (SWH)	89	0.337	0.404	0.326
None	40	0.150	0.150	0.125
Grazing land ($N = 196$)		*	*	*
Most (MGL)	27	0.481	0.593	0.296
Some (SGL)	97	0.454	0.402	0.361
None	72	0.208	0.306	0.139

[a](No. of respondents).
Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

Only 25% of growers reported experiencing a food safety conflict with their on-farm conservation efforts, and no significant correlations were observed with farm revenue, organic status, or proximity to wildlife habitat. However, farms that border grazing lands were more likely to report that food safety impaired their conservation efforts (MGL: 30%, SGL: 36%, none: 14%).

Conservation practices

Respondents were asked if their farm operation actively provides or maintains wildlife habitat on land it manages by using any of six specific practices (Table 9). Only 4% of farms reported using none of the queried conservation practices. The most popular practices included preserving natural areas such as forests, wetlands, or prairie (55%); maintaining hedgerows, shelterbelts, or windbreaks (53%); and maintaining vegetated riparian buffers along waterways (52%). Other practices were less prevalent: adjusting cultivation or harvest tasks to reduce impact to wildlife (39%), providing nesting or perching sites for birds or bats (39%), and planting flowers or providing habitat for native pollinators (36%). Separately, the survey asked respondents whether their farm operation used filter strips, grassed waterways, or other vegetated practices to manage runoff and protect on-farm surface water. Most respondents (54%) reported efforts to manage farm runoff, though there were no clear differences by farm size or organic status.

Few clear trends were observed between farm size and conservation practices. Revenue was significantly associated with adjusting the timing of cultivation and harvesting practices, while planting flowers to support pollinators appeared to significantly decline with increasing revenue.

Organic status likewise showed little association with conservation practices, except that organic growers were more likely to adjust operation timing (48%) and use bird or bat houses (48%) than conventional growers (28 and 28%). Meanwhile, both proximity to wildlife habitat and to grazing lands were significantly correlated with four of the six conservation practices—hedgerows or windbreaks, natural area preservation, vegetated buffers along waterways, and flowers for pollinators.

Probit regression analyses

In the results presented thus far, we examined differences among respondents with respect to the primary outcomes of interest for our study, the prevalence of use of both on-farm food safety and conservation practices. The results of our probit models further disentangle the relationships among farm characteristics and the probability of using these farm practices (see Table 10). Specifically, we use these analyses to investigate the extent to which key farm-level factors can help explain the differences in outcomes we observed in our results discussion above.

Revenue category

Larger farms often benefit from economies of scale, particularly in the context of pre-harvest food safety practices, which could lead

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Table 9. Conservation practices

Classification[a]	N	Proportion of respondents that reported use							
		Practices to manage runoff	Maintain hedgerows	Preserve natural areas	Maintain veg. buffers	Adjust operation time	Use bird/ bat houses	Plant flowers	No practices
All farms	209	0.541	0.531	0.545	0.517	0.388	0.388	0.364	0.043
Revenue in US$ ($N = 199$)						*		*	
<25k	19	0.474	0.579	0.526	0.421	0.211	0.316	0.684	0.105
25–250k	57	0.439	0.474	0.544	0.404	0.316	0.333	0.474	0.035
250–500k	30	0.667	0.433	0.600	0.500	0.400	0.367	0.200	0.067
500k–1M	28	0.643	0.536	0.429	0.571	0.464	0.429	0.286	0.036
1–5M	47	0.681	0.681	0.638	0.660	0.596	0.447	0.340	0.021
5M+	18	0.444	0.556	0.611	0.722	0.278	0.556	0.222	0.056
Organic prod. ($N = 193$)						*	*		
Any	124	0.604	0.548	0.573	0.540	0.476	0.476	0.323	0.024
None	69	0.455	0.536	0.551	0.522	0.275	0.275	0.435	0.072
Wildlife habitat ($N = 196$)		*	*	*	*			*	
Most (MWH)	67	0.657	0.642	0.701	0.567	0.418	0.463	0.597	0.060
Some (SWH)	89	0.607	0.640	0.573	0.629	0.461	0.416	0.270	0.022
None	40	0.375	0.275	0.400	0.350	0.300	0.325	0.300	0.075
Grazing land ($N = 196$)			*	*	*			*	
Most (MGL)	27	0.519	0.741	0.704	0.556	0.481	0.444	0.333	0.000
Some (SGL)	97	0.660	0.619	0.649	0.660	0.464	0.485	0.320	0.031
None	72	0.486	0.431	0.444	0.403	0.319	0.306	0.500	0.083

[a](No. of respondents).

Note: The response rates for each classification are reported in parentheses. For each classification group, separate Pearson's χ^2 tests of independence were conducted using the count data underlying each column of proportions reported. A single asterisk (*) indicates $P \leq 0.05$ for each test.

to differences across revenue categories in grower use of certain practices. Moreover, the potential losses from a food safety incident increase with farm size, thereby incentivizing larger farms to prioritize more aggressive measures to control and deter wildlife intrusion over conservation efforts. We use average annual farm revenue as a proxy for farm size to directly examine these relationships. Based on the probit regression results, farm revenue category was significantly associated with the likelihood of using just two practices: very small and small farms were less likely to clear vegetation near fields, and large farms were more likely to use bird deterrents such as Mylar strips, bird cannons, and other noise-making devices, compared to farms exempt from FSMA.

Organic production

Organic production poses unique production constraints for growers, which can also affect their use of food safety and conservation practices relative to conventional growers. Our probit model results indicate that organic growers are neither more nor less likely to use food safety practices required by the Produce Rule relative to conventional growers. Organic growers are, however, more likely than conventional growers to use non-crop vegetation as buffer strips and to control wildlife access to fields by expanding buffers, installing wildlife corridors, and draining/filling ponds. To directly deter wildlife, organic growers are more likely to use fencing around bodies of water, but less likely to use poison bait than conventional growers. Lastly, organic farms are more likely to engage in certain conservation practices to provide or maintain wildlife habitat: adjusting operation timing to protect nesting wildlife and using bird or bat houses.

Produce acreage share

The financial risk posed by a food safety incident related to animal intrusion increases as a farm's proportion of fruit and vegetable acreage increases. We might therefore expect that as produce growers specialize in fruits and vegetables, they adopt food safety practices at higher rates. The probit regression results indicate that growers with a greater produce acreage share are no more likely to use any of the practices we asked about, and are actually *less* likely to use mechanical traps, poison bait, and maintain vegetative buffers.

DTC sales share

Growers that sell the majority of their produce through DTC channels and meet certain size requirements are effectively exempt from the FSMA Produce Rule. Regardless of this exemption, DTC sales are typically not subject to third-party food safety audits and additional requirements associated with other marketing channels. Furthermore, environmental concerns have been reported to be a significant motivation for consumers to shop in DTC channels, but food safety concerns were not (Low *et al.*,

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Table 10. Probit model results for factors affecting farm operating practices

Dependent variable	Revenue $25k–$500k	Revenue > $500k	Any organic (0/1)	Produce acreage share (0–1)	DTC sales % (0–100)	Bordering wildlife hab. = most	Bordering wildlife hab. = some
Water testing						(+)	(+)
Treat soil amendments						(+)	
Monitor wildlife							(+)
Deter wildlife						(+)	
Hygiene practices						(+)	
Employee training						(+)	
Sanitize tools						(+)	(+)
Recordkeeping							
Bare ground or dirt							
Mowed grass						(+)	(+)
Low risk crops							
Non-crop vegetation			(+)				
No buffer use							
Clear buffers							(+)
Expand buffers			(+)				
Low-risk crops							
Fallow fields							
Wildlife corridors			(+)				
Drain or fill in ponds			(+)				
Clear veg. near water					(–)		
Clear veg. near fields	(–)						
Deer fencing						(+)	(+)
Plastic fencing					(–)		
Fencing around water			(+)		(–)		
Mechanical traps				(–)			(+)
Poison bait			(–)	(–)		(+)	
Hunt or shoot animals						(+)	
Mylar strips or cannons		(+)				(+)	(+)
Maintain hedgerows					(–)	(+)	(+)
Preserve natural areas					(–)	(+)	
Maintain veg. buffers				(–)		(+)	(+)
Adjust operation time			(+)				
Use bird/bat houses			(+)			(+)	
Plant flowers					(+)		
No cons. practices					(+)		

Note: Each row is a separate regression model. (+) and (–) identify the regressors that are positive/negative (respectively) and statistically significant at the 5% level. The full regression results for each model are included in the online supplementary material Appendix A.

2015). All these factors suggest that growers with higher shares of DTC sales may be less likely to prioritize pre-harvest food safety practices over environmental conservation practices than growers selling into wholesale or similar channels.

The results of the probit analyses indicate a lower likelihood that growers use practices to control wildlife access and directly deter intrusion as DTC sales share increases: growers are less likely to clear vegetation near water, install plastic fencing, or use fencing around water as the proportion of DTC sales increases. Unexpectedly, with higher DTC sales, growers are also less likely to use conservation practices including maintaining hedgerows or preserving natural areas, but they are more likely to plant flowers or simply not use any of the conservation practices included in this study.

Bordering wildlife habitat

Intuitively, the extent of a farm's proximity to wildlife habitat directly affects the possibility of animal intrusion into growing areas, all else equal. We might therefore expect operations with greater proportions of bordering wildlife habitat to be more likely to use practices that reduce the possibility of animal intrusion as well as food safety practices that safeguard against contamination if animal intrusion occurs.

Growers with SWH or MWH, relative to growers with no bordering habitat, were more likely to report the use of certain food safety practices, vegetative buffers, wildlife access controls, direct deterrence, and conservation practices. For food safety practices, growers with SWH are more likely to test water, monitor wildlife, and sanitize tools. Growers with MWH are more likely to test water, treat soil amendments, deter wildlife, use hygiene practices, train employees, and sanitize tools.

Growers with SWH and MWH are both more likely to use mowed grass as vegetative buffer strips; however, growers with SWH are also more likely to clear out vegetative buffers to control wildlife access. To directly deter animals, growers with SWH are more likely to use deer fencing, mechanical traps, and Mylar strips or bird cannons; while growers with MWH are more likely to use deer fencing, poison bait, hunting, and Mylar strips or bird cannons. Lastly, growers with SWH are more likely to practice conservation by maintaining hedgerows and maintaining vegetative buffers; and growers with MWH are more likely to do so by preserving natural areas and using bird/bat houses, in addition to those practices.

Discussion

We set out to determine which kinds of food safety practices growers use in their pre-harvest operations. Overall, rates of adoption for commonly accepted best practices—many of which are mandated by the US FDA's Produce Safety Rule (PSR) for most farms that responded to our survey—were surprisingly low, with anywhere from one-third to over one-half of respondents reporting that they do not, for example, monitor for animal intrusion, attend food safety trainings, or sanitize tools. These low rates of adoption may be partly explained by a limitation in our survey design, which did not distinguish farms growing only crops that are not commonly consumed raw (such as beets, potatoes, or asparagus) or that are destined for processing with a kill step (e.g., canning). Results from the largest national survey of food safety practices among US growers to date found that 11.8% of growers ($N = 4618$) fit these categories (Astill *et al.*, 2018, pp. 64–65). However, even if this proportion holds true for our sample, adoption rates among farms growing produce typically consumed raw are only underestimated by at most 8 percentage points.[2] Taking into account this limitation, these results still broadly corroborate findings from previous national surveys on grower adoption of food safety practices conducted prior to the implementation of the PSR and highlight continued gaps in food safety practice adoption by produce growers (Adalja and Lichtenberg, 2018a; Astill *et al.*, 2018). Our findings also suggest that most growers take significant steps to deter animals from entering fields, even when those practices may be environmentally or economically impactful, yet strategies vary substantially. This raises the question, why do some growers use these practices while others do not?

One possible explanation proposed in the literature is that growers adopt practices primarily to control risks that they actively perceive in their operating environment (Olimpi *et al.*, 2019). Our survey data allow us to test this in two ways: (1) comparing responses by self-reported proximity to potential sources of pathogenic contamination in the biophysical environment, and (2) examining growers' own assessment of the food safety risks posed by various wild and domestic animals. We found limited evidence to support this hypothesis. Our probit model shows that farms with more wildlife habitat appear more likely to use direct animal deterrence methods, particularly deer fences and lethal deterrents. However, proximity to wildlife habitat appeared to have no clear effect on activities to control wildlife habitat by targeting non-crop vegetation. Our probit model showed that farms with *some* wildlife habitat (SWH) were more likely to clear a buffer zone around fields than farms with *none*, which the hypothesis predicts, but unexpectedly also were more likely to clear a buffer zone than farms that *mostly* bordered wildlife habitat (MWH), contrary to what the hypothesis predicts. Table 5 suggests that this pattern may hold for other methods to control wildlife habitat, including fallowing fields and creating wildlife corridors. Meanwhile, our probit model also indicates that farms *mostly* bordering wildlife habitat are significantly more likely to practice six of the eight queried food safety practices (Table 3), though farms with only *some* wildlife habitat were significantly more likely to monitor for wildlife intrusion. In addition, our findings suggest that growers' assessment of food safety risks posed by animals is largely independent of either biophysical or supply chain factors (Table A2), implying that further work is needed to tease out the precise origins of growers' beliefs regarding the pre-harvest food safety threat posed by animals.

A second possible explanation from the literature is that supply chain pressures drive food safety practice adoption (Baur, 2020). Our data allowed us to test this in two ways: (1) by comparing rates of adoption among respondents by farm size, market channel, and organic status, and (2) by examining the sources from which growers received external input on animal intrusion risks. Our findings partially support this hypothesis. A significant majority of large farms, organic farms, and farms with little to no DTC sales reported that someone outside the operation had raised a food safety concern regarding animals or animal habitat near to crop production area *within the past year*. However, these concerns were more likely to come from auditors, inspectors, or farm advisors than directly from a buyer, suggesting that supply chain pressures are indeed mediated by third parties (Lytton, 2017; Havinga and Verbruggen, 2017). At the same time, we found only scattered evidence that rates of adoption for particular food safety practices, including techniques intended to mitigate risks from wildlife, correlated with farm size, organic status, or wholesale or contract market channels (measured as the inverse of DTC sales).

From this evidence, we suggest that the adoption of particular food safety practices is influenced by a complex assemblage of factors that include environmental context, supply chain pressures, and growers' perceptions of risk. Costs are another important factor that may drive different behavior among growers, particularly since the cost burden of food safety compliance decreases with farm size (Adalja and Lichtenberg, 2018b). Moreover, the relationship between adoption of certain farm management practices and farm size may not be monotonic. For example, one

[2] We thank an anonymous reviewer for identifying this limitation and the reference statistic.

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comparative study of conservation adoption among Ohio farmers suggested that 'optimal scale [for conservation] is a non-linear phenomenon' influenced by economics, tradition, values, and social relationships (Parker, 2013). Similarly, recent evidence from California strongly suggests that adoption of ecologically based farming practices is highest for the middle range of farm size, with both the smallest and largest farms facing higher, albeit qualitatively distinct, barriers to adoption (Esquivel *et al*., 2021). There may also simply be high stochasticity. The point is that we see little to no evidence of a simple biophysical or socioeconomic explanation for why some farms clear vegetation and seek to suppress wildlife activity around fields as a food safety practice and others do not.

While nearly all farms practice some form of environmental conservation, most did not report experiencing a conservation conflict with food safety management. It is worth noting, however, that the sizeable minority of growers (25%) who *did* report that concerns with food safety impaired their conservation efforts is higher than the 8% of fruit growers and 16% of vegetable and melon growers who reported such a conflict in a 2014 survey in California (Baur *et al*., 2016), a state long thought to be a hotbed for such tensions (Beretti and Stuart, 2008). Our findings therefore suggest that tension between on-farm conservation and food safety management remains an important issue in US specialty crop agriculture, aligning with calls for more comprehensive assessment of the intersection between food safety and sustainability in food systems more broadly (Baur, Lundén and Jay-Russell, 2021).

Importantly, this study highlights that this tension affects regions besides California, the region where the majority of research on food safety-conservation trade-offs in produce preharvest environments has previously been conducted. More research is needed to determine precisely what differentiates the one in four growers who report experiencing this conflict from those who do not. Our results on this point were inconclusive for all but one potential explanation we analyzed, including farm size, organic status, and proximity to wildlife habitat. Only proximity to grazing land was correlated with perceiving friction between food safety and conservation. It may be that factors we were unable to assess, such as underlying ethical commitments or values, beliefs, and attitudes, play an important role in shaping this friction, as has been reported in studies from California (Stuart, 2009; Baur *et al*., 2016). Different growers may harbor different beliefs as to what constitutes conservation or food safety, for example, or filter their responses through different attitudes toward oversight and regulation in agriculture. Another potential factor to consider is possible cost dependencies between particular food safety and conservation practices. If such complementarities exist in the cost structures for some operations, it may rationalize the tension those growers reported in our survey.

Conclusion

Produce growers may face tradeoffs between on-farm conservation and pre-harvest food safety as a result of economic considerations, regulatory concerns, and external pressure from stakeholders. Yet, detailed data on the frequency and extent of these tradeoffs across regions of the US remain sparse. We designed and implemented a national grower survey to address this gap. We examine usage of pre-harvest food safety practices and on-farm conservation practices, with a particular emphasis on managing non-crop vegetation, potential wildlife habitat, and animal intrusion into growing areas. To illuminate the nuanced factors that affect these tradeoffs, we also estimate the effects of revenue, organic production, produce acreage share, DTC sales share, and bordering wildlife habitat on the probability that growers use different on-farm food safety practices, vegetative buffers, wildlife habitat control, wildlife direct deterrence, and conservation practices.

Our two-way cross-tabulations indicate numerous statistically significant correlations across operations' farm characteristics and food safety program organization, food safety practices, vegetative buffer usage, control of wildlife access to fields, wildlife direct deterrence, self-reported risk assessment of wildlife, external input to risk assessment for wildlife or non-crop vegetation, on-farm conservation activities, and conservation practices. Our probit regression results further disentangle these relationships and establish quantitative estimates of the effects of farm characteristics on the probability of using these food safety and conservation measures. Broadly speaking, these results highlight a large degree of heterogeneity in use across farm characteristics and can serve as a basis for developing adaptive strategies to better co-manage agricultural environments for both food safety and on-farm conservation.

As is increasingly the case in survey-based research with growers, we experienced significant difficulty in recruiting survey respondents. Although we provided a financial incentive, coordinated survey distribution with numerous extension offices and trade organizations, and used a convenience-sampling approach to issue 'blast' appeals for growers to take the survey through local networks, social media, and various grower listservs, the final number of growers who completed the survey (209) limited the statistical power of our dataset. A higher *N*-value would have permitted higher-resolution parsing of the dataset, allowing us to meaningfully analyze combinations of characteristics, such as region, farm size, and organic status. Additionally, using an open-ended online recruitment strategy without a clearly defined target population poses several issues. Because we do not know how many or precisely which growers were contacted to take the survey, we cannot fully ascertain how effectively our sample captures relevant populations and regional heterogeneity, and it is difficult to estimate sampling bias or calculate response rates.

Our findings present several clear opportunities for future research. First, based on the limitations exposed in this study of an online recruitment strategy, we recommend that future complementary studies utilize a judgment sample of relevant growers, built in collaboration with extension programs, farmer advocacy groups, and other stakeholder organizations, to further explore trade-offs between on-farm conservation and food safety aims. A more grounded, in-person approach would enable researchers to construct an accurate list of active growers from which to sample and foster key alliances with local stakeholders that can lend credence to the study.[3] Given our conclusion that food safety practices are driven by a complex assemblage of factors, we also recommend that future studies take an iterative approach, with each step focusing on a narrower range of dependent variables, for example, limiting the sample to specific commodity groups, market channels, or geographic areas.

While our results suggest that some produce growers are in fact making tradeoffs between conservation efforts and pre-harvest food safety practices, particularly in the context of non-

[3]We thank an anonymous reviewer for sharing this idea.

crop vegetation and wildlife habitat, their underlying decision-making framework remains unclear. Each grower's decision is subject to myriad constraints such as food safety costs, conservation costs, pressure from external supply chain agents, environmental context, and competing land uses, to name a few. In addition to these factors, however, future research should also analyze the interaction among growers' values, attitudes, and beliefs regarding conservation and food safety, and their impact on farmers' perceptions of risk, conflict, and opportunity in farm management decisions. Salient future research questions include Does the amount of time, effort, and money that growers invest in conservation practices correlate positively, negatively, or not at all with their investment in food safety practices? How are rates of adoption for food safety and conservation practices changing over time? And how does this vary by revenue, cropping system, market channel, geography, and values, attitudes, and beliefs? Clearer answers to these questions can aid in modeling growers' decision problem. Characterizing optimal decision-making under different farm conditions and operational goals is the first step toward helping growers navigate this complicated issue. Developing a decision support tool based on such a model would empower growers to act on these insights.

Another opportunity for future research lies in the policy realm, where a better understanding of competing market, regulatory, cultural, and financial incentives faced by growers can inform future policymaking. In particular, understanding heterogeneity in the costs (and benefits) associated with wildlife habitat conservation and pre-harvest food safety across operations of differing farm size and production characteristics is critical for effective policy design that is not unduly burdensome to any particular group of growers.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170523000261.

Data availability statement. The data that support the findings of this study are openly available in GitHub at https://github.com/aaronadalja/AVF-replication-1.

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