Co-Managing Farm Stewardship with Food Safety GAPs and Conservation Practices:

A Grower's and Conservationist's Handbook

Wild Farm Alliance—2016

Wild Farm Alliance
PO Box 2570
Watsonville, CA 95077
831-761-8408
info@wildfarmalliance.org
www.wildfarmalliance.org

Acknowledgments

This handbook was produced by the Wild Farm Alliance (WFA) and written by Jo Ann Baumgartner of WFA, with Karen Lowell then of L & L Consulting and Meaghan Donavan then of WFA. Substantial input was given from Trevor Suslow at University of California, Davis, William Boyd then of NRCS, and William Reck of NRCS. It was funded in part by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). Support also came from: Clif Bar Family Foundation, Columbia Foundation, Gaia Fund, Newman's Own Foundation, Organic Farming Research Foundation, Tompkins Imhoff Family Fund, True North Foundation, and United Natural Foods Foundation and Veritable Vegetable.

Others who gave input to parts of this publication include: Andrew Gordus of California Department of Fish and Wildlife; Becky Weed of Thirteen Mile Lamb and Wool Company; Cathy Carlson then of Community Alliance with Family Farmers (CAFF); Conrad Vispo of Farmscape Ecology Program, Hawthorne Valley; Dana Jackson then of Land Stewardship Project; Dan Imhoff of Watershed Media; Dave Runsten of CAFF; Elizabeth Bihn of Cornell University; Jose Perez then of Florida Organic Growers (FOG); Kaley Grimland of Agriculture and Land-Based Training Association (ALBA); Kate Mendenhall then of Northeast Organic Farming Association of New York, Inc.; Michele Jay-Russell of UC Davis; Nancy Flores of New Mexico State University; Nathan Harkleroad of ALBA; Paul Robins of Resource Conservation District of Monterey County; Rachael Long of Yolo County University of California Cooperative Extension; Steve Warshauer of Beneficial Farm and liason for National Sustainable Agriculture Coalition; Travis Mitchell of FOG; Vance Russell of National Forest Foundation; and Luana Kiger of NRCS.

Cover photos: Filter strip, S. Earnshaw; compost application, J. Redmond; European starlings with cows, APHIS; *Campylobacter*, CDC; clear water, NRCS; feral piglets, V. Dinets, University of Miami, Bugwood.org.

Table of Contents

Figures and Tables

Figures

Figures in Appendix

Tables

Tables in Appendices

1: Introduction to Co-Managing Food Safety and Conservation

1.1 Introduction

Building evidence over the past two decades and recent food-borne illness outbreaks have significantly influenced growers' production management and, as an unintended consequence, their conservation decisions in many of the produce growing regions of the United States. On-farm food safety requirements by private industry or the government may be perceived as in conflict with conservation practices; too often the actions taken make this a reality. Consequently, agricultural food safety requirements, or independent actions taken to ensure compliance and continued market access, affect the work of conservation planners and stewardship growers. As these requirements increase across the country, planners and growers will have to understand and address food safety issues to work toward implementing integrated solutions and removing obstacles.

J.A. Baumgartner

Conservation practices, like this vegetative buffer, can help reduce the movement of pathogens to produce fields, but some buyers view these plantings as a food safety threat because they may attract wildlife.

This handbook helps conservation planners who work with produce growers, and the growers themselves, to co-manage food safety and conservation (see Figure 1) by understanding food safety risks in the growing environment, and by learning details of how specific management practices may reduce or increase food safety risk. Many of the vegetative conservation practices implemented by growers, such as filter strips, riparian forest buffers, windbreaks and wetlands, will likely help to reduce the risk of produce contamination by pathogens that cause human illness, though limited specific data is available at this time. Non-vegetative practices used to control soil erosion, decrease runoff, and manage animal wastes also aid in lessening the movement of human food-borne pathogens across the landscape, thus reducing the risk of crop contamination. The *Healthy, Diverse Ecosystems Help Keep Pathogens in Check* illustration (Figure 2) provides a summary of these conservation practices and food safety Good Agricultural Practices (GAPs). GAPs help to identify and remedy potentially overlooked well-recognized areas of concern, such as creating a "no-harvest-zone" around feces in the crop field, not growing leafy green vegetables immediately adjacent to manure or compost piles, and not planting under bird roosts. While no on-farm practice (conservation related or otherwise) provides complete and conclusive protection against food-borne pathogens, implementation of diverse conservation practices, with judicious monitoring, can support a farm's food safety management plan.

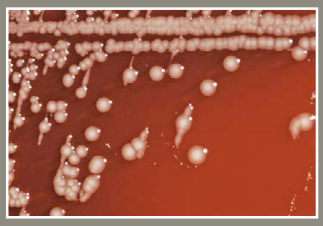
Figure 1 *Co-Management of Food Safety and Conservation*

"'Co-Management' means farm system management approaches that respond to site-specific conditions by integrating cultural, biological, and mechanical practices that promote ecological balance and public health by conserving biodiversity, soil, water, air, energy and other natural resources, while also reducing pathogen hazards associated with food production." (National Sustainable Agriculture Coalition)

1.2 Food-Borne Illness Attributed to Produce and the Farm

By the time produce reaches the table in the United States, it may have encountered contamination from any one of many sources along the supply-chain from farm to food preparation. From 1998 to 2008, approximately 46% of the illnesses documented by the Center for Disease Control (CDC) were attributed to produce. Contamination could have come from the farm, processing, storage, or shipping. It could also have come from handling by a store, or poor preparation in a restaurant or home.

Center for Disease Control (CDC) Facts



CDC

From 1998 to 2008, about 46% of the illnesses documented by the CDC were attributed to produce. (Painter et al. 2013)

Of the food-borne outbreaks with identified causes that might come from the farm:

- *5% was reported between 1998 and 2008.* (CDC 2013 (a))
- *0.5% in 2009 and 2010.* (CDC 2013 (b))
- *1.3% in 2011*. (CDC 2014 (a))
- *0.1% in 2012*. (CDC 2014 (b))

To understand how much food-borne disease may originate on the farm, it is helpful to look at the causes by which CDC tracks illnesses and outbreaks—defined as an occurrence of two or more illnesses in a population. CDC has only been able to identify approximately 40% of all the causes. Of disease outbreaks data with identified causes between 1998 and 2008, 5% might have come from the farm. CDC tracked farm causes using the category "Raw product/ingredient contaminated by pathogens from animal or environment (*e.g.,* Salmonella enteritidis *in egg, Norwalk* (Norovirus) *virus in shellfish,* E. coli *in sprouts*)." In the following four years, the percentage attributable to the farm decreased. Of the food-borne disease outbreaks with identified causes between 2009 and 2010, 0.5% might have come from the farm; in 2011, 1.3%, and in 2012, 0.12%. CDC's category for farm causes changed to: "Foods originating from sources shown to be contaminated or polluted (such as *a growing field or harvest area*)." Other farm activities, such as manufacturing, processing, packing, holding, and transportation, are not included here. As indicated, the data are not sufficiently granular to differentiate between produce and other farm products, such as eggs or meat, and 60% of the causes are not identified. While the percentage attributable to the farm could rise if the reporting mechanism for outbreaks becomes more refined in the future, this does give an indication that many of the outbreaks are coming from non-farm causes.

Agricultural crops eaten without a kill step, such as cooking, are associated with a higher risk of illness than those that require cooking, acidification, or other actions expected to reduce pathogen populations. Some types of produce harbor more optimal surface sites for pathogens to persist or avoid wash-disinfection, such as netted melons with rind crevices or the water-congested stem-scar region of tomatoes. Several studies provide evidence that minimally processed leafy greens, subjected to varying degrees of cutting or shredding, provide thousands of attachment sites, entryways, and nutrients for pathogen growth and survival. The Food and Drug Administration (FDA) classifies cut leafy greens as a "potentially hazardous food" that requires regulated time-temperature controls for food safety. When illness is traced back to the farm, it has often been to these types of crops. FDA has published specific on-farm food safety guidances for melons, tomatoes, sprouts, leafy greens, and fresh-cut lettuces and leafy greens to help reduce human illness.

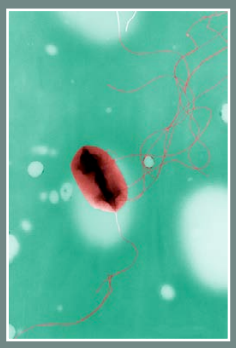
1.3 Pathogens of Concern for Produce

The human body contains ten times more bacterial cells than human cells. Many beneficial bacteria in the gut help with digestion and immune responses. But not all microbes are beneficial. Ingesting contaminated food can allow pathogenic microbes to attach, invade, and reproduce in the gut, causing stomachaches and, in some cases, life-changing complications or death. Food-borne pathogens often

have a low infectious dose, meaning that it only takes a few cells or infectious viral elements to cause illness in an individual. Because of this, washing produce to remove pathogens, while a good practice, cannot ensure safe consumption. The few pathogens that may remain after washing could still make someone sick, depending on the individual dose response.

This document covers the four bacteria, from human and non-human sources, most likely to contaminate U.S. produce and cause illness—Shiga toxin-producing *Escherichia coli* (e.g., *E. coli* O157:H7), *Salmonella*, *Campylobacter*, and *Listeria* species. While better adapted to survive in the moist, anaerobic guts of their hosts, all may survive outside as well for different durations, depending on conditions. Uniquely, *Listeria,* a true environmental survivor, has many forms, though only two are pathogenic to humans.

Outbreaks of Shiga toxin-producing Escherichia coli*, such as* E. coli *O157:H7 pictured here, have been traced back to produce, including fresh-cut spinach, lettuce, and salad mix.*



E. H. White, CDC

This review includes a protozoan, *Cryptosporidium* species, because of its survival strategy, even though it is less likely to cause contamination. While the protozoan may persist in the environment longer than the others due to its ability to form an oocyst—a thick-walled protective spore—it usually only makes a few individuals, rather than large numbers of people, sick because it doesn't replicate outside the host.

Antimicrobial resistance in *E. coli* O157:H7, *Salmonella*, *Campylobacter*, and *Listeria* species sometimes appears in livestock, wildlife, and environmental sources, potentially making illnesses from these cases difficult to treat and even more of a health hazard. For more discussion about these pathogens, see Appendix I.

1.4 Food Safety Regulations, Guidances, GAPs, and Plans

Even though produce farms have not caused the majority of produce outbreaks, growers must respond to today's heightened awareness of food safety on the farm. Many food buyers, state or regional commodity marketing agreements, orders, associations, and some government agencies require (under voluntary signatory or mandatory programs) produce growers to follow specific food safety procedures, as well as to record the actions they take to implement these procedures. FDA's regulation, *Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption* (hereafter referred to as FDA Produce Rule), under the 2011 Food Safety Modernization Act, was written in order to help reduce food-borne illnesses and outbreaks with the consumption of fresh produce. This handbook only addresses the most pertinent conservation-related regulations; there are many other regulations covered in FDA's Produce Rule. FDA also published guidance for on-farm food safety in 1998 and more recent commodity specific updates. Some states have their own food safety standards and government audit requirements. Many public institutions, including military, hospitals, penitentiaries, and providers to schools under USDA programs, as well as private food buyers, require food safety plans accredited by third-party auditors.

Just as an environmental assessment can be done as part of a farm stewardship plan to identify areas or activities that impact a farm's natural resources, a food safety risk assessment can be done as part of its food safety plan. This assessment done by the grower, ideally with the assistance of a food safety specialist, identifies areas or activities that may directly or indirectly expose crops to pathogen contamination. The plans are typically based on a set of GAPs developed by multiple stakeholders including industry, government, auditors, academia, and agricultural extension agencies. These GAPs usually focus on five categories of assessment, four of which are highly relevant for the co-management

of food safety and conservation: (1) water quality, (2) soil amendments, (3) wild and domestic animals, and (4) the surrounding environment. The fifth, worker health and hygiene, is critically important but not a focus in co-management considerations. Co-managing for food safety and conservation involves managing non-crop vegetation, water bodies, soil amendments, and domestic animals and wildlife to minimize dissemination and persistence of pathogens on the farm and in the landscape. In a well-intentioned but misplaced effort to eliminate all risk of pathogen contamination, some GAP requirements by produce buyers, or the subjective misinterpretation of them by auditors, prove unintentionally counterproductive or indifferent to conservation goals.

1.5 Conflicts with Conservation Goals

When growers have to comply with multiple food safety requirements, they may aim for the highest common denominator, implementing the strictest food safety management practices to appease all buyers and regulating bodies. In the preamble to FDA's Produce Rule, which contains their thinking about why they wrote what they did, they acknowledge that animals do not pose a universally significant food safety risk. In the Produce Rule itself, FDA does not authorize "the 'taking' of threatened or endangered species . . ." and does not require growers "to take measures to exclude animals from outdoor growing areas, or to destroy animal habitat or otherwise clear farm borders around outdoor growing areas or drainages." (FDA Produce Rule § 112.84). However, since wildlife feces, generally a low risk, is a recognized source of human pathogens and in certain localized populations is a significant risk factor, wildlife—and the habitat that harbors it—is often a major focus of standards in food safety GAPs. While current GAP documents rarely target the direct removal of habitat or encourage the killing of wildlife, the observation of presence and perceived risk of wildlife and wildlife habitat can translate into a drop-off of sales, particularly when produce buyers refuse to buy the portion of a grower's crop that is located near wildlife habitat. This situation negatively incentivizes growers and has resulted in their removing conservation practices that support ecological functions critical to public health.

J. Couperus, Lighthawk 2008

In response to food safety pressures in the 5 years after the 2006 spinach contamination, about 13% of remaining riparian habitat was eliminated or degraded in the Salinas River Valley, such as this which is shown between the red lines.

In 2006, spinach contaminated with *E. coli* O157:H7, traced back to a farm on California's Central Coast, was cited as the cause of death of five people. While it was never determined how the spinach became contaminated, non-native feral pigs, contaminated irrigation water, and adjacent cattle operations were all considered potential sources during the official environmental investigation. Wildlife and the habitat it occupied were seen as a serious food safety risk with potential to transfer pathogens to the crop. Although research thus far has indicated that native wildlife has a low relative prevalence of carrying pathogens that cause food-borne illness in humans, localized conditions may create situations that cause concern, such as proximity to known domestic animal sources of key pathogens.

Surveys conducted by the Resource Conservation District (RCD) of Monterey County after the 2006 spinach outbreak found growers adopting environmentally destructive measures to comply with food safety audit requirements and to keep their markets. In 2007, 89% percent of growers managing 140,000 acres on California's Central Coast reported that they had actively discouraged or eliminated wildlife from crop areas. Growers began creating bare ground buffers around their crops, trapping wildlife, using poison bait stations, and fencing out wildlife. A later survey conducted by the RCD of Monterey County in 2009, showed that some of these reactionary measures had lessened. Research published in 2013 found that over a five-year period after the 2006

contamination, approximately 13% of the remaining riparian habitat in the region had been eliminated or degraded. If practices such as these occurred throughout all California croplands, estimates predicted that up to 40% of riparian habitat and 45% of wetlands in some of its counties would be impacted. In a 2015 study that combined land use maps with pathogen prevalence in produce, irrigation water and rodents, researchers found that from 2007 to 2013 habitat removal was not effectively reducing *E. coli* or *Salmonella* pathogen contamination risk on California's Central Coast. This study and many others cited in this handbook support the idea that successful food safety measures can incorporate wildlife habitat and conservation practices with the end goal of protecting human health.

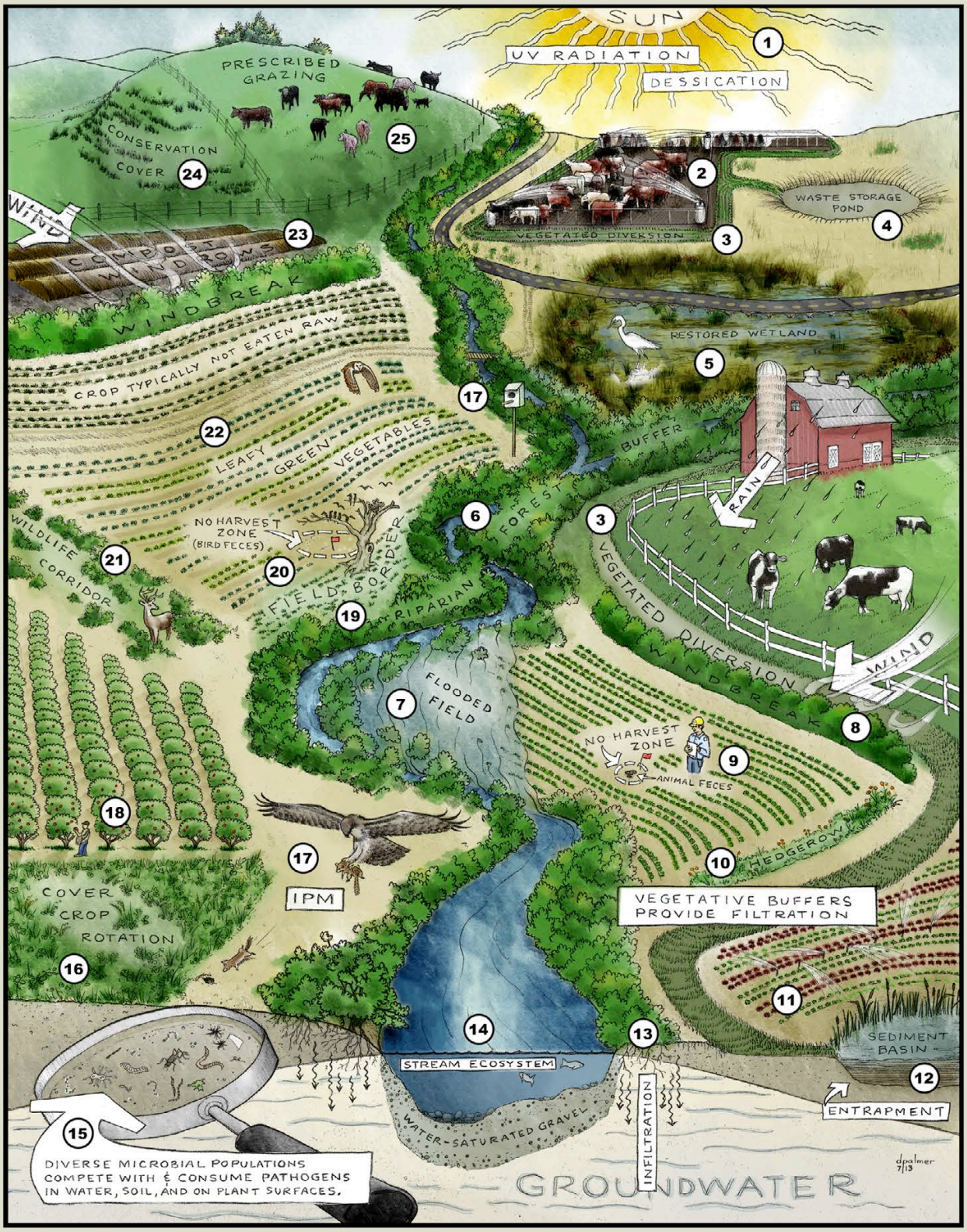
1.6 Addressing Food Safety and Conservation

Growers can achieve co-management of food safety and conservation in diverse situations, ranging from those whose markets demand the strictest food safety protocols, to those who are internally motivated to do the best they can at the least expense to the environment. Actions depend on how much preventive planning, monitoring, and exclusion they deem necessary. Using the multiple-barrier approach, growers can: (1) minimize the likelihood of pathogens entering the farm; (2) diminish likelihood of pathogens contaminating crops; (3) reduce the spread of pathogens to crops when livestock are on the farm; and (4) prevent pathogens from leaving the farm.

This document builds on the ongoing work by major research scientists, food safety regulatory agencies, and extension personnel, many of whom are already working on similar teaching tools, though not necessarily targeting food safety and conservation co-management strategies. This text includes key points learned from grower phone surveys and farm visits in Florida, New York, and California—such as how the diversity of production, climate, regulatory, landscape, and wildlife features influence produce production management decisions. Many of the growers who participated in these interviews supported conservation measures and wanted to identify pathogen sources and the management practices they could use to help reduce the risk of pathogens that might contaminate their produce.

FDA's Produce Rule has made co-management of food safety and conservation possible. In the Preamble to the Rule FDA states that they "encourage the application of practices that can enhance food safety and that are also consistent with sustainable conservation." Conservationists and growers knowledgeable about basic food safety issues can help plan for and/or can implement co-management practices that benefit natural resources and biodiversity on the farm and in the larger landscape.

Figure 2 *Healthy Diverse Ecosystems Help Keep Pathogens in Check*



This illustration first appeared in WFA's publication "A Farmer's Guide to Food Safety and Conservation" October 2013.

Key to Illustration: Healthy, Diverse Ecosystems Help Keep Pathogens in Check

Note: The Healthy, Diverse Ecosystems Help Keep Pathogens in Check *illustration* ***is not drawn to scale****; it serves as a visual summary of the conservation practices and food safety actions used to address food safety referenced in this document. These practices and actions do not provide complete and conclusive protection against food-borne pathogens on a given farm/ranch, and some vegetative conservation practices may attract wildlife that can vector pathogens. When implementing in-field practices to address food safety, one should take into account the conditions present on the farm/ranch and use this information to assess the effectiveness of a given practice in* ***reducing the risk of food-borne pathogen contamination*** *of crops.*

1. Sun: Ultraviolet (UV) radiation from the sun may inactivate recently deposited pathogens on the surfaces of soil and leaves, as well as in clear water. The sun also facilitates the desiccation of pathogens, which leads to pathogen reduction.

2. Dust from animal activity (NRCS Conservation Practice Standard 371) is reduced with the application of water by sprinklers and with manure harvesting. Reducing emissions and removing manure proactively are cost-effective means of mitigating pathogen transfer.

3. Diversions (362) redirect water runoff from confined animal feeding operations to waste treatment and sedimentation lagoons, preventing the movement of waterborne pathogens to nearby farm traffic areas, fields, and waterways. Vegetated diversions also intercept organic matter and soil carrying pathogens in runoff from pastures and divert potentially contaminated water away from produce fields. The diversions slow pathogen dispersal and provide a matrix for beneficial bacteria and protozoa that compete with and consume pathogens. Plants should be selected for low-flow filtering capacity and the ability for high flows to flow through the vegetation. Selection criteria should also consider how well air and sunlight can penetrate the vegetation, as the cool, moist, shaded interior vegetation may provide favorable habitat for pathogen survival. Otherwise additional maintenance will be required that regularly harvests and removes excess vegetation.

4. Waste storage pond (313) temporarily stores waste, such as manure runoff from concentrated animal feeding operations, thereby reducing pollution potential in the landscape. The waste storage pond should be properly designed and maintained to not overflow. Food safety Good Agricultural Practices (GAPs) recommend that the effluent from the ponds not be used on raw agricultural commodities. Monitoring of animal movement around the pond and between waste handling areas and crop fields should be a scheduled activity.

5. Restored wetlands (657) can considerably reduce pathogen transport by slowing the water, which increases the interaction time, and providing a matrix for beneficial microbes. The diverse plant and microbial community establishes desirable interactions that serve to limit pathogen persistence. Use of vegetation and designs that facilitate water moving slowly over long periods in the wetland allow the best chance for pathogen reduction in water draining from the wetland. The vegetation in the wetland may decrease the ability of UV light to reach the pathogens, which may increase survival. However, pathogens may be retained on vegetation. As water recedes, the pathogens that are retained on the vegetation may be exposed to sunlight and desiccation.

6. Riparian forest buffers (391) are vegetated areas along bodies of surface water**,** including streams, wetlands, and lakes. They may trap wind-borne pathogens on their vegetation and filter waterborne pathogens attached to suspended organic-soil particulates and other solids. The diverse plant and microbial community in the buffers encourages interactions limiting pathogen persistence.

7. Flooded field: Food safety GAPs recommend that raw agricultural commodities not be planted on lands that often flood. If and when a flood occurs, it may take time for pathogens present in the soil to die off. Depending on the frequency of floods, the field could be fallowed for a period, replanted to a cover crop, or possibly, permanently taken out of production with the restoration of riparian habitat.

8. Windbreaks (380) can trap dust containing pathogens and prevent it from entering produce fields. Plants should be selected with foliar and structural characteristics that optimize dust/pathogen interception. If interior vegetation is too dense, it may provide a cooler, moister, and shadier environment, which may create a favorable conditions for temporary pathogen survival.

9. Evidence of animal intrusion in a crop field should be monitored. FDA requires that growers monitor a raw agricultural commodity during the growing season for significant evidence of potential contamination, and if found, take measures to reduce risk of harvesting the contaminated crop (FDA Produce Rule § 112.83). Food safety GAPs recommend placing a no-harvest buffer around the contaminated crop. The following considerations all factor into determining the appropriate risk reduction actions taken: significant numbers of animals; significant amounts of animal feces; significant crop destruction; the type of animals; whether they are present intermittently or continually; if they are there because of food, a movement corridor, or live next to the crop; and if they are seen before planting or right before harvesting.

10. Hedgerows (422) may trap waterborne pathogens in their root systems and wind-borne pathogens on their vegetation. Shaded interior of the vegetation may provide favorable conditions for temporary survival of pathogen if too dense.

11. Irrigation (449): FDA requires growers use irrigation water sources that do not exceed specified levels of generic *E. coli*, when water is directly touching raw agricultural commodities (FDA Produce Rule §112.44). Management techniques that promote infiltration of the water into the soil can reduce runoff and may aid in reducing the movement of pathogens already present in the field.

12. Sediment basins (350) capture and detain sediment-laden runoff that may contain pathogens. Correctly designed, basins allow sufficient time for the sediment to settle out of the water. With moist, cool conditions, the basin may support the survival of pathogens. Having a sediment basin that dries down as rapidly as possible helps to alleviate these moist conditions and helps reduce pathogen survival. Moist sediment that is removed from the basin and put on cropland should be treated as contaminated, with an established time period similar to non-composted soil amendments between its application and the next crop's harvest.

13. Riparian forest root zone: The roots of the riparian forest promote water infiltration and provide biological activity. This helps divert pathogens from surface water, and encourages interactions with other soil microorganisms that can limit pathogen persistence.

14. Stream ecosystem: In a stream ecosystem, diverse microbial communities are thought to reduce pathogens by competition, parasitism, and predation. Clear water allows light to reach pathogens, which can lead to their reduction. However, some algae and protozoa may serve as an alternate host for pathogens, allowing them to live even when environmental conditions are unfavorable for their survival.

15. Diverse microbial populations compete with and consume pathogens in water and soil and on plant surfaces. When diverse microbial populations are present, beneficial microbes compete with pathogens for carbon and nitrogen, while others kill and consume them. Diverse microbial communities in water and on plants also compete for resources and/or consume pathogens. In some instances, biofilms—a matrix of bacteria and carbohydrates—can support beneficial microbes and in other cases harbor pathogens.

16. Cover crops (340): Rotating with cover crops increases soil organic matter and supports soil microbial communities that may aid in suppressing pathogens. Cover crops may also reduce the movement of pathogens in water runoff by trapping pathogens in their roots and leaves. They can be grown during a "waiting period" between events that might pose contamination risk (e.g., grazing, flooding or significant animal intrusion) and the planting of a raw agricultural commodity. Cover crops also reduce open soil, which helps reduce dust transmission problems.

17. Integrated Pest Management (IPM) (595) of vertebrates such as mice and squirrels can help control pest animals that enter crop fields. Having a few predatory animals, such as hawks or owls, on the farm is less of a risk than numerous prey species. A crop should not be planted directly under a raptor nest box or a roost, so that it is not contaminated with raptor feces. Farm traffic should not carry fecal droppings into the cropped area or equipment and storage yard.

18. Harvesting orchard fruit from the tree, not the ground, when it will be consumed fresh, is required by FDA (FDA Produce Rule § 112.114). Fallen fruit may have come in contact with animal feces.

19. Field borders (386) can intercept and reduce waterborne pathogens moving in overland flow from the field. This planting encourages infiltration and serves as a buffer between the field and the riparian vegetation.

20. Tree bird roost: Food safety GAPs recommend that a no-harvest zone be established under branches that hang over the field to ensure bird feces will not touch the crop.

21. Wildlife corridors allow wildlife to access resources (water, food, and cover) without having to cross crop fields or leave their preferred habitat.

22. Crop placement: Food safety GAPs recommend that leafy green vegetables or other raw agricultural commodities not be planted near manure stockpiles or composting facilities and windrows, or other areas of contamination, as pathogens may transfer to the field via water or wind.

23. Compost (317): FDA requires compost to maintain aerobic conditions while heating up to a temperature that results in significant pathogen reduction (FDA Produce Rule § 112.54). Compost itself supports beneficial organisms that compete with, inactivate, and consume pathogens. Unfinished compost or compost that has become re-contaminated could be a source of pathogens; thus, measures should be taken to prevent these below par composts from moving onto adjacent fields through wind or water. For information on proper compost management practices refer to "Chapter 2: Composting" in Part 637 of the USDA, NRCS National Engineering Handbook.

24. Conservation cover (327) is used to establish and maintain perennial vegetative cover to protect soil and water resources on land retired from agricultural production or land in need of permanent protective cover that will not be used for forage production. Perennial plants may trap windborne pathogens on the vegetation and waterborne pathogens in the root system.

25. Prescribed grazing (528) uses animals to manage vegetation. It also helps to increase water infiltration, reduce runoff, and prevent erosion. This aids in stopping the movement of pathogens in water runoff. Grazing animals are a reasonably foreseeable source of pathogens; thus, measures should be taken to prevent pathogens from the animals' feces from moving onto adjacent fields through wind or water.

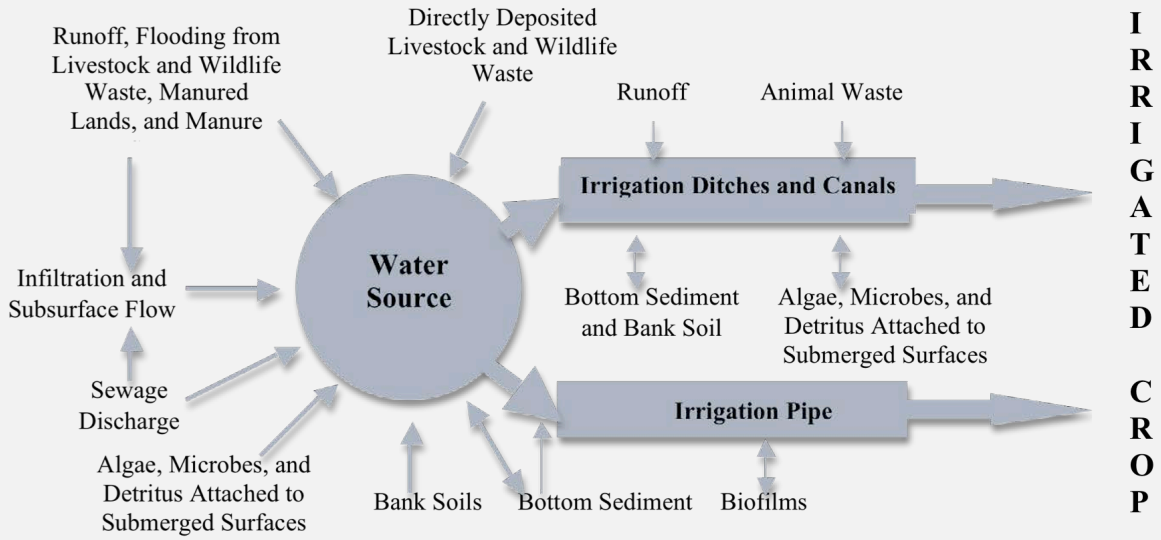
2: Pathogen Routes and Prevalence on the Farm

Successful co-management requires awareness and assessment of contamination pathways and prevalence (dynamic percentage of pathogens in a population) in order to plan, install and manage conservation practices with sensitivity to food safety concerns. Just as it is impossible to completely eradicate pathogens from the growing areas, it is impossible to predict with certainty when and where pathogens will occur. The high diversity of natural environments and the changing way in which pathogens react to them make prediction difficult. Typically pathogens move in water, on the wind, with animals, and through human actions. Prevalence of pathogens in wild and domestic animals can be assessed, but regional influences may cause significantly different outcomes. Prevalences serve as indicators of common risk potential rather than the foundation for sweeping generalizations at either extreme of absolute risk to absolute safety.

2.1 Waterborne Pathways

Water may carry pathogens to produce production areas via numerous pathways, as shown in Figure 3. Manure applied to nearby lands, overflow from manure lagoons, runoff from manure and compost storage sites, and fecal matter deposited by livestock and/or wildlife throughout a watershed may be carried in surface runoff down slope to crop areas or to surface waters. Concentrated rainfall events can cause runoff, preferential flow, and flooding, which can quickly transport pathogens over large areas. Crops that come in contact with floodwaters are considered adulterated by the FDA regardless of ability to detect chemical or biological hazards.

Figure 3 *Process Affecting Microbial Quality of Irrigation Water*



Adapted from Pachepsky et al. 2011.

Groundwater irrigation sources may also become contaminated. Pathogen movement through the soil profile is largely controlled by soil structure and preferential flow channels, which are determined by the diameter and continuity of macropores in soil. Movement of pathogens through the soil profile to shallow groundwater supplies is possible with high rainfall/irrigation rates and very porous soils. Improperly managed or leaking septic systems may also present a risk, particularly those in close

proximity to water sources used for irrigation or in areas where improperly percolating drain fields allow contamination. However, in many cases groundwater contamination is caused not by movement of pathogens through the soil profile, but rather by contamination around an active, or abandoned and unsealed, well-head or in the water distribution system.

In some areas of the country tertiary treated wastewater may be used as an irrigation water source. After going through primary and secondary treatment, wastewater is subjected to tertiary (advanced) treatment, which may include processes that use ultraviolet light and/or chlorination to maximize the removal of enteric bacteria, protozoan parasites, and human enteric viruses. While there are no federal standards for using tertiary treated wastewater for irrigation on crops, almost half of the states do have regulations of various kinds. California and Florida produce the most tertiary treated wastewater. As with municipal water sources, testing should ensure that these waters are safe for use; to date, no illness has been linked to the use of these reclaimed water sources in produce production. If either municipal or tertiary treated waters are inadequately treated, these could present contamination risk.

Water may become contaminated by direct animal deposits or by bioaerosols in systems that employ irrigation ponds, reservoirs, ditches, and canals where either rainfall or surface runoff is used in distribution. Studies have found that the mammals and aquatic birds that inhabit wetlands can disseminate *Cryptosporidium, Giardia,* and other human pathogens. If waterfowl or other wildlife congregate in a wetland in large numbers, caution should be taken, as the water flowing out of the wetland may be contaminated with pathogens. Contact with pathogens attached to algae, bank soils and re-suspended sediment in ponds, reservoirs, ditches, and canals may also lead to contamination. Pathogen concentration is frequently higher in sediments of water storage areas and waterways than in overlying water.

USDA NRCS

Water running off livestock yards may be contaminated with pathogens.

Disturbing these sediments may reintroduce pathogens into the water supply. Water transported through pipes interacts with biofilms—bacterial communities that establish on surfaces and create a protective extracellular matrix of polysaccharides—that may or may not harbor pathogens. Distribution systems handling reclaimed water have been shown to have an increased pathogen presence in these biofilms. Water unintentionally contaminated by pathogen sources during transport may end up in irrigation used on crops.

Only a few produce outbreaks have been traced back to irrigation water as the confirmed source of pathogen contamination. To make the link from water to humans, scientists have begun to use a DNA fingerprinting technique to compare the DNA of pathogens isolated from water samples collected at the suspected contamination site to that of the pathogens isolated from the contaminated crop and from the reported ill persons (Table 1). Many unconfirmed cases (not shown) have suggested that irrigation water may have been the source of contamination. These cases remain unconfirmed because there was no direct match between the outbreak strain and the strain found in the water; there was no direct use of the pathogen-laden water (groundwater was used for irrigation but pathogens were found in nearby river water); or potential environmental sources of the pathogens (animals, manure, and compost) near the water tested negative.

Table 1: Confirmed Outbreaks Associated with Irrigation Water			
Crop	**Pathogen**	**Irrigation Source**	**Farm Location**
Tomatoes (a)	*Salmonella* Newport	pond	Virginia
Lettuce (b)	*E. coli* O157:H7	small stream	Sweden
Shredded lettuce (c)	*E. coli* O157:H7	well water accidentally mixed with dairy lagoon water	California
Hot peppers (d)	*Salmonella* SaintPaul	holding pond used for irrigation water	Mexico
From: (a) Greene et al. 2008; (b) Soderstrom et al. 2008; (c) US FDA and CA Food Emergency Response Team 2008; (d) CDC 2008.			

2.2 Airborne Pathways

Pathogens may enter the crop environment as bioaerosols—windborne particles that contain living organisms. Windborne particulate matter may include desiccated fecal matter with viable pathogen cells or dust/soil/debris with adhered pathogens. Such contaminated materials may originate from a variety of nutrient management systems, including manure lagoons, manure piles, and compost facilities. Locations with heavy fecal depositions where animals congregate, such as wild or domesticated animal loafing areas, pasture/range land, and large or small confined livestock operations, can also serve as sources of pathogen-containing bioaerosols. Additionally, vehicle traffic or farm equipment traversing these areas can send contaminated dust into the air.

Factors influencing the risk level of produce contamination include the distance between the contamination source and the produce field; particle size and buoyancy; wind intensity, speed, and direction; land surface topography; and physical features. Land applied with untreated wastewater and biosolids may contain persistent populations of pathogens. Winds may distribute fine droplets of contaminated water or particulates to adjacent areas. Some of these cases are described in more detail in Table 2. However, not all animal-generated bioaerosols cause contamination—for example, only non-pathogenic bacteria were found in the air next to fields where sheep grazed in a leafy green producing region of California.

Table 2: Selected Cases of Airborne Pathogen Contamination		
Types of Airborne Pathogens	**Location**	**What the Research Examined**
E. coli O157:H7 (a)	Colorado 6,000-head cattle feedlot	Airborne transport of *E. coli* O157:H7 from feedlot to various distances of leafy green crops.
Newcastle disease virus (b)	Pennsylvania poultry farms	Vegetative buffers in Pennsylvania reduced dust and respiratory virus transmission from commercial poultry farms.
Larynogtracheitis virus (c)	Delaware poultry farms	A four-fold increase in risk of poultry developing the disease for a farm located within the downwind plume of the farm with contaminated poultry.
E. coli O157:H7 (d)	Ohio fairgrounds	One hundred people were sickened when a dance was held in the same building that had earlier exhibited animals.
Many pathogenic *E. coli* strains (e)	Mexico City household and street dust	Intestinal infections caused by dust collected from indoor and outdoor environments was greater than thought.
E. coli O157 and *Salmonella* (f)	Texas cattle feed yards	Exposure to dust in the cattle load-out area of feed yards increased pathogen contamination of cattle hides.
Salmonella enteritidis (g)	Chicken houses	Infected hens in houses transferred disease to healthy hens via the air.
Bacteria, fungi, and dust (h)	Croatia laying hen houses	Free-range aviaries have higher content of airborne pollutants than the conventional cage system.
Several kinds of bacteria and fungi (i)	Egyptian dairy barns and beef sheds	Concentration and frequency of airborne microorganisms on cattle farms and their potential health hazards to farm workers.
Several kinds of bacteria and fungi (j)	Romanian dairy barns	Barn hygiene decreased airborne microbe concentrations.
Several kinds of bacteria (k)	Arizona agricultural fields	Wind is a possible mechanism for the aerosolization and off-site transport of land-applied biosolids.
Newcastle disease virus (l)	In the laboratory and in the open air	Vaccination of birds leads to a great reduction in the amount of virus liberated into the air.
Generic *E. coli* (m)	California leafy green fields near rangeland	Generic *E. coli* present in water was related to aerial transmission. Concentration increased by 60.1% for each 1 meter/second increase in wind speed and decreased by 3% for each 10 meter increase in the distance between the sample location and rangeland.
From: (a) Berry 2011 (interim report); (b) Burley et al. 2011; (c) Johnson et.al. 2001; (d) Crump et al. 2003; (e) Rosas et al. 1997; (f) Miller et al. 2008; (g) Holt et al. 1998; (h) Vucemilo et al. 2010; (i) Abd-Elall 2009; (j) Popescu 2011; (k) Baertsch et al. 2007; (l) Hugh-Jonesa 1973; (m) Benjamin et al. 2013.		

2.3 Wildlife Prevalence and Pathways

Pathogen Prevalence in Wildlife

Native wildlife has so far been found to have a low relative prevalence of carrying human pathogens. Even though the widespread risk appears low, pathogen prevalence in localized wildlife populations remains a concern.

While hundreds of studies have detected food-borne pathogens in wild animals, only a few have shown a direct relationship with human illness. In each of the cases in Table 3, the DNA patterns in the samples taken from animal feces were indistinguishable from those in the contaminated crop and the reported ill persons. Unconfirmed instances orange juice and the presence of a nearby toad, and with apple juice and deer in the orchard were not listed because there was no direct match of outbreak strain.

Table 3: Recorded Outbreaks Associated with Wildlife

Crop	Pathogen	Wildlife	Location
Spinach (a)	*E. coli* O157:H7	non-native feral pigs*	California
Straw-berries (b)	*E. coli* O157:H7	black-tailed deer	Oregon
Peas (c)	*Campylobacter jejuni*	sandhill cranes	Alaska
Carrots (d)	*Yersinia pseudotuberculosis*	shrews	Finland

* While feral pigs were found with the same DNA pattern of *E. coli* O157:H7 as that found on the spinach, so were nearby cattle and pasture soil, and water/sediments from a creek that may have contaminated the irrigation well.

From: (a) Jay 2007; (b) Laidler and Keene 2012; (c) McLaughlin 2008; (d) Kangas 2008.

More often, native and non-native wildlife that harbor food-borne pathogens have not been implicated in cases related to human illness outbreaks. These studies may simply determine that certain wildlife have the pathogen, or may discern how many carry the pathogen—the prevalence. The discussion below and in Figures 4—7 in Appendix II describe the prevalence found in wildlife.

It is helpful to understand that many biological factors and sampling methodologies influence the detection of pathogens in wildlife. If wildlife populations live near contaminated sources, they are much more likely to become infected or simply mechanically transport pathogens on their skin, fur or feathers. Just as with humans, animals tend to be more susceptible to pathogens depending on their health, stress level, age, and immunity. Some pathogens have no known virulence to the animal host but have serious consequences in a human host. The ability to detect pathogens in individual wildlife depends on the amount of pathogen it carries, the degree of activity and fitness of the pathogen, and the specific methods used to sample, recover, and detect the target pathogen. Sampling from the animal itself is a much more reliable indication of prevalence than sampling feces from the ground, which may introduce contamination or exposure to conditions that increase, decrease, or inactivate the pathogen. The pre-process handling and sample size is important for credibility—if too small, it may not accurately represent prevalence. As with any research, studies documenting pathogens in wildlife are snapshots that reflect the local conditions but do not necessarily give a comprehensive picture of pathogens in the landscape. For a more thorough discussion of the complexities of data interpretation, see Appendix II.

E. coli *O157:H7 Prevalence in U.S. Native and Non-Native Mammal and Avian Species*

Since cattle are considered the primary reservoirs of *E. coli* O157:H7 and possibly other *E. coli* pathogens, most wildlife studies examining its prevalence take place near cattle. Zero to less than 1% prevalence was found in deer, rodents, and in various other native mammals; and about 2% prevalence

was found in elk and coyotes. The same low rate was found in songbirds (0–1%), non-native rock pigeons (0%), and European starlings (0–2%) that visited dairies or cattle feedlots. A few species have somewhat higher levels, including brown-headed cowbirds (about 3%), American crow (over 5%), and feral pigs (4–5%), possibly because they come in contact with the pathogen-laden organic matter more often. Brown-headed cowbirds eat seeds and insects from cattle feces, and American crows and feral pigs eat garbage and carrion. Pigs are also known to eat other animal's feces. As mentioned in Table 3, feral pigs were one of several possible *E. coli* O157:H7 sources in the 2006 spinach outbreak in California, and black-tailed deer were the source of this pathogen in a strawberry outbreak in Oregon. Figure 4 in Appendix II gives further details.

Salmonella *Prevalence in U.S. Native and Non-Native Mammal and Avian Species*

Feral pigs (>14%) presented twice the prevalence of *Salmonella* than any other wildlife species. Deer studies showed less than 3% prevalence with the exception of one study in Texas where deer shared rangeland with sheep and both had prevalences around 8%. Other wildlife prevalences were detected for raccoons (>7%), European starlings (0–7%), tule elk (4%), rodents (3%), and various other native mammals (4%) and birds (3%). As mentioned above, birds that feed on insects and seeds in manure, and scavenge or eat carrion seem to more often carry the pathogen. Due to the significant numbers of European starlings in one cattle feedlot, it was thought that the *Salmonella* contamination of the cattle's feed and water was related. Figure 5 in Appendix II gives additional details.

B. Higginbotham, TX AgriLife Ext. Service, Bugwood.org

Current research suggests that non-native feral pig populations may have higher prevalence of many food-borne pathogens than populations of native wildlife.

Salmonella *Prevalence in U.S. Native Amphibians and Reptiles*

Even though most human illnesses are caused by the "warm-blooded" *Salmonella enterica* subsp. *enterica*, all of the 1,500 "warm-blooded" and 1,000 "cold-blooded" *Salmonella* serotypes found in animals and the environment must be considered potentially dangerous. One-quarter of the "cold-blooded" *Salmonella* serotypes are now known to be human pathogens. People, especially children, often become sick after handling pet reptiles. Various studies have shown that, in nature, from one to almost 40% of amphibians, and from zero to almost 100% of reptiles carry *Salmonella*. Such a large range of prevalence suggests that the higher occurrences of this pathogen may relate to other contamination in the landscape. Figure 6 in Appendix II gives further information.

Campylobacter, Cryptosporidium, *and* Listeria *Prevalence in U.S. Native and Non-Native Mammal and Avian Species*

Feral pigs were found with high levels of *Campylobacter jejuni* in both their mouth and gut (40%), suggesting that contamination can come from pigs eating the crop as well as defecating on it. Different types of waterfowl (36%) have also been found at times to carry high levels of these pathogens, including Canada geese (4–16%), which carried antibiotic-resistant *Campylobacter.* Other wildlife known to carry *Campylobacter* include deer, raccoons, elk, skunks, squirrels, and California gulls. One study reported that most of *Campylobacter* serotypes found in gulls were not closely related to species commonly associated with human illness. As shown in Table 3, sandhill cranes carrying *Campylobacter* pathogens precipitated an outbreak traced back to peas. Figure 7 in Appendix II gives further details.

Feral pigs were found with a 5% prevalence of *Cryptosporidium.* Various rodent species were found to have 7% prevalence, while deer mice were found with a much higher of prevalence of 26%.

A preliminary study reported that the prevalence of rodents with *Cryptosporidium* is inversely related to the biodiversity present. It suggests that non-crop vegetation clearing and indiscriminate poison baiting led to the decrease of rodent species diversity and the increase of a single species (deer mice). As the single species proliferated, the interaction between individuals of that species increased, which may have caused an increase in pathogen prevalence in those individuals.

Listeria has been found in many types of mammals and birds, including deer, moose, elk, fox, raccoon, skunk, geese, and crows.

Pathogen Vectoring by Wildlife

Fecal matter contact with a crop, as when feral pigs or native wildlife come into cropped areas and defecate on or trample the crop with contaminated feet, is an obvious pathway of contamination, though not all fecal matter contains pathogens of human health concern. Pathogens may also be transferred when animals eat part of the crop or brush up against the crop with contaminated fur and feathers. Crops that grow close to the ground (e.g., lettuce, spinach) or are harvested from the ground (e.g., almonds, walnuts) are at higher risk of contamination.

Wildlife is universally present in growing areas, some more so than others depending on the surrounding environment, but not typically in high numbers. Animal movement is virtually impossible to completely control, and minute amounts of fecal matter contamination may escape notice during harvesting, allowing contaminated product to enter the supply chain.

At times, wildlife has been found to vector pathogens from areas of high pathogen concentration to crops. High concentration areas may include livestock operations, waste storage facilities, or landfills/dumps. These areas attract some species of mammals, birds, and insects, presenting unique co-management challenges because of the ease with which they may move around the landscape and the difficulty of restricting their access to crop areas.

Wild mammals that share rangeland with livestock may pick up pathogens and transport them to crops. Feral pigs on cattle rangeland in California especially pose a problem. While deer may also share grazing lands with cattle, they carry lower levels of pathogens than the pigs. Both deer and sheep grazing on rangeland have had somewhat similar elevated levels when compared to animals that do not share grazing areas. Birds feeding in confined cattle operations may, but not always, become infected with pathogens encountered there. Not all birds are equally likely to frequent areas with potentially high concentrations of pathogens. For example, arboreal chickadees are less likely to feed at a landfill than seagulls, and brown-headed cowbirds are more likely than chickadees to eat seeds and insects in manure. Understanding which wildlife frequent the growing area, as well as how far and where they forage for food beyond the farm, may guide risk assessment.

Filth flies, which breed or feed in animal wastes, carry some pathogens on their bodies and may present a risk. Researchers remain uncertain that the amount of contamination likely to occur via this pathway denotes a measurable risk, and note that pathogens deposited on an exposed crop surface in typical growing conditions may not survive for long. Other insects, for example bees, syrphids, leaf hoppers, and a range of other beneficial and pest insects may also visit produce fields, though because they are not specifically drawn to animal wastes, their activity does not elicit the same concern as a contamination pathway. Additionally, bees have been found to avoid flowers inoculated with *E. coli*

pathogens, and bee propolis has toxicity factors that reduce survival of the pathogens bees might carry to the hive.

2.4 Domestic Animal Prevalence and Pathways

Pathogen Prevalence in Livestock and Companion Animals

Since many crops may be part of a mixed crop/livestock operation, or may be grown near neighbors with livestock, it is important to understand the role livestock play in the spread of food-borne pathogens onto crops. For a thorough discussion, see *Introduction to Waterborne Pathogens in Agricultural Watersheds, USDA NRCS Nutrient Management Technical Note No. 9.*

USDA NRCS

Salmonella *and* Campylobacter *are most common in poultry.*

Livestock and companion animals can carry pathogenic *E. coli, Salmonella, Campylobacter, Listeria,* and *Cryptosporidium*. Some pathogens are more common in some animals than in others. Depending on their innate immunity, the virulence of the pathogen, and the nature of the infection, many animals remain asymptomatic.

E. coli *O157:H7 Prevalence in Domestic Animals*

Pathogenic *E. coli* is widespread in dairy and beef cattle in North America, whereas sheep are major reservoirs in Australia. Depending on the area, 7% to 100% of cattle operations may contain animals infected with *E. coli* O157:H7 (see Table 14 in Appendix II). Even in infected herds, relatively few individuals may carry the pathogenic *E. coli*. However, a small number can excrete large intestinal loads of the bacteria for long periods, while others may have a large load but excrete it quickly without being a constant source. Cattle in particular may carry pathogenic *E. coli* asymptomatically, tending to excrete it in the warm months of the year. A comprehensive USDA review indicates that grain-fed cattle in concentrated animal feeding operations have higher prevalence rates than those on pasture eating forage, even though both can be found with pathogenic *E. coli*.

Pigs, dogs, poultry, and bison raised for slaughter also harbor pathogenic *E. coli*. Horses and cats rarely carry it. Young livestock carry higher levels of pathogens than adults.

Salmonella *Prevalence in Domestic Animals*

Salmonella, most commonly found in poultry, can also be found in pigs, horses, and cattle. In studies of different layer chicken houses, the occurrence of *Salmonella* ranges from 7% to 68%. About 31% of the dairy herds studied had at least one cow with a positive *Salmonella* culture. In a multi-state study, 4.7% of the 2,496 environmental samples tested positive for *Salmonella*. Of the positive samples, 57.3% came from swine farms, 17.9% from dairy farms, 16.2% from poultry farms, and 8.5% from beef cattle farms (see Table 15 in Appendix II). *Salmonella* is seen in horses but not commonly in cats and dogs.

Campylobacter, Cryptosporidium, *and* Listeria *Prevalence in Domestic Animals*

Campylobacter is of most concern in poultry, but is also seen in cattle and other livestock. In one study, 90% of broiler chicken farms tested positive, and in another 100% of broiler cecal droppings were positive. Based on multiple studies, 34% to 51% of dairy cows test positive for these pathogens, while one study showed beef cattle prevalence at 5% (see Table 16 in Appendix II). Many of the other animals including sheep, dogs, cats, and pigs are susceptible to *Campylobacter* infection, though subspecies of the pathogen not typically found in human patients may be implicated.

Cryptosporidium parvum is known to infect cattle, sheep, goats, pigs, horses, geese, chickens, and turkeys. Some *Cryptosporidium* species found in animals appear to be host-adapted and rarely infect humans. *Listeria,* most commonly found in ruminants (sheep, goats, and cattle), occasionally occurs in dogs, cats, pigs, poultry, and other species. However, only *Listeria monocytogenes* is considered a human pathogen of significance.

Pathogen Vectoring by Domestic Animals

Like wildlife, free-range livestock, escaped livestock, and companion animals (dogs, cats, etc.) may contaminate produce if they enter a field and defecate on the crop. Livestock and companion animals may transfer pathogens onto the crop through their saliva (by eating a crop) or through manure-soiled feet. Contamination may also occur when inadequate time elapses between when feces is left by grazing animals gleaning harvested fields and harvest of the next crop. More rarely, contamination occurs when growers use animal traction (e.g., horses or oxen) to work the field.

2.5 Human Pathways

While not the focus of this document, humans who do not take appropriate sanitary measures before harvesting or handling produce may also contaminate it. Manure or other animal-based soil amendments brought onto the farm may create a direct pathway for pathogens. Humans may then unintentionally spread the pathogens if they do not change or wash boots after working with manure or animals, or properly clean produce-handling surfaces, equipment, and vehicles used to transport produce. Pathogen spread can be reduced if employees practice good hygiene, such as properly washing their hands after using the restroom, and do not come to work sick.

3: Environmental Factors That Influence Pathogen Reduction

Pathogen survival and growth depends on a number of biotic and abiotic factors. In general, pathogen numbers decline over time outside the host, usually with an initial steep decline followed by a small amount of lingering persistence, sometimes prolonged. Understanding this decline and recognizing the circumstances of the expected decline are critical elements of risk assessment and subsequent management in the produce growing environment.

The major factors that influence pathogen reduction are summarized below. Tables 17, 19, and 21 in the Appendix provide further details on how these factors influence pathogens, specifically in water, soil, and air, respectively.

3.1 Sunlight/UV Exposure

UV radiation from the sun both dries and damages pathogens, typically leading to their quick reduction on the surfaces of soil, compost, manure, and leaves, as well as in clear, shallow water. Factors that compromise these beneficial actions—shade from vegetation, turbid water, algal mats that cover water, depth in the soil and manure—reduce the effectiveness of sunlight/UV exposure. Open orchard canopies foster sunlight/UV penetration to the orchard floor much more than dense, deeply shading canopies. Water without algae and suspended sediments fosters sunlight/UV penetration throughout the water column, but sunlight/UV only act as an effective biocide at shallow depths. Pathogens may also attach to macro-algae and persist both in the water and in dried mats on banks, riprap stones, or concrete. The effectiveness of sunlight/UV radiation in reducing pathogens in animal feces through heat and desiccation is related to the volume and surface area of the feces. For example, sunlight/UV radiation will reduce the total pathogen load in songbird feces faster than it will in cattle feces.

3.2 Predation/Competition/Antagonistic Microbial Interactions

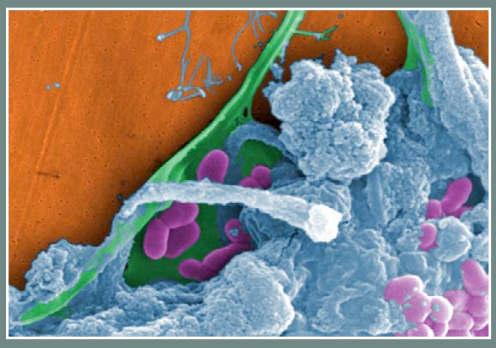
Diverse and abundant indigenous soil microbial populations generally decrease pathogen survival and reduce growth potential. Soil management practices that promote a robust native soil microbial community (e.g., high organic matter inputs from cover crops, manure, and compost; reduced tillage; infrequent fumigations) promote predation, competition, and antagonism. Laboratory work has demonstrated that pathogen survival time increases if native soil microbial communities are decreased through autoclaving or fumigation, although this relationship is not always straightforward. Studies employing variable degrees of soil pasteurization commonly result in a corresponding inversely proportional effect of bacterial pathogen persistence: the more severe the treatment, the greater the pathogen survival. Management practices that reduce the complexity of native microbial communities (e.g., fumigation) may create conditions favorable for prolonged pathogen survival, particularly if pathogens are re-introduced to this microbiological “vacuum” of limited microbial community density and diversity.

Native microbial communities effectively reduce pathogens in other media besides soil. Predation and competition for nutrients in water bodies is thought to reduce pathogen rates. Plants intercepting waterborne pathogens do so with the aid of biofilms, composed of microbial communities, which then help to reduce the pathogens. When biofilms form on the surfaces of leaves and roots, they may confer protection against pathogenic bacteria colonization, although in some instances, biofilms on plant surfaces may facilitate the survival and growth of pathogen populations. While predation, competition, and antagonism can play a significant role in enhancing food safety, they are insufficient for completely eliminating pathogenic contamination.

3.3 Harborage/Symbiosis

Although some biofilms may protect surfaces from pathogen colonization, others on living or inert surfaces—such as soil, vegetation, water, water systems, algae, and sediments—may serve as a reservoir for pathogens. While studies have proven the ability of many types of aquatic organisms to foster the survival of pathogens, the relative role of pathogens in water used for agriculture is currently unknown (see Section 2.1).

Pathogenic bacteria and protozoans may persist in biofilms, somewhat protected from environmental stressors such as UV radiation and predation. In sediments, biofilms may facilitate the capture and retention of pathogenic bacteria on individual and/or flocculated particles suspended in the water columns as well as in settled sediments. Amoebas and other protozoans grazing on bacterial biofilms may consume but not kill pathogenic bacteria and harbor the pathogens, thereby allowing them to persist or amplify even in unfavorable environmental conditions.



E. H. White, CDC

Biofilms are communities of microorganisms. Depending on the circumstances they may reduce or promote pathogen survival.

Evidence suggests that *E. coli*, *Campylobacter,* and *Salmonella* species may survive longer in a symbiotic relationship with algae, and in some circumstances their populations may amplify in association with algae. Nutrient-rich conditions that foster algal growth frequently occur in agricultural landscapes. Because algal blooms and algal mats may facilitate pathogen survival, management strategies should consider aquatic environments with abundant algae as possibly favorable habitat for extended pathogen survival.

3.4 Salinity, pH, and Nutrient Sources

Food-borne pathogenic bacteria generally survive well on soils with low salts and a neutral pH of around 6 or 7. Nutrients can support the growth of both pathogens and the microbes that compete with or predate upon them. Pathogens reduce more rapidly with low levels of bio-available carbon and nitrogen to consume, such as in clean water or sandy soils that typically contain less soil organic matter. The active area of the root zone that produces exudates can create a nutrient-rich environment for diverse microbial communities. For pathogens to survive, they have to compete with rival microbes for nutrients and avoid defensive antimicrobials produced by the plant. Different pathogens have different levels of ability to survive.

3.5 Temperature, Moisture, and Microscopic Niches

Lower temperatures tend to extend pathogen survival in soil and water, as there is less competition from native microbial populations. Cloud cover and increased moisture associated with cooler times of the year may also contribute to pathogen survival, though higher temperatures and humidity may favor growth on suitable substrates, including crops. Freezing temperatures by themselves cannot be assumed to inactivate most pathogens; however, rapid freeze-thaw cycles of weather can cause their reduction in the soil. Very high temperatures (> 55^{o}C/131^{o}F), such as those found in thermophilic composting processes, reduce most pathogen populations with sufficient exposure time.

4: Pathways and Persistence of Pathogens in Soils and Soil Amendments

4.1 Dynamic Influences of Soil Pathogens

Soil amendments of animal origin (e.g., manure, slurry, compost) serve as important soil fertility products for some growers, but may also serve as a pathway for produce contamination in the absence of appropriate management or treatment measures. Raw manure conveys higher risk than aged manure or finished compost.

The application method (surface applied vs. incorporated) and environmental conditions at the time of application influence pathogen survival and transport. Manure or other soil amendments exposed to a period of desiccation and UV radiation at the soil surface will have reduced pathogens present. Rainfall or irrigation events occurring shortly after manure application will likely release more pathogens. Manure composted using the full thermophilic process will carry reduced pathogen loads.

USDA NRCS

Thermophilic composting can reduce the number of pathogens in manure.

As outlined in Section 3, many factors influence pathogen survival. Yet food-borne pathogen persistence in the soil and manure is still not well understood. Most studies are compartmentalized and do not look at the whole dynamic picture—the fitness and virulence of pathogens, the interplay between indigenous microbes and pathogens, and the fixed features of soils, water sources, and climate. Many studies were conducted in labs, not in production fields. Even studies that do account for the majority of variables are only predictive of situations matching those same study conditions, not the entire scope of possible growing situations. Therefore it is difficult to accurately predict pathogen survival in the soil.

4.2 Range of Pathogen Persistence

Food-borne pathogens, with the exception of *Listeria*, are not part of normal indigenous soil microbial communities, and so are not perfectly adapted to them. Table 4 shows that in some cases pathogens can be reduced quickly, and in others they can be present for over a year. In several studies, survival related to whether the soil was sterilized—sterile soil lacks diverse populations of pathogen-suppressing microorganisms typically found in non-sterilized soil. Along these same lines, the presence of cover crops may influence the survival of indigenous soil microorganisms due to the support of increased microbial diversity. Different types of pathogens have different survival characteristics—*Cryptosporidium* oocysts typically persist outside of the host in soils or manure longer than bacteria. The type of the manure used, soil characteristics, and the rate of pathogens used for inoculation also influence persistence.

Table 4: Selected Cases of Pathogen Persistence in Soils and Manure		
Pathogen	**Pathogen Persistence**	**Relevant Details**
Salmonella	7 days (a)	*Salmonella* in land-applied manure survived for 7 days when sampled at 2 cm depth.
Salmonella	14–21 days (b)	Pig slurry containing *Salmonella* was incorporated into the soil.
E. coli O157:H7	25–96 days (c)	Fallow fields and fields planted with cover crops were amended with manure contaminated at a rate of 10^6 bacteria or cfu per gram (cfu/g) feces of pathogen.
E. coli O157:H7	28 days (d)	Pathogen was not detected on plant shoots after seven days but did survive in soil for up to 28 days.
Salmonella, *Campylobacter*, *Listeria, E. coli* O157:H7	<31 days (e)	Manure inoculated at levels of 2–5 log cfu/g was spread on land. *Listeria* survived longer than the other pathogens.
E. coli O157:H7	32–110 days (f)	Survival time varied with soil type.
Listeria	43 days (g)	Initial inoculation level of 5–6 log cfu/g was used in manure.
Salmonella and *E. coli*	50–70 days (h)	This was a multi-year field study in sandy loam soil. No contamination of vegetables was detected.
Fecal bacteria	56 days (i)	Poultry litter at 15 or 30 t/ac (recommended application rates for poultry litter typically is 2 t/ac).
E. coli O157:H7	>56 days (j)	Crisphead lettuce was grown in soil fertilized with manure inoculated at 4 log cfu/g. No contamination of lettuce observed. Study terminated at harvest; actual soil survival unknown.
E. coli O157	60 days (k)	Pathogen prevalence and densities were modeled probabilistically through the primary production chain of lettuce (manure, manure-amended soil, and lettuce).
Listeria, *Salmonella, Campylobacter, Cryptosporidium, E. coli* O157	64–128 days (l)	Initial inoculation of 6 log cfu/g; type of amendment used played large role in recovery. *E.coli* was not recoverable after 64 days, *Salmonella* or *Campylobacter* 120 days, *Listeria* sometimes persisted up to 128 days.
E. coli O157:H7	69–92 days (m)	A 3 log cfu/g *E. coli* was present at day 19; no *E. coli* recovered from radishes harvested at day 69 or from soil at day 92.
Listeria	90 days (n)	Time required for a 7 log reduction of the pathogen.
E. coli O157:H7	>99 days (o)	Soils amended with manure inoculated at rate of 10^8 to 10^9 cfu/g and then spread on grassland.
E. coli O157	105 days (p)	Samples of soil and sheep feces were collected from the campsite and tested for the presence of *E. coli* O157.

Table 4 (continued)

Pathogen	Pathogen Persistence	Relevant Details
E. coli O157:H7	154–196 days (q)	Study used a rate of 10^7 cfu/g of pathogen. (Cattle with *E. coli* O157:H7 may shed the organism at levels ranging from 10^2 to 10^7 cfu/g; on rare occasion more.)
E. coli O157:H7	154–217 days (r)	Used a rate of 10^7 cfu/g of pathogen. Reduction rates changed based on crop grown in inoculated soils.
E. coli O157:H7, *Salmonella*	180 days (s)	90% reduction at 13 days, 99% at 33 days, low level survival to 180 days at project termination.
Salmonella	184 days, 332 days, and 405 days (t)	Pathogen survived 184 days in manure, 332 days in manure-amended non-sterilized soil, and 405 days in manure-amended sterilized soil.
E. coli O157:H7	226 days (u)	Used a rate of 10^7 cfu/g of pathogen and placed manure in sterile soil that did not support diverse microorganisms antagonistic to the pathogen. Pathogens declined more rapidly in non-autoclaved soil.
Cryptosporidium	1 year (v)	This pathogen is primarily transmitted to humans through water rather than soil.
Cryptosporidium	<1 year (w)	The oocysts of these protozoans typically survive for prolonged periods of time in the environment.
E. coli O157:H7	21 months (x)	Detected in a manure pile, not in soil that had a manure application.

From: (a) Gessel et al. 2004; (b) Baloda et al. 2001; (c) Gagliardi and Karns 2002; (d) Patel et al. 2010; (e) Nicholson et al. 2005; (f) Ma et al. 2011; (g) Jiang et al. 2004; (h) Cote and Quessy 2005; (i) Zhai et al. 1995, Dunkley et al. 2001; (j) Johannessen et al. 2005; (k) Franz et al. 2008; (l) Hutchison et al. 2005; (m) Mukherjee et al. 2006; (n) Girardin et al. 2005; (o) Bolton et al. 1999; (p) Ogden et al. 2002; (q) Islam et al. 2005, Himathongkham et al. 1999; (r) Islam et al. 2004; (s) Nyberg 2010; (t) You et al. 2006; (u) Jiang et al. 2002; (v) Peng et al. 2008; (w) Sorber & Moore 1987; (x) Kudva et al. 1998.

4.3 Antimicrobial Resistance

Manure from livestock may contain antibiotics and similar drugs, also known as antimicrobial agents. Pathogens present in such manure typically have genetic traits for antimicrobial resistance; wildlife feces may also carry pathogens with antimicrobial resistance. This resistance can transfer to soil microbes, increasing the risk of *E. coli*, *Salmonella*, and other bacteria with low virulence traits becoming a health hazard by complicating medical interventions. Microbes that do not infect healthy people can sicken people with compromised immune systems, and antimicrobial resistance makes any illness more difficult to treat. The use of resistance-related antibiotics during initial treatments may allow symptoms and infection to worsen.

5: Conservation Practices That Influence the Reduction of Pathogens in Produce

Many produce growers employ conservation practices in their efforts to protect water, air and soil, as well as to support plants and animals. Understanding how some practices that contain vegetation, water or manure impact the fate and transport of pathogens is key in the co-management of food safety and conservation. Vegetation and water attract wildlife, and their presence near growing areas, while generally a low risk, may create co-management challenges. The text below and the supporting Tables in the Appendix (Tables 18, 20, and 22) describe how conservation practices may reduce pathogens in agricultural landscapes.

5.1 Water Management Practices That Encourage Pathogen Reduction

Vegetation may influence the fate and transport of pathogens in surface and groundwater. By acting as a physical barrier to pathogens carried in fecal matter, contaminated soil, or debris in runoff, vegetation may prevent pathogens from moving down slope to crop production areas or surface waters. Organic matter in the soil, which supports diverse microbial populations that compete with and predate on pathogens, increases in the presence of vegetation. Soil structure and porosity also improves with vegetation, both of which increase water infiltration rates. The decreased pathogen presence and the improved infiltration reduce pathogen movement in surface runoff and to groundwater.

Wetlands

Constructed (NRCS Practice Standard 656), created (658), enhanced (659), and restored (657) wetlands may retain pathogens. Wetlands that allow water to move slowly through aquatic vegetation over long periods of time work best to decrease pathogen survival. Within the wetland, biotic and abiotic mechanisms—including predation, the release of antibiotics by other microbes, sedimentation, and multiple plant interactions—can contribute to pathogen reduction in water. Several explanations for the observation regarding the effect of vegetation have been offered: physical filtration, increased oxygen levels in the water column creating less favorable conditions for some pathogens, the presence of antagonistic rhizosphere interactions, adsorption of pathogens on biofilm-covered surfaces in contact with contaminated water. Root exudates of some aquatic plants may be toxic to some pathogens; conversely, these exudates may be a nutrient source to others.

USDA NRCS

Wetlands can be used to intercept and reduce waterborne pathogens.

Better interception of pathogens occurs in a constructed wetland than in a natural one due to less channeling and more uniform filtration. However, vegetation in a uniformly constructed wetland may decrease UV penetration whereas in natural systems with patchy vegetation, more UV radiation exposure may occur. When the water levels fluctuate, more susceptibility to UV radiation and desiccation may also occur to pathogens retained on vegetation above the water line. Large flocks of migrating waterfowl, runoff from adjacent lands, access by wildlife or domesticated animals, or other factors can cause water pollution in the wetlands at certain times of the year, possibly increasing pathogen loads and diminishing pathogen reduction mechanisms.

Vegetative Buffer Strips

Many livestock waste, pastureland, and riparian area studies have documented that vegetative buffers reduce bacteria and protozoan parasites. More recently, a study reported that vegetative buffers were important between produce farm operations and reservoirs of pathogens, such as livestock operations, ditches, and roads.

A review of 40 vegetative treatment systems found that efficacy depends on a good stand of dense vegetation with strong fall growth and well-established winter vegetative cover to provide optimum filtration. Regularly harvesting and removing excess vegetation alleviates the build-up of dense thatch layers, which may provide a moist, cool environment for pathogen survival and in some cases amplification. Grazing should not be used as a harvest option since the animals may contribute to the contamination. Uniform flow conditions are maintained by the prevention of channeling, and the traffic is minimized.

Filter strips (393), grassed waterways (412) and riparian herbaceous buffers (390) may reduce movement of pathogens in runoff, although regular harvesting that removes excess vegetation may be required for them to function optimally and to allow for desiccation of the pathogens. Other vegetative buffers such as riparian forest buffers (391), tree and shrub establishments (612), field borders (386), vegetative barriers (601), and conservation covers (327) may also intercept pathogens in runoff. When these practices contain taller woody vegetation, the understory herbaceous vegetation is less thick because of diffused light and root competition, which results in less capacity to intercept pathogens. However, unlike the herbaceous only buffers, these other practices would not become too thick and require regular harvesting of thatch to reduce the moist, cool conditions that support pathogen survival. Depending on the situation, it may be more appropriate to use vegetative buffers with woody vegetation, if regular harvesting is not possible.

Riparian buffers are critical because they may offer the last chance to filter pathogens in agricultural runoff before it enters waterways. The natural vegetation can reduce the momentum of surface runoff and can trap debris with pathogens. Steep-sided riparian areas and those compromised by bank erosion may require extra wide buffers and/or vegetation with deep root systems to help stabilize banks and provide more opportunity for effective riparian filtration.

Irrigation Water

Waterborne pathogens can be reduced by other practices besides those involving vegetation. Crop fields with recently applied manure or unfinished compost may harbor pathogens in the soil. By using irrigation water management (449) techniques, the water is applied at rates that minimize pathogen transport to surface and ground water.

Diversion

The use of a diversion (362), placed at approximate right angles to the slope with a supporting ridge on the lower side to capture runoff, can direct upland contaminated runoff from entering a produce field. Diversions can also move water in agricultural waste systems.

USDA NRCS

Terraced diversions, like the one pictured above, help divert potentially contaminated runoff water away from crop fields.

Sediment Basin
Sediment basins (350) help to trap sediments with attached pathogens in runoff, allowing them to settle out before reaching a waterway. In situations where soils are very porous, water that contains pathogens may infiltrate from the basin to groundwater. Care must be taken with the placement of excess sediments removed during catch basin cleaning. Since pathogens need moisture, allowing the sediments to dry out before removing them may support pathogen inactivation, although extended survival of low or localized populations is possible.

Waste Storage Pond
A waste storage facility (313) can temporarily store wastes such as manure, wastewater, and contaminated runoff that might otherwise pollute the watershed. If not managed properly, these ponds can leak or overflow.

5.2 Airborne Management Practices That Aid in Pathogen Reduction
As Table 2 pointed out, airborne material may include desiccated fecal matter with viable pathogen cells, or pathogens adhered to dust, soil, or debris. Mitigations used to minimize this "fugitive dust" may provide the additional benefit of reducing pathogen transfer via air.

Dust Mitigation Practices
Produce farms raising livestock in confined areas may need to reduce the generation of dust that could become a source of pathogens for crops. Air filtration and scrubbing (375) can help to capture fugitive dust particles in confined animal housing or other enclosed structures. Dust control for animals (371) can help to reduce particulate matter arising from animal activity on open lot areas, holding pens, corrals, working alleys, or other fugitive sources of particulate emissions. Practices can entail periodic manure harvesting and watering down areas of high animal activity. Managing animals on pasture with prescribed grazing (528) generates less dust and thus serves as an effective management tool to reduce the spread of pathogens.

Vegetation That Intercepts Fugitive Dust
Produce fields located close to livestock yards or adjacent to land with areas of high pathogen concentration (e.g., manure storage or uncovered compost) may benefit from vegetative barriers such as windbreaks (380), hedgerows (422), and riparian forest buffers (391) that intercept fugitive dust. Vegetative buffers can remove between 35% and 55% of downwind dust in the air. They work both by dropping particulate matter and by lifting dust into the upper air stream for greater diffusion. A preliminary study indicates that vegetative buffers similar to windbreaks significantly reduced the aerial transfer of pathogens between poultry houses. Use of plants not intended for human consumption reduces concern about the pathogens trapped in the plantings.


J. A. Baumgartner

In high wind situations, windbreaks surrounding the crop are sometimes needed to reduce the movement of fugitive dust.

When a vegetative buffer captures dust that contains pathogens, UV radiation may facilitate pathogen inactivation. Higher numbers of bacteria have been found on underside surfaces of leaves, suggesting UV radiation reduces survival on upper surfaces of leaves.

Canopy structure and leaf area influence UV penetration into the vegetation and may influence the fate of pathogens intercepted by vegetation. Dust deposited on vegetation may itself desiccate the pathogens; conversely, if enough moisture is present, it may serve to keep leaf surfaces moist and pathogens viable longer. Some evidence suggests that conifers work better than deciduous trees in high wind situations for providing dense foliage and interception. In the case of pesticide spray capture, the needle-like foliage of conifers captures two to four times more spray than broadleaves because the latter don't alter their leaf alignments in high winds.

5.3 Soil Management Practices That Influence Pathogen Reduction

Nutrient Management

Managing the amount, placement, and timing of manure applications through the nutrient management (590) practice helps to prevent harmful levels of pathogens from entering surface water and groundwater. Placing manure on fields that don't have significant runoff concerns, and limiting the amount of manure applied, reduces pathogen runoff. Thoroughly mixing manure with the soil may increase pathogen inactivation by exposing pathogens to desiccation, nutrient stress, and predation by native soil microbial populations, from which pathogens might be protected if they remain in intact clumps of manure.

Incorporating manure into the soil immediately (via injection or tillage methods) to reduce scavenging bird and fly contact with the manure may reduce risk. When feasible, given crop needs and land use options, applying manure in warmer, drier months may facilitate more rapid pathogen reduction as pathogens tend to survive longer in cool, moist conditions. Application on frozen ground may increase risk of pathogen runoff and wild bird exposure. If a rain event that may create runoff and erosion is forecast, or if high winds that may cause the production of pathogen-laden particulate matter are predicted, delaying the application can reduce the transfer waterborne and airborne pathogens.

Compost

Incorporating compost fosters long periods of pathogen inactivation due to its long-term effect of increasing microbial diversity in the soil from its slow release of nutrients. The composting facility (317) documentation can help in the planning and making of compost, and in preventing pathogens in unfinished compost from moving onto adjacent crop fields through wind or surface water or from polluting the groundwater.

Cover Crops and Crop Rotation

The planting of many types of cover crops (340) can greatly increase the activity and diversity of microorganisms in the soil. As mentioned in Section 3.2, soil microbial diversity is a major factor in decreasing pathogens through competition, predation, and antagonism. Some do have an antimicrobial effect on various microbes, including pathogens—for example, a mustard cover crop can reduce *Salmonella* pathogens. The use of conservation crop rotation (328) can also promote diverse soil microbial communities when organic matter is increased with high residue crops. Both cover crops and crop rotation can reduce dust and runoff that may contain pathogens from leaving the field.

5.4 Animal Management Practices That Help in Pathogen Reduction

Integrated Pest Management (IPM)

IPM (595) practices that use correctly placed raptor perches and owl boxes, rather than removing non-crop vegetation or using poison bait that may affect non-target animals, can help to reduce rodent populations that may carry pathogens. Management of refuge piles and other areas on the farm where rodents congregate, such as irrigation pipes stacked on ground, help to avoid population increases. Monitoring for rodents and other pests help to target suppression strategies that are used.

Wildlife Corridors

Because terrestrial wildlife may be in the growing environment, strategic use of wildlife corridors can help draw animals away from crop fields and reduce food safety risk. Many types of wildlife prefer to move in non-crop vegetation that provides their native food and a cover from predators. Giving wildlife access to a vegetated corridor may keep them from traveling through a crop field where they may cause unacceptable damage.

Prescribed Grazing

Prescribed grazing (528) can benefit widespread food safety goals. Grazing management encourages water infiltration and reduces runoff, both important since livestock may shed pathogens. Instead of concentrating animal feces in confined yards, grazing animals disperse their feces on landscapes managed to have a filtering capacity for any runoff that might make it to an irrigation source used by produce growers. The dispersed feces are also subject to the sun's desiccation and UV radiation, which inactivates pathogens. However, there is very limited data available to base predictions of persistence under a diverse set of crop/soil/animal scenarios.

6: Multiple-Barrier Approach to Minimizing Food Safety Risk on the Farm and in the Watershed

Co-management of food safety and conservation objectives can be developed when keeping in mind what is known about pathogens and how they move and persist on the farm. Resource assessment and risk analysis are integral to farm planning. For optimum management, multiple barriers (blockades) reduce the number of pathogens transported in and around the farm environment. The multiple-barrier approach focuses on preventing pathogens from (a) entering the farm, (b) contaminating the crop, (c) spreading from livestock operations to the crop, and (d) moving out to the wider landscape where they may lead to contamination. If one barrier fails, others prevent contamination of crops and water supplies. Many of the barriers mentioned below in Tables 5—8 are also depicted in Figure 2.

Some of the management suggestions presented here, such as the value of composting to reduce pathogens, are based on benefits observed in well-controlled research. Other insights come from the underlying understanding of functions known to affect pathogen fate and transport. For example, UV radiation can cause pathogen inactivation; therefore, practices that encourage the exposure of pathogens to sunlight and UV radiation may aid in reducing pathogen populations. It is understandable that growers must consider market factors when making co-management decisions. What works for a grower with one marketing outlet and a given set of regulatory pressures may not be acceptable to a grower in another set of circumstances.

6.1 Barriers That Intercept Pathogens at the Farm's Border

NRCS Conservation Practice Standards (CPS) and Good Agricultural Practices (GAPs) as shown in Table 5 are barriers that filter or divert contaminated water, intercept fugitive dust and help control non-native wildlife at the farm's perimeter. While the CPS in the table are explained here and in the text of the three subsequent tables, GAPs are more fully described since CPS were covered in Section 5.

Table 5: Barriers That Intercept Pathogens at the Farm's Border

NRCS CPS/ GAP	*CPS Code(s)/ GAP*	*# in Fig. 2*
I. Intercepting Waterborne Pathogen		
Conservation Cover	327	24
Critical Area Planting	342	
Diversion	362	3
Filter Strip	393	
Tree and Shrub Establishment	612	
Wetlands	656-659	5
II. Intercepting Particulate Matter with Pathogens		
Hedgerow	422	10
Windbreak	380	8
III. Discouraging Non-Native Feral Animals		
Deterring Feral Animals	GAP	
IPM	595	17

I. Intercepting Waterborne Pathogens

Vegetative buffer strips, diversions, and wetlands can be important management tools for intercepting waterborne pathogens at the farm's border. These conservation practices typically address runoff and flooding from livestock and wildlife waste, manured lands and manure stockpiles.

II. Intercepting Particulate Matter with Pathogens

Windbreaks and hedgerows placed along the farm's perimeter can intercept fugitive dust with pathogens blowing in from surrounding areas. This may be especially important when livestock are concentrated and manure is ground into the dust.

J.A. Baumgartner

Hawks and other birds of prey can help to frighten away pest birds, as well as reduce rodent populations.

III. Discouraging Non-Native Feral Animals

Deterring Feral Animals

Wildlife on the farm is inevitable, and in some cases desired. However, excluding non-native invasive animal species from the farm is good for conservation as well as for food safety. Non-native invasive species are the second major reason for biodiversity losses worldwide, and they sometimes carry pathogens. Controlling invasive species populations not only reduces potential food safety risks, but also opens up space for native species to thrive. Various non-toxic Integrated Pest Management (IPM) strategies exist for controlling populations of European starlings, house sparrows, rock pigeons, and Norway rats. Hawks and other birds of prey frighten away pest birds. Supporting healthy populations of predatory birds by installing perches and nesting boxes at the farm's border, or hiring falconers to visit the farm, can help disperse pest birds. Food safety GAPs recommend that nest boxes and perches be placed in locations that will not pose a food safety liability from bird droppings or leavings. Installing noisemakers and scare balloons may also frighten birds away. Placing food attractants in non-production edges of a farm may aid in keeping pests away from production fields.

Food safety GAPs recommend controlling rodent populations. Attracting raptors as mentioned above, as well as supporting healthy populations of terrestrial predatory wildlife, can help reduce the rodents. Removing features that attract rodents—brush piles, cull piles, puddles of standing water, and stacks of irrigation pipe—will also help. Installing vegetative cover to replace weedy annuals abundant with seeds that rodents may prefer can discourage these animals. The use of traps instead of poison baits near drainages and waterways will prevent water pollution.

Non-native feral pigs may present particularly challenging intrusion problems. Seeking out high-quality or favored food sources across broad territories, feral pigs may cause extensive damage by feeding on or trampling crops. They may also contaminate produce with their fecal matter. Food safety GAPs recommend trapping, hunting, or fencing feral pigs after obtaining proper permits. Temporary electrical fencing may dissuade less determined pigs, while short hog-wire fencing may be required in an area with a high population density. For added protection, running an electrified wire on the outside of the hog-wire fence, approximately 6 to 8 inches above the ground, may improve the fence's effectiveness. Feral pigs may travel up to 6 miles to reach a desirable forage opportunity. Close observation of movement patterns may help growers recognize food sources that attract feral pigs, allowing for efficient and effective fence placement.

6.2 Barriers That Reduce Likelihood of Pathogens Contaminating Produce

As shown in Table 6, there are many types of Conservation Practice Standards (CPS), conservation-related FDA Produce Rule requirements (FDA) and food safety Good Agricultural Practices (GAPs) that help to reduce the possibility of crops becoming contaminated.

Table 6: Barriers That Reduce the Likelihood of Pathogens Contaminating Produce

NRCS CPS/GAP	*CPS Code(s)/ GAP*	*# in Fig. 2*
I. Choosing Appropriate Sites		
Avoiding Nearby Contamination	GAP	22
Avoiding Frequently Flooded Land or Instituting a Waiting Period After Flooding	GAP	7
Planting Crops for Livestock	GAP	
Planting Fresh-cut Leafy Greens Away from Eroding and Sensitive Areas	GAP	
Avoiding Overhanging Vegetation	GAP	20
Avoiding Areas with Abundant Wildlife	GAP	21

I. Choosing Appropriate Sites

Avoiding Nearby Contamination

Food safety GAPs recommend that land use history and environmental risk factors be considered before planting a crop. Areas near chicken pasture operations, sites adjacent to grazing livestock (including small numbers of horses, goats, or other non-working farm animals), and high-impact areas near troughs or water sources may require special consideration for risk mitigation. Fields next to large concentrated feeding operations present a higher risk because of the amount of manure and increased soil compaction that results in higher runoff rates. Increased risk may also occur near landfills, manure storage sites, and exposed compost facilities. The degree of risk depends on the proximity of the crops to the high-risk site, slope and direction of water flow, wind patterns, and environmental loading rate (if any) for pathogens. Large numbers of birds or insects moving from contaminated areas into cropped areas also increase risk of pathogen contamination.

Avoiding Frequently Flooded Land or Instituting a Waiting Period After Flooding

Lands that flood are often considered a higher food safety risk than areas not susceptible to flooding. Food Safety GAPs recommend that the flooded ground undergo a waiting period before it is considered safe for replanting. Risk from deposited sediment as well as saturation with waters of unknown quality are difficult to predict. FDA guidance, as well as many buyer guidances, cautions the use of flooded land without an adequate waiting period. Continual flooding may lead to lost productivity if an area must remain out of production for an extended period of time.

Planting Crops for Livestock

Farms that grow both produce and animal feed can benefit from their operation's diversity by planting crops destined for livestock in areas of higher risk for pathogen contamination. For example, a grower who plans to plant hay or feed corn as well as produce will plant the livestock feed rather than fresh-cut leafy greens next to a neighbor's cattle pasture. Choosing the location with the lowest risk of contamination can be an effective risk management strategy when growing produce that will be eaten raw by consumers.

Planting Fresh-cut Leafy Greens Away from Eroding and Sensitive Areas

Produce buyers often perceive non-crop vegetation that may attract wildlife on the farm as a serious food safety threat. However, in many cases, conservation practices and natural habitat may actually help keep wildlife out of crop fields by providing an area of preferred food and shelter. Despite this, many buyers still require that produce, especially fresh-cut crops such as salad mix, be separated from

vegetative conservation practices and natural areas by bare-ground buffers, which incentivizes the removal of all non-crop vegetation. These requirements may pose significant challenges for on-farm conservation. The lack of non-crop vegetation in erosion-prone areas and along waterways with heavy nutrient and pesticide loading can cause significant impacts to the watershed. In some cases, configuring the crop fields so that roads serve as bare-ground buffers between crops and the conservation practice may satisfy food safety concerns. When markets demand the absence of conservation areas, planting the crop away from eroding and sensitive sites may alleviate some of the adverse impacts on soil, water, and wildlife resources.

Avoiding Overhanging Vegetation

Food safety GAPs recommend minimizing the risk of birds above row crops by reducing the likelihood that they will perch, roost, or feed in areas where their feces will fall on crops. Conservation practices that include trees, shrubs, or other vegetation may inadvertently attract and/or create perch areas for birds, thereby increasing the risk that birds will defecate into irrigation canals or on the crops below. Risk of fecal contamination can be reduced by not planting (or harvesting) crops directly under established vegetation. Mechanically harvested crops, such as baby spinach and spring mix, may also need to avoid physical hazards (i.e., acorns, stems) that could be included in the bagged product. Selecting conservation plants that have an upright instead of branching growth form can help minimize the loss of adjacent production area. Installing large branching trees and fruit bearing plants attractive to birds a distance away from produce is another strategy to allow growers to balance conservation objectives with food safety risk management. Without non-crop vegetation, wild birds have been known to perch on anything they can find, including irrigation sprinklers positioned directly above the crop.

Avoiding Areas with Abundant Wildlife

Because wildlife is frequently drawn to vegetation and water, its presence in the farm landscape may create co-management challenges. Understanding how animals use these features, as well as how they move between conservation areas and crops, will help with co-management. Animal intrusion into crop fields can be significantly reduced by taking wildlife movement patterns into account when planning crop-planting locations. Avoiding disruption of wildlife corridors allows animals to travel to needed resources without having to traverse crop fields. Avoiding locations with nearby frog habitat reduces entry of frogs into fields. This is especially important with certain crops, such as fresh-cut leafy greens, that are machine-harvested using blades that are close to the ground and are not as careful at avoiding small animals as with hand-harvests.

J.A. Baumgartner

Taking wildlife movement patterns into account when delineating fields reduces the need for wildlife to traverse through crops.

II. Preventing Pathogens from Coming in Contact with Crops:

Table 6 (continued)		
NRCS CPS/FDA/GAP	***CPS Code(s)/ FDA/ GAP***	***# in Fig. 2***
II. Preventing Pathogens from Coming in Contact with Crops		
a. Reducing Pathogens Through Animal Management		
Monitoring Animal Intrusion in the Crop	FDA	9
Harvesting the Crop	FDA	
Deterring Wildlife	GAP	
IPM	595	17
b. Reducing Pathogens Through Water and Particulate Matter Management		
Sediment Basin	350	12
Diversion	362	3
Field Border	386	19
Grassed Waterway	412	
Hedgerows	422	10
Windbreak	380	8
Vegetative Barrier	601	
Ensuring Adequate Water Quality	FDA	
Irrigation Water Management	449	11
c. Reducing Pathogens Through Soil Management		
Nutrient Management	590	
Waiting Between Manure Application and Next Harvest	GAP	
Applying Manure and Compost Near the Crop	FDA	
Using Compost	FDA	
Compost Facility	317	23
Cover Crops	340	16
Conservation Crop Rotation	328	
Managing Contaminated Crop Sites	GAP	
Fostering Pathogen Desiccation in Soils and Sediment in Basins	GAP	12

a. Reducing Pathogens Through Animal Management

<u>*Monitoring Animal Intrusion in the Crop*</u>

FDA requires monitoring raw agricultural commodities during the growing season for significant evidence of potential contamination by domesticated and wild animals. Observation of significant numbers of animals, significant amounts of animal feces or significant crop destruction, determines how much of the crop can be harvested (FDA Produce Rule § 112.83). Animal tracks, signs of feeding, and downed fencing all signal that animals have passed through. Monitoring the crop itself for these signs and responding help prevent or minimize potential crop contamination. Monitoring adjacent habitat is unnecessary since signs found there, are not an indication that animals are entering the crop. Many factors play into determining appropriate actions to reduce food safety risks to the crop, including how long and with what frequency they enter the crop (Are they rushing through and eating a little or staying awhile and eating a lot? Has their presence been noted once or several times?); the purpose of their visit (Are they there because of food? Is this a movement corridor to water or food, including other crops or prey? Do they live next to the crop?); and when they are seen in relation to crop production schedules (Were they just seen before planting or did they appear right before harvest?). Monitoring may be especially important when factors such as drought or post-fire conditions lead to increased animal movement into crops.

FDA requires growers to use identifying measures where contamination of raw agricultural commodities occurs during the growing season so that later during harvest, that part of the crop is excluded (FDA Produce Rules § 112.83 and §112.112). Food safety GAPs recommend placing a no-harvest buffer around any contamination source in the field. No-harvest buffers are commonly established in operations, including those under the Leafy Green Marketing Agreement. Farm employees walk the fields and mark animal tracks and evidence of feeding or trampling, with the assumption that fecal contamination may be present but undetectable without extensive testing. Sometimes bare-ground buffers are used for easy monitoring of wildlife tracks, although these areas

may be preferred passageways by some kinds of wildlife, and as mentioned above, there are natural resources concerns such as increased erosion associated with their use. It is common practice to use wire field flags of a specified color to mark off the no-harvest area, so workers harvesting the crop can easily identify them. The area of the buffer depends on many factors, such as whether feces landed nearby or contacted the crop, the size and type of the feces, whether rain or irrigation water has created a splash zone, and whether the harvestable portion of the crop grows close to the soil. Some GAPs recommend flagging a 5-foot radius around the contaminated area.

Harvesting the Crop

FDA requires growers conduct a visual assessment for contamination immediately prior to and during harvest of raw agricultural commodities (FDA Produce Rule § 112.112). For crops such as tree fruit and bush berries that do not have the harvestable portion close to the ground, FDA requires that fruit with bird or other animal damage, or fruit on the ground, not be harvested (FDA Produce Rule § 112.114).

Deterring Wildlife

If monitoring detects significant wildlife intrusion in the crop, actions will need to be taken. Many of the same non-toxic Integrated Pest Management (IPM) strategies used on non-native feral animals can be used for native wildlife. In addition, silt fencing may deter some types of small native wildlife such as ground squirrels and rabbits, which typically do not climb or enter something they cannot see over or through. Sprinklers activated by motion detectors, flashing red lights sensed as eyes, and judicious use of fencing may keep out larger wildlife. If fencing is deemed necessary, it should avoid obstructing wildlife corridors as much as possible, or should be placed around the crop fields rather than around the whole farm.

Frogs may present challenges for growers producing loose-headed lettuce or machine-harvested tender greens and tender-leaf culinary herbs. Some buyers suggest silt fencing around the perimeter of the crop to dissuade frog entry, but this strategy does not appear effective for fields immediately adjacent to water. As mentioned above, locating those crops away from frog habitat may reduce seasonal frog intrusion. Some growers use copper sulfate to eliminate tadpoles in water bodies, and even though it is typically used at low application rates to control algae growth in water bodies, it is not labeled as an amphibian control product. Amphibians are in decline worldwide due to a multitude of challenges.

USDA NRCS

FDA Produce Rule requires that irrigation water meet specified water quality standards for raw agricultural commodities.

b. Reducing Pathogens Through Water and Particulate Matter Management

Vegetative practices both within the farm and on the farm's border can function as valuable barriers in protecting crops from waterborne and airborne contamination. On slopes that receive fresh applications of manure, vegetative terraces can reduce the runoff of contaminated water by allowing water to pond and infiltrate the soil. Diversions can catch and redirect the water away from the crop. Contaminated runoff flowing through grassed waterways may be filtered by the vegetation, and captured by sediment basins. Vegetative buffer strips adjacent to fields can intercept waterborne pathogens. Taller conservation plantings can intercept fugitive dust from compost and manure storage areas. Taking into account topography and prevailing wind patterns can help determine optimal placement of vegetation.

Ensuring Adequate Water Quality

FDA has a strict requirement that no generic *E. coli* be present in water for certain uses, such as when it is applied during or after the harvest. However, FDA's requirement for irrigation water that touches raw agricultural commodities during their growth is less strict. The frequency of generic *E. coli* testing depends upon whether surface or groundwater is used for irrigation. Treatment may be determined necessary, depending on the results. Growers using public water systems need to obtain records that the water is safe (FDA Produce Rules § 112.43 – § 112.46).

Streams, ponds, and basins that are managed to encourage clear water may allow more UV penetration, which may reduce pathogens. Maintaining low turbidity conditions may be important in areas with high pathogen inputs, such as locations where animals may contaminate water bodies. Low turbidity has the additional benefit of lessening the sediment load that could extend pathogen survival. Wildlife drinking from clean water sources will not pick up pathogens to spread later. Conservation planners can help growers with irrigation management to produce less runoff. They can also help develop a well-balanced nutrient management plan to reduce nutrient loads in drainage water systems. Together these management strategies decrease sediments and algae growth, which may support pathogen survival.

c. Reducing Pathogens Through Soil Management

Waiting Between Manure Application and Next Harvest

While incorporating manure and other biological soil amendments containing pathogens in agricultural soils provides valuable fertility input, they may also present contamination risk. Food safety GAPs recommend and the USDA National Organic Program requires a waiting period between manure application and the next harvest to give the soil's indigenous microbial community time to inactivate pathogens. At this time, FDA does not require a waiting period, but they plan to in future after detailed research is conducted. Nutrient management strategies that reduce the risk of using manure include managing the amount, incorporating it quickly and thoroughly, and timing applications based on season and predicted rainfall or high winds.

Applying Manure and Compost Near the Crop

FDA has a strict requirement that raw manure be applied in a manner that does not contact raw agricultural commodities during application, and minimizes the potential for contact after application. However, the agency only requires that compost be applied in a manner that minimizes the potential for contact during and after application (FDA Produce Rule § 112.56).

Using Compost

FDA requires that aerobic conditions are fostered in compost and that it heats up to a minimum temperature during production (FDA Produce Rule § 112.54). When compost is made on the farm, specified composting procedures should be followed and documented. When purchased from a supplier, the compost should come with a certificate guaranteeing that process used is scientifically valid (FDA Produce Rule § 112.60). The use of the compost facility practice can help to keep the raw manure feedstuff, and the compost itself, from polluting air and water resources.

Composted manure is an excellent alternative to raw manure. To ensure that it heats up correctly, compost should have adequate moisture, a proper carbon to nitrogen ratio, and regular turning if not managed as a static pile. During the heating process, high temperatures must be reached to reduce pathogens, but the compost should not get so hot that it kills off the compost's indigenous microbial community. This community helps to mitigate the growth of pathogens, should they be reintroduced. Adding compost to soil also supports soil conditions favorable for microbial populations, which in turn keep pathogen populations in check.

Manure is considered a riskier compost feedstock, given that it is likely to contain pathogens. Non-manure compost feedstocks, such as green waste, may be less likely to contain pathogens. Caution should still be used, as it is possible for green waste to become contaminated with fecal material. Green waste may also contain other types of hazards, such as broken glass or heavy metals.

Some produce buyers will not purchase crops grown on fields amended with raw manure. California's Leafy Green Marketing Agreement suggests a one-year waiting period between application of soil amendments with raw manure and the next crop. In these cases, growers may need to use non-manure-based soil fertility practices, such as nitrogen-fixing cover crops and non-manure-based composts.

Events that might introduce pathogens into a field include grazing, applying raw manure, spreading dredged sediments, flooding, or extensive fecal contamination by intruding animals. Planting cover crops after a contamination event allows for a longer waiting period between the contamination and the harvest of the next crop, giving more time for pathogen inactivation. This is especially important for higher risk crops such as fresh-cut leafy greens. A rotation of a low-risk crop (crops typically cooked or pasteurized before they are eaten) can also lengthen the time for pathogen die off. Cover crops and crop rotations limit the movement of pathogens in runoff water. Like compost, cover crops and rotations with high-residue crops increase soil organic matter and support robust soil microbial communities that may selectively exclude pathogens through predation, antagonism, and competition.

Managing Contaminated Crop Sites

When a large section of a crop is contaminated (e.g., through flooding or feces from a herd of feral pigs), it may be necessary to destroy that part unharvested. Since research suggests that pathogens may survive in the soil environment for an extended length of time following the incorporation of crop residues, mowing or undercutting the crop and allowing for desiccation of the plant material prior to disking and incorporation may allow for a reduction of pathogens. When a small amount of feces is found in the crop, after being cordoned off, as mentioned above, the feces is removed and disposed of out of the field or it is buried deeply.

Fostering Pathogen Desiccation in Soils and Sediment in Basins

Desiccation of pathogens contained in or on soil is a process that lends itself to management control. Allowing a crop field to fallow during the warm part of the year to dry out soils can reduce pathogen viability. Likewise, allowing sediment basins to dry as completely as possible provides pathogen control benefits. The design of a sediment basin can help drop sediments out of the water before they reach the main basin/pond. Designs that include a runway with a slight elevation decrease that is periodically cleaned out can have this effect. Trapping sediments in the runway makes them more susceptible to desiccation than if they fall out in the main basin. It also reduces sediment loads in the larger body of water. Although inactivation of pathogens may be hastened by drying periods, finer textured clay may retain sufficient water to support pathogen survival and may require more management to mitigate potential risk. Short intervals of wet/dry cycling may accelerate pathogen reduction in some soils.

In situations where produce buyers will not purchase crops grown near non-crop vegetation because of the perceived threat of wildlife as significant food safety risks, water quality and soil erosion are concerns. The use of sediment retention basins to capture sediment and other contaminants before water is discharged to waterways can mitigate where significant areas of soil are bare. Since sediment basins themselves may be perceived to attract wildlife, developing an understanding of wildlife movement patterns around the site, and choosing vegetation to deter animal presence, can help. Depending on the wildlife present in the area, short vegetation in the sediment basin tends to dissuade mice, while tall vegetation tends to deter geese.

6.3 Barriers That Reduce Spreading Pathogens to Produce When Livestock Are on the Farm

The barriers shown in Table 7 can help to decrease the spread of pathogens to crops in diverse farm production systems that raise both crops and livestock.

Table 7: Barriers That Reduce Spreading Pathogens to Produce When Livestock Are on the Farm

NRCS CPS/GAP	*CPS Code(s)/ FDA/ GAP*	*# in Fig. 2*
I. Livestock in and Near Production Areas		
Avoiding Contamination	GAP	
Prescribed Grazing	528	25
Waiting Between Fecal Deposits and Next Harvest	GAP	
Managing Working Animals	FDA	
II. Decreasing Pathogens Through Air and Water Management		
Air Filtration and Scrubbing	371	
Dust Control from Animals	375	2
Diversion	362	3
Waste Storage Pond	313	4
Ensuring Adequate Water Quality	FDA	
Hedgerows	422	10
Windbreak	380	8
III. Restricting Wild and Feral Animal Movement Between Livestock Areas and Crops		
Controlling Animals	GAP	
IPM	595	17

I. Livestock in and Near Production Areas

Avoiding Contamination

Placing food and water sources, as well as other features around which livestock generally congregate, away from produce fields may help reduce the proximity of potential contamination sources to crop boundaries. Prescribed grazing can optimize infiltration and reduce runoff of water that may contain pathogens.

Waiting Between Fecal Deposits and the Next Crop

Animals that have access to crop production areas—livestock included as part of a pasture/crop rotation schedule or allowed to graze crop residues prior to the next planting—provide nutrients for crops while receiving sustenance. FDA Produce Rule recommends, but does not require, a waiting period between fecal deposits and the harvest of the next crop, given that pathogen reduction in the soil takes time.

Managing Working Animals

FDA requires that when animals are part of the operation, such as growers using animal traction, guard dogs or weeder geese, standard risk assessment and management practices be developed to control contamination risk of the raw agricultural commodity and water sources (FDA Produce Rule § 112.134). These may include ensuring that no feces are deposited in the crop field after the crop has been planted, keeping animals distant from the crop, and avoiding moving animals through a production area close to harvest time.

II. Decreasing Pathogens Through Air and Water Management

When animals are confined in an area for any length of time, practices can be used to reduce fugitive dust and runoff containing pathogens.

Ensuring Adequate Water Quality

FDA does not allow water from an animal waste storage pond be used to irrigate raw agricultural commodities (FDA Produce Rule § 112.42). This water is best used on crops grown for livestock.

III. Restricting Wild and Feral Animal Movement Between Livestock Areas and Crops

Controlling Animals

Animals that feed on livestock manure, or on the insects and seed found in it, may pick up pathogens. For this reason, food safety GAPs recommend that measures be taken to reduce the presence of these animals with access to produce fields. This recommendation also assumes that animal control measures will take place only after obtaining any local, state, or federal environmental permits. IPM and other practices mentioned previously can be used to ensure that certain species of birds, rats, or feral pigs do not serve as mechanical vectors, tracking fecal matter from livestock feces, bedding, food, or water sources to crops or farm equipment. Tracking movement patterns and behavior of these animals can help land managers assess risk. Birds that are attracted in large numbers to a livestock operation for feed and water, who then perch on irrigation sprinklers or the crop itself, present a risk that must be managed.

6.4 Barriers That Prevent Pathogens from Leaving the Farm

In Table 8, the conservation practices shown can help to restrict pathogens from moving off the farm.

Table 8: Barriers That Prevent Pathogens from Leaving the Farm

NRCS CPS	*CPS Code(s)*	*# in Fig. 2*
I. Intercepting Waterborne Pathogens		
Filter Strip	393	
Riparian Forest Buffer	391	6
Riparian Herbaceous Buffer	390	
Sediment Basin	350	12
Wetlands	656-659	5

I. Intercepting Waterborne Pathogens

Many of the conservation practices that reduce the movement of pathogens onto the farm or into produce fields can also be used to ensure that pathogens don't leave the farm to contaminate the larger landscape. Just as a wetland high up in the watershed can help to clean water before it reaches the farm, one may also help to treat runoff before it leaves the farm to possibly contaminate surface waters downstream. Sediment basins may function as one of the last barriers to capture pathogens in runoff on a farm that is not on a waterway, and riparian buffers make the last stand at reducing pathogens from entering streams. In this way, pathogen contamination risk reduction is practiced throughout produce production systems.

USDA NRCS

Riparian buffers aid in reducing pathogens from entering waterways.

7: Converting Co-Management Knowledge to Action

7.1 Produce Food Safety Plans and Audits

It has become common practice for buyers to request food safety plans from the farms where they purchase produce. A food safety plan is the documentation and rationale of the management strategies a farm will take to address food safety risks. Major elements of any farm food safety plan include the personal hygiene of people on the farm, water purity and testing, use of soil amendments, land use history, neighboring issues, wild and domestic animals, and harvest. Food safety plans aid growers in proactively identifying and addressing food safety concerns to avoid making anyone sick. Food safety plans are recommended, but not required by the FDA Produce Rule.

Using the multiple barriers approach, conservation practices and GAPs are identified to address food safety risk on the farm and then translated into actions in the food safety plan—for instance, installing a diversion to redirect pathogen-laden water running off a livestock area so it does not contaminate a crop field, monitoring the diversion periodically, and taking corrective actions when necessary. These steps, along with the rationale that supports them, are written down in the food safety plan.

Many buyers also require a third-party food safety audit done either by a specific food safety auditor or by one chosen by the grower. If a grower sells to certain handlers, such as those in the Leafy Green Marketing Agreement, a third-party audit conducted by a specific government agency can be mandatory. The USDA Agricultural Marketing Service (AMS) offers food safety audits, as do some states. Many private auditing companies exist as well. Each auditing entity usually has a very specific checklist of GAPs and makes general observations. The purpose of the auditor's visit is to verify that the risk mitigation steps identified in the food safety plan are actually taken. Growers who fail to address mitigation steps or the record keeping identified in the plan lose points during the audit, resulting in mandated corrective actions. Losing too many points or having a critical major non-compliance will result in a failed audit.

The USDA AMS food safety audit, Harmonized GAPs (United Fresh Produce Association), and several other audit programs do not deduct points for the presence of non-crop vegetation near produce fields. However, the auditors of some food safety buyers will not allow a crop to be located near non-crop vegetation because of the perceived threat of wildlife intrusion. These buyers do not understand or do not accept current evidence about how conservation practices may help reduce food safety concerns. Growers can effectively advocate for their farming practices with food safety auditors by using risk assessment strategies outlined in the multiple-barrier approach and by explaining their rationale for management decisions that address those risks.

Conservation planners can assist growers by providing them with records of conservation practices that they helped plan or install. These records are documentation of expert conservation actions and do not constitute recommendations for food safety compliance by conservationists. Records can be kept with their food safety plans to show to their produce buyers, who in turn specify the acceptable audit scheme.

In addition to records, growers can provide their auditors with co-management training scenarios developed specifically for food safety auditors. These scenarios help

S. Earnshaw

Conservation planners can give growers records of conservation practices, such as a hedgerow or windbreak, so they can include them in their food safety plan.

explain how conservation practices work to address food safety concerns on farms or give examples of how auditors could respond to different risk situations. Two resources available are: The University of California's *Introduction to Auditor Resource Materials*, and Wild Farm Alliance's *Training Scenarios for USDA and Third Party Auditors on the Co-Management of Food Safety and Conservation as Well as Small- and Mid-Size Farm Concerns*. The latter publication offers USDA auditors continuing education units since many of them are not familiar with co-management concepts. These materials help growers address food safety without sacrificing responsible on-farm conservation measures.

7.2 Top Co-Management Concerns

In the preamble to FDA's Produce Rule, FDA states "We continue to encourage the co-management of food safety, conservation, and environmental protection." Fostering public health is nothing new for conservation. Protecting natural resources and providing clean air and water thereby supports public health objectives. What has changed is the national focus on food safety and the perceived conflicts between wildlife habitat and food safety requirements.

Awareness, understanding, and management of on-farm food safety concerns in conjunction with conservation practices are evolving. Some buyers and food safety auditors who would formerly reject crops near conservation practices are now learning more about the value of conservation. Resource planners who assist growers in managing conservation practices with food safety in mind, and the growers themselves, are helping to change that, but challenges still remain. While the food safety and conservation co-management strategies detailed in this document focus on pathogen reduction measures, not complete elimination strategies, they help growers reduce the risk of pathogen contamination in their produce.

Fundamental Co-Management Steps to Be Taken for Produce

Grower:

1. Strategically selects crop and field location.
2. Monitors for wild and domestic animals in crop field.

Conservationist assists grower in developing a plan for:

3. Reducing pathogens through water management.
4. Decreasing fugitive dust with pathogens through particulate matter management.
5. Diminishing pathogens through soil and manure management.
6. Lessening contamination through animal management.

Grower:

7. Determines what other requirements need to be implemented, such as further controlling wildlife and domestic animals, ensuring manure applications don't touch the crop, and water testing.
8. Develops a food safety plan that incorporates co-management of food safety and conservation practices and actions.

The overwhelming majority of food-borne illnesses do not originate on the farm, but rather from any one of many sources or points along the supply-chain from farm to food preparation. This handbook provides an understanding of the fate and transport of food-borne pathogens and offers a systematic way to check for and address possible on-farm food safety concerns related to conservation. There is still much unknown in terms of looking at food safety from a reductionist perspective of single factors to seeing it from a holistic one. In general it is understood that conservation plays a vital role in farm production, food safety, and ecosystem functions. Farms that grow produce can manage for food safety and conservation without compromising natural resources.

Appendix I: Pathogens of Concern

Enteric bacteria naturally live in the healthy gut of animals and people and are necessary for good digestive health. Some enteric bacteria are pathogenic and if ingested may lead to gastrointestinal illness and, in some extreme cases, to life changing or fatal medical complications. This appendix focuses on four such bacteria—Shiga toxin-producing *Escherichia coli* (STEC), *Salmonella*, *Campylobacter*, and *Listeria* species—and a protozoan, *Cryptosporidium* species, which may also lead to severe gastrointestinal illness. These pathogenic bacteria are most likely to contaminate U.S. produce from non-human sources (i.e., animals, water, soil, air). While the protozoan does not cause as many food-borne illnesses, it was included because of its unique survival strategy. The discussion that follows focuses on understanding attributes of each pathogen that may influence its fate and transport in the growing environment.

Escherichia coli species are present in the healthy animal gut and are frequently used as an indicator species to determine if fecal contamination has occurred. There are several types of pathogenic *E. coli*, among them Shiga toxin-producing *E. coli,* which may lead to severe and life-threatening Hemolytic-Uremic Syndrome (HUS), a disorder that occurs when the infection produces Shiga toxins that destroy red blood cells, causing kidney damage. Depending on the specific clinical symptoms of a patient's illness, an infectious pathogenic *E. coli* may be classified as a subset of Shiga toxin-producing *E. coli*—namely Enterohemorrhagic *E. coli* (EHEC). Other pathotoxigenic *E. coli* that do not cause HUS may also pose a serious risk to human health.

Among the Shiga toxin-producing *E. coli*, *E. coli* O157:H7 is a frequently identified strain in ill patients in the United States. However, numerous other strains may also be of human health concern and have been implicated in large outbreaks. Discussion of Shiga toxin-producing *E. coli* in this document is based on research that is predominantly focused on *E. coli* O157:H7, as this is the most frequently studied strain in the United States. Different strains of pathogenic organisms have been found to persist and behave differently both in the host and in the environment, so it is important to realize that more than one Shiga toxin-producing *E. coli* exists and all have unique characteristics that impact their virulence, survival, and multiplication.

Survival Outside the Host

Shiga toxin-producing *E. coli*, *Salmonella*, *Campylobactor*, and *Listeria* bacteria are well adapted to survive in the moist, anaerobic intestinal environments of their hosts, but all may survive outside their host as well. The protozoan parasite *Cryptosporidium* is likewise capable of surviving outside a host, and in fact may persist longer due to its ability to form an oocyst, a thick-walled spore that may survive for long periods of time. The oocyst may resist damage from environmental stressors such as desiccation, freezing, and scarce nutrient supplies more readily than bacterial cells. Survival times for pathogenic organisms outside of the host are highly variable and subject to environmental conditions as well as to specific characteristics of the pathogen.

Variable Expression of Traits

Several pathogens of human health concern have the ability to express a range of traits related to motility, virulence, and toxin production, among other factors. This variability impacts both direct human health risk and risk associated with pathogen survival outside of the host. For example, *Listeria monocytogenes* commonly occurs in the soil as saprophytic bacteria in decaying organic matter. When presented with certain environmental stressors, certain forms of *L. monocytogenes* may express varying traits influencing virulence, from wide-spread soil bacteria posing little human health concern to

pathogenic bacteria capable of causing serious illness or death. *L. monocytogenes* can resist desiccation and grow in a wide range of temperatures and adverse conditions. *E. coli* bacteria also have a range of virulence factors that may or may not be active, leading to challenges in identifying risk presented by strains of the bacteria identified in the environment. For example, *E. coli* may carry but not express the genetic code to produce Shiga toxins.

Resistance to Antimicrobials

Antimicrobial resistance of pathogens is a human health concern because it is not only found in livestock and in soils with manure, but has also spread to wildlife. This resistance can be transferred among many types of soil microbes and can increase the risk of *E. coli*, *Salmonella*, and other bacteria with low virulence traits becoming a health hazard. Antimicrobial resistance makes any illness more difficult to treat. People with compromised immune systems, such as the young and the elderly, are particularly vulnerable. The Centers for Disease Control and Prevention (CDC), U.S. Food and Drug Administration (FDA), and World Health Organization (WHO) have recognized that human health and economic implications of resistance vary widely depending on antibiotics and pathogens of concern, and have concluded that feeding certain antibiotics to livestock for production purposes, to promote growth or increase feed efficiency, poses a public health problem.

Tables 9—13 give basic information about the pathogens considered in this document, including information about why each is considered important in food safety risk assessment in produce.

Table 9: Pathogen Basics—Bacteria—Shiga toxin-producing *Escherichia coli*

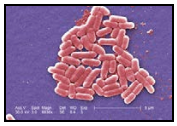
Photo/ Description	Forms of Most Concern for Human Health	Foods Associated with Illness	Additional Information
 J. Haney Carr, CDC Rod-shaped, non–spore-forming gram-negative bacteria, facultative anaerobe	Common serotypes include O157, O26, O111, O103, O121, O145, and O45.	Commonly associated with beef, raw milk, and cheese; CDC recorded outbreaks in the following produce: sprouts, leafy greens, hazelnuts, fresh spinach, apples, and grapes.	**Additional information:** ➢ Documented to survive freezing temperatures in soil. ➢ Survives better in sand, sediments, and soil than in water, but is relatively well adapted to survive in water (compared to other enteric pathogens). ➢ Appears to be less sensitive to UV radiation inactivation than *Campylobacter* or *Salmonella.* ➢ May survive and amplify outside the host.

Table 10: Pathogen Basics—Bacteria—*Salmonella* spp.

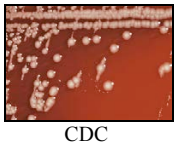
Photo/ Description	Forms of Most Concern for Human Health	Foods Associated with Illness	Additional Information
 CDC Rod-shaped, non–spore-forming gram-negative bacteria, facultative anaerobe	*Salmonella enterica* subsp. *enterica, found in* "warm-blooded" animals, is the most common cause of food-borne illness in the United States. While "cold-blooded" animals carry different types of *Salmonella*, all must be considered dangerous.	Commonly associated with chicken, eggs, and domestic turkey; CDC recorded outbreaks in the following produce: peanut products, sprouts, cantaloupes, peppers, pine nuts, pistachios, mangoes, tomatoes, potatoes, onions, watermelons, leafy greens, blueberries.	➢ Widespread in the environment. At least some serotypes appear to be more resistant to environmental stressors and can resist inactivation by desiccation, starvation, freezing, and UV radiation better than some other pathogenic bacteria. ➢ Appears to be intermediate in its sensitivity to UV radiation in aquatic environments (more sensitive than *E. coli* but less sensitive than *Campylobacter*). ➢ Research indicates apparent ability to colonize plant surfaces. ➢ May survive and amplify outside the host.

Table 11: Pathogen Basics—Bacteria—*Campylobacter* spp.

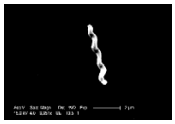
Photo/ Description	Forms of Most Concern for Human Health	Foods Associated with Illness	Additional Information
 J. Haney Carr, CDC Spiral-shaped gram-negative bacteria, micro-aerophilic facultative anaerobe	*Campylobacter jejuni* Many animals are susceptible to the infection of other *Campylobacter* subspecies, some of which are not typically found in human patients.	Chicken and other fowl are the most frequent source of contamination. Human illness most likely as sporadic cases (not outbreaks) leading epidemiologists to theorize that cases may be caused by cross contamination of produce with raw meat during meal preparation. CDC recorded outbreaks for the following produce: leafy greens, root vegetable (unspecified), and tomatoes.	➢ Thermophilic organism with limited growth below approximately 30° C (86° F), though it may survive longer at lower temperatures (< 10° C; 50° F). May be damaged by freezing temperatures. ➢ Fairly vulnerable to inactivation by a range of environmental stressors; tends to be less persistent than *E. coli* O157:H7, *Salmonella* spp., *Listeria* spp., or *Cryptosporidium* spp. outside of the host. ➢ Appears to be highly vulnerable to inactivation via UV radiation. ➢ Protozoa may internalize *Campylobacter* and extend survival. ➢ Does not appear to amplify outside the host.

Table 12: Pathogen Basics—Bacteria—*Listeria* spp.			
Photo/ Description	**Forms of Most Concern for Human Health**	**Foods Associated with Illness**	**Additional Information**
 CDC Rod-shaped, non–spore-forming gram-positive bacteria, micro-aerophilic facultative anaerobe	*Listeria monocytogenes*	Commonly associated with turkey, processed meats, soft cheeses, raw milk and products made from it. CDC multi-state recorded outbreak for cantaloupe.	➢ Two forms, one a benign saprophytic bacterium in the environment, but when virulence genes activated, becomes pathogenic. ➢ Has strong resistance to desiccation, can grow in wide range of temperatures, including those commonly found in refrigerators. ➢ Nutrient limitations can induce starvation survival response in *Listeria monocytogenes* that enables long-term viability under environmental stress. ➢ Protozoa may internalize *Listeria* spp. and extend survival. ➢ May survive and amplify outside the host. ➢ Appears to persist in manure longer than *E. coli* O157, *Salmonella,* and *Campylobacter.*

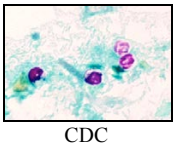
Table 13: Pathogen Basics—Protozoa—*Cryptosporidium* spp.			
Photo/ Description	**Forms of Most Concern for Human Health**	**Foods Associated with Illness**	**Additional Information**
 CDC Single-celled protozoan of the Phylum Apicomplexa	*Cryptosporidium parvum* and *C. hominis* (previously C. *parvum* genotype 1) are most frequently implicated in human illness. *C. canis* from dogs, *C. felis* from cats, *C. meleagridis* from birds, and *C. suis* from pigs may cause human illness, although they appear to be better adapted to their hosts and rarely affect people.	CDC recorded outbreak for one type of produce, apples.	➢ Can't grow or replicate outside of host, but may persist in the environment as an infectious life stage (an oocyst) for a long time and remain capable of infecting a new host when ingested. ➢ Since it does not replicate outside the host, outbreaks where many people get sick are rare, and individuals are more at risk. ➢ Not all species infectious for humans. ➢ Oocysts may be filtered and retained in sediments; type of oxide coatings on sediment particles and nature of particles influence effectiveness of retention.

Table 9—13: Atwill et al. 2012; Brandl 2006; Byappanahalli et al. 2006; Center for Disease Control 2012; Czajkowska et al. 2008; Desmarais et al. 2002; US FDA 2012; Guan and Holley 2003; Hilton et al. 2002; Jiang et al. 2002; Kudva et al. 1998; McElhany and Pillai 2011; Nicholson et al. 2005; Sinton et al. 2007; Snelling et al. 2005.

Appendix II: Prevalence of Pathogens in Wild and Domestic Animals

Evolving methodologies in collecting, analyzing, and reporting data, and the difficulties inherent in interpreting research results make precise risk analysis difficult. Nevertheless, the data are a useful element of risk analysis used to guide management decisions. The discussion of livestock and wildlife pathogen sources in Appendix II is not meant to be all encompassing, but rather to show the diversity of studies mainly occurring in the United States.

The current food-borne pathogen data on animals around the country and the world reflect snapshots of research in a range of settings and animal populations, rather than comprehensive understanding of pathogens in the environment, because thorough study is very difficult and expensive. Research has focused on assessing relationships between human illnesses and livestock, between human illnesses and wildlife, and increasingly on how wildlife and livestock may share pathogens. Wildlife science literature has also examined pathogens found in animal feces through wildlife surveys, and to a lesser extent how pathogens influence wildlife mortality rates. Before reviewing the information from current pathogen prevalence data, it is helpful to understand what the data measure, how they are collected, and their limitations.

Pathogen loading rate, prevalence, and sampling challenges

- Environmental loading rate of pathogens on the landscape is the most useful information for food safety risk analysis. It considers not only prevalence (percent of an animal population sampled that tests positive for a pathogen), but also the amount of pathogens per gram of an animal's feces, the amount of feces excreted per day by each animal, and population density. This type of data is currently scarce for wildlife species in particular.
- Prevalence data in this Appendix show percent of samples in which the target pathogen was found. Many studies have small sample sizes, and caution must be used when inferring risk from these small sample size prevalence rates; both 1/10 and 100/1000 positive test results will yield a prevalence rate of 10%, but the latter may provide more insight into environmental load of the pathogen and risk from the animal in question. Interpretation of data may be further complicated by the fact that total population size is often unknown, so it is not possible to know how well the population has been represented in any sample size.
- Unless samples are collected directly from the animal, it is not clear whether each fecal sample reflects an individual or one of multiple samples from a single individual.
- Samples collected from an animal's gut, mouth, skin, and blood are more reliable than feces collected from the ground, where they may have been contaminated by other animal, wind, or water pathways.
- Studies often only determine presence or absence instead of quantifying the amount of pathogen.
- Ease of pathogen detection increases with larger animals because ample samples may be collected from large fecal deposits.

Animal stress, age and immunity, and habitat

- Seasonal stress of some animals may result in the variability of pathogen shedding rates.
- Resistance to some diseases, such as *Salmonella*, *Campylobacter*, and *Cryptosporidium*, may increase as the animal host ages, perhaps due to immunity that is built from past exposure.
- If an area has a high background level of pathogens in the environment, animals in that region may reflect a similarly high pathogen load.

- Young animals tend to shed more pathogens than adults; for example, calves shed more than cows.

Human pathogens versus animal pathogens
- Improvements in pathogen testing methods now allow DNA fingerprinting to precisely identify pathogen serotypes implicated in human illness. Earlier work did not have this ability, and may have inaccurately identified certain organisms as pathogens of human concern, though it is now known they are adapted to specific animal hosts and present little risk to humans. This may be particularly relevant for pioneering *Cryptosporidium* studies. Thus, it is important to understand the methodology when reviewing literature or developing new research programs.
- Conversely, while some *Salmonella* studies report that pathogens are uniquely adapted for animal hosts, more recent work suggests they are also capable of infecting humans. Thus, unique adaptation to animal hosts does not exclude the possibility of human virulence unless research has specifically investigated that aspect.
- Many pathogen studies report all strains that may be able to infect humans, even in the absence of epidemiological studies showing that they have made people sick. This may be occurring in part because the pathogens may be evolving faster than research can identify them.

Pathogen presence, degree of activity, and fitness
- Before improved recovery and detection technologies and DNA fingerprinting, some studies may have under-reported pathogen presence.
- Other pathogens have been under-reported because of physician sampling, lack of illness reporting by sick people, lack of use of reporting systems, and pathogen sub-types not being included on mandated public health reporting lists.
- Modern genetic testing procedures determine if presumptive virulence gene(s) or a diagnostic pathogen marker gene(s) is (are) present, not if it is alive, in an inactive state, or dead. Non-viable pathogens, and/or remnant DNA of pathogens that were previously present, do not present risk, though they may help scientists understand pathogen pathways. In environmental samples, due to the low abundance, an enrichment step is generally required prior to detection, which virtually assures viability in PCR (Polymerase Chain Reaction) tests. This is often followed by cultural confirmation.
- Differential fitness among pathogens in competition with different background microbiota present in a sample can also impact pathogen growth sufficient to allow molecular detection and/or culturability.

A.II.1 Prevalence of Pathogens in Wildlife

Figures 4—7 present a snapshot of prevalence data in a range of animals from documented wildlife studies. The data were selected for inclusion if the animals were in the United States; the number of animals sampled was at least 25; the samples were taken from the animal itself, not off the ground; the animals did not die of a disease; and the animals were not farm-raised or in a zoo. This data may or may not mean that populations of the same species in other areas will show similar percentages of pathogens. Pathogen prevalence data is an area of active research, with increasing emphasis on collecting companion data to facilitate better understanding of environmental loading rates and pathogen pathways in the landscape.

E. coli *Pathogen Sources*

Prevalence of *E. coli* O157:H7 pathogens in native and non-native feral animals in the United States is depicted in Figure 4. The animals were in association with cattle in all but four of the studies (c, d, g, and p). No black-tailed deer in California coastal counties or white-tailed deer in Texas were found with *E. coli* pathogens, even though cattle and sheep were detected with the pathogens in the latter study. White-tailed deer in Louisiana and in the northeastern and southern states were found with a low *E. coli*

pathogen prevalence, as were cattle in the south, although the *E. coli* had different genes encoding Shiga toxins.

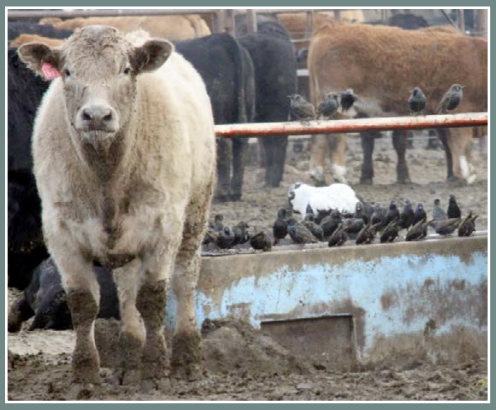
Other deer studies reporting animals without *E. coli* pathogens in California, and with them in Idaho, Kansas, and Nebraska were not shown in Figure 4 because of unacceptable data collection parameters. A link between pathogenic *E. coli* illnesses, strawberry consumption, and deer feces found on an Oregon strawberry farm was made with DNA fingerprinting techniques (see Table 3 Recorded Outbreaks Associated with Wildlife).

E. coli pathogens were also found in a few coyotes, tule elk, and a deer mouse (see Figure 4), but not in other rodents or various other wildlife (opossums, rabbits, skunks, ground squirrels, mice, or raccoons) in California Coast farmlands and rangeland. No *E. coli* pathogens were found in rodents in dairies and cattle feedlots in the Northwest.

Links between rodents and cattle have been established in European studies. *E. coli* strains with multiple antimicrobial resistances were detected in wild rodents originating from areas with high livestock density in Germany, suggesting a possible transmission from livestock to wild rodents.

Feral pigs were found with *E. coli* pathogens in California Coastal Counties in three studies (Figure 4), one of which also detected prevalence in about one-third of the cattle present. Although the definitive source of *E. coli* O157:H7 in the California 2006 spinach outbreak was never determined, feral pigs, cattle, pasture soil, water, and sediments were suspected. These non-native pigs may share the pathogens directly with the cattle, or indirectly through contaminated water and soil. Because they tend to preside in riparian areas and exist in high populations in this region, they may increase the spread of these pathogens through waterways.

Numerous bird species that frequent feedlots and farms with livestock have been found positive for food-borne pathogens, leading to speculation about the role of birds in the transfer and dissemination of this pathogen from livestock. Eight of the studies (Figure 4: a, f, j, k, l, m, n, o) looking at birds were conducted at cattle feedlots, dairy farms, or on rangeland and nearby produce fields to determine if birds acted as a significant carrier of *E. coli* pathogens, and two of those studies established that antibiotic resistance had developed in the pathogens found. European starlings near an Ohio dairy farm were found with *E. coli* O157, while those near a Kansas cattle feedlot were not in one study but were in another. One pigeon tested positive for *E. coli* O157 near a Wisconsin dairy farm, but the European starlings, sparrows, or turkeys also present did not. Rock pigeons near Colorado dairy farms were not found with *E. coli* pathogens, but *E. coli* virulence characteristics were detected. In California cattle ranches and nearby produce fields, American crows and brown-headed cowbirds were found with *E. coli* pathogens, but a large number of bird species (perching birds and wild geese) tested negative for *E. coli* pathogens in this region. Tundra swans tested negative for *E. coli* pathogens in Alaska. *E. coli* antibiotic resistance was reported in the gut flora of natural populations of Yellow-headed blackbirds in North Dakota (not shown).



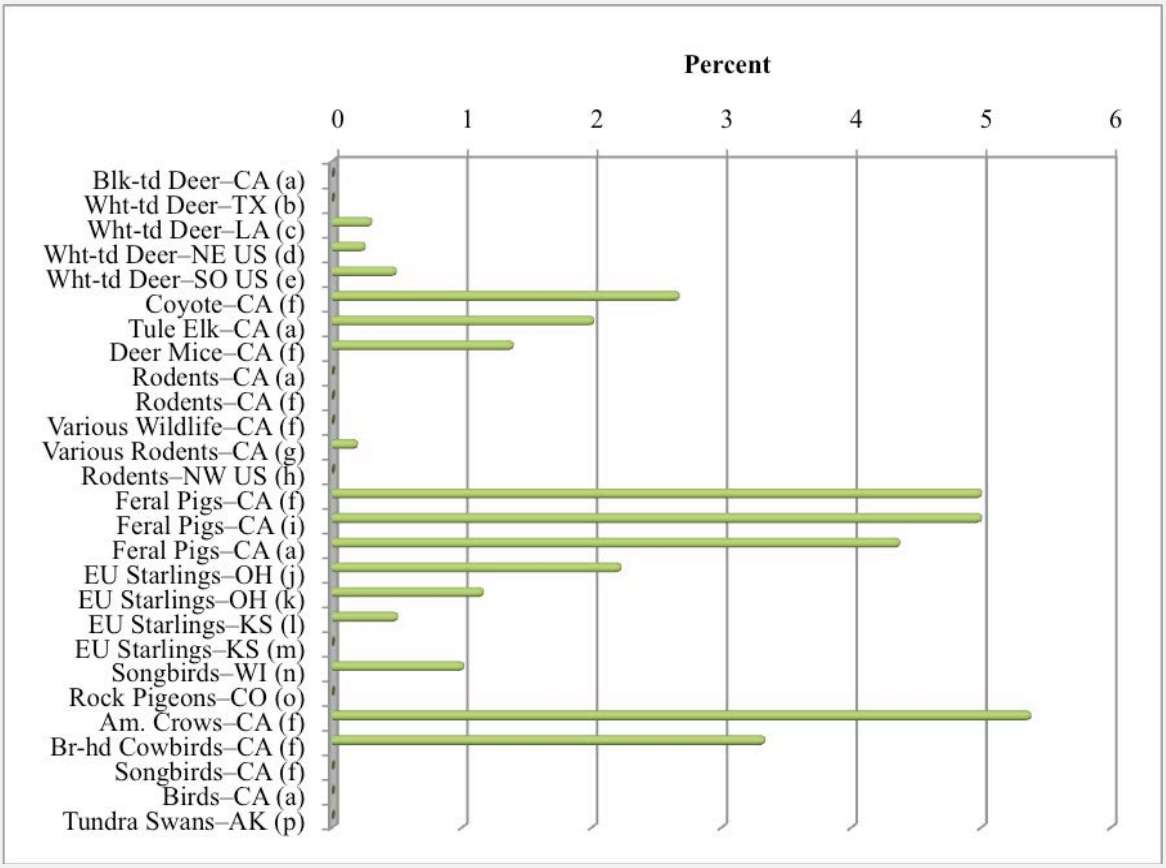
USDA APHIS

Birds that frequent farms with livestock have been found to test positive for pathogenic E. coli *and* Salmonella.

Figure 4 does not show invertebrate data. Of all the invertebrates, flies are most often associated with spreading diseases, especially since they are attracted to manure as a food source and developmental site, and can contaminate animal and human food through regurgitation, fecal deposition, or mechanical transfer. Flies collected at Midwestern state agricultural fairs where livestock were exhibited were found with *E. coli* pathogens. In Kansas, house flies in a cattle feedlot were found to carry antibiotic resistant *E. coli* pathogens, which they passed on to cattle, causing the researchers to conclude that flies play a role in disseminating the pathogen among animals and the surrounding environment. In California, flies were found to carry multiple strains of *E. coli* pathogens and may be able to transfer viable cells to spinach leaf surfaces. On the other hand, black soldier fly larvae were found to reduce the incidence of *E. coli* in dairy manure.

Other kinds of invertebrates have been the subject of *E. coli* pathogen tests. Slugs in a Scottish sheep ranch were found to carry *E. coli* pathogens. While bees weren't tested, a study showed how they tended to avoid flowers inoculated with *E. coli* pathogens. Bee propolis has toxicity factors that reduce survival of those pathogens that might make it to the hive.

Figure 4: *Percent of U.S. Native & Non-Native Mammal Colon and Avian Cloacal Swab/Tissue Samples with* E. coli *0157:H7 Pathogens*



From: (a) Gordus et al. 2011; (b) Branham et al. 2005; (c) Dunn et al. 2004; (d) Renter et al. 2001; (e) Fischer et al. 2001; (f) Jay-Russell et al. 2010; (g) Kilonzo et al. 2013; (h) Hancock et al. 1998; (i) Jay et al. 2007; (j) LeJeune et al. 2008; (k) Williams et al. 2011; (l) Gaukler et al. 2008; (m) Gaukler et al. 2009; (n) Shere et al. 1998; (o) Pedersen et al. 2006; (p) Milani et al. 2012.

The data presented in this figure were included if the animals were in the United States; the number of animals sampled was at least 25; the samples were taken from the animal itself, not off the ground; the animals did not die of a disease; and the animals were not farm-raised or in a zoo.

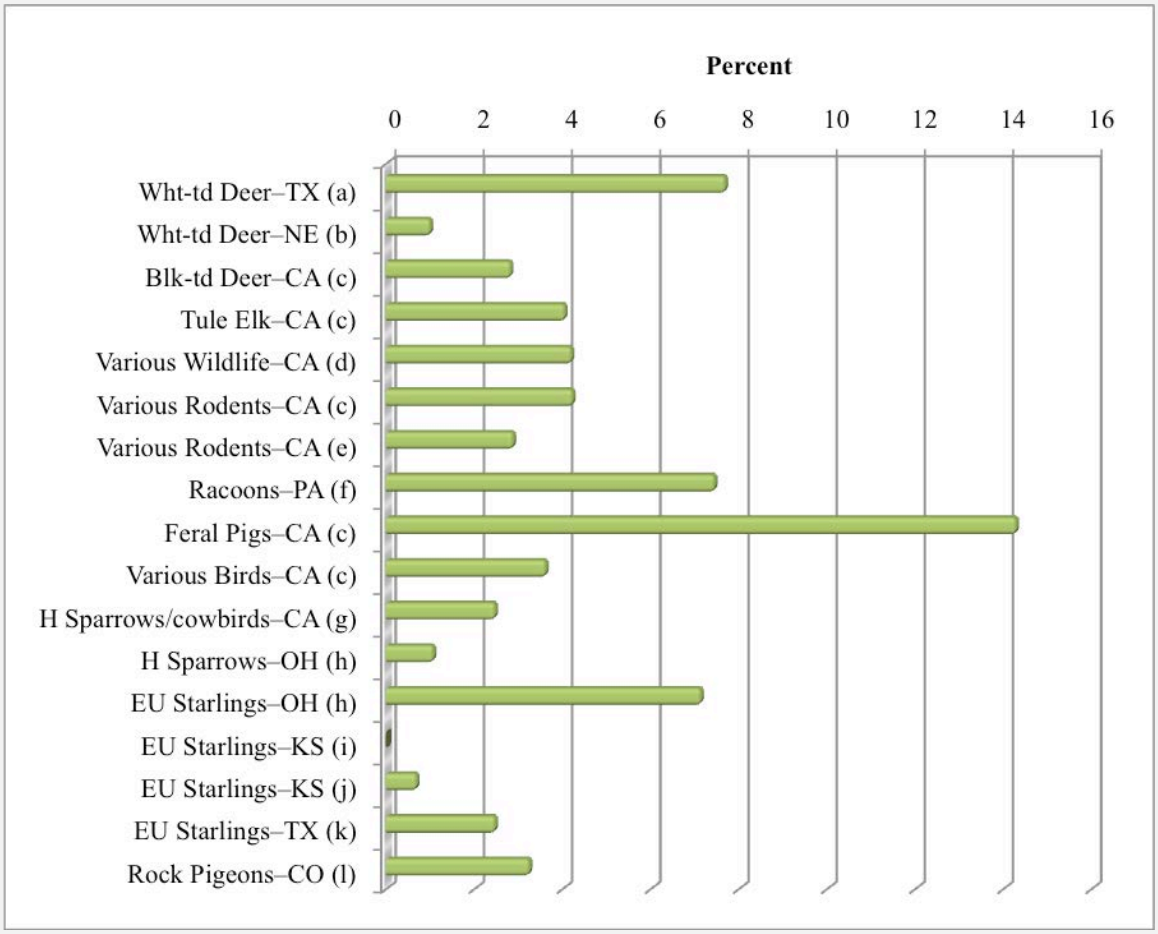
Salmonella *Pathogens in Mammals and Birds*

Figure 5 depicts prevalence of *Salmonella* in native and non-native animals in the United States. *Salmonella* was detected in white-tailed deer in Texas where they shared rangeland with sheep that had the similar pathogen levels, and in white-tailed deer in Nebraska. Some black-tailed deer and a few tule elk were found with *Salmonella* in California Coast farmlands and rangeland, as were various wildlife (coyote, skunk, opossum) and various rodents (deer mice, house mice, black rat, and ground squirrels). No *Salmonella* was detected in rabbits or raccoons in the California study, although raccoons have been found with *Salmonella* in Pennsylvania. Feral pigs roaming cattle rangeland and occasionally in produce fields of California were detected with a higher prevalence of *Salmonella*.

Salmonella bacteria are found in birds, especially in scavenging or carrion-eating birds such as crows and gulls. Others birds are more susceptible, such as the perching birds that died from *Salmonella* in very large numbers at bird feeders in Great Britain (not shown). It is suggested that the prevalence is low in healthy perching birds because its presence would otherwise soon mean death.

Another study included in Figure 5 found that while a great number of bird species near cattle ranches and produce fields in California tested negative for *Salmonella*, there were various perching bird species that tested positive. House sparrows and brown-headed cowbirds had low prevalence of *Salmonella* near California dairies, while the cattle had much higher levels. In an Ohio study, house sparrows and European starlings were found with *Salmonella* at sites on or near dairy, poultry, or swine farms, or near human populations. European starlings were detected with antibiotic resistant *Salmonella* in one Kansas feedlots study but not in another. While starlings were found with low prevalence in Texas cattle feedlots, it was thought that the contamination of both the cattle feed and water troughs was significantly related to numbers of starlings present. Rock pigeons near Colorado dairy farms were found with *Salmonella* more often in the summer and fall than the winter.

Figure 5: *Percent of U.S. Native & Non-Native Mammal Colon and Avian Cloacal Swab/Tissue Samples with* Salmonella *Pathogens*



From: (a) Branham et al. 2005; (b) Renter et al. 2006; (c) Gordus et al. 2011; (d) Gorski et al. 2011; (e) Kilonzo et al. 2013; (f) Compton et al. 2008; (g) Kirk et al. 2002; (h) Morishita et al. 1999; (i) Gaukler et al. 2008; (j) Gaukler et al. 2009; (k) Carlson et al. 2011; (l) Pedersen et al. 2006.

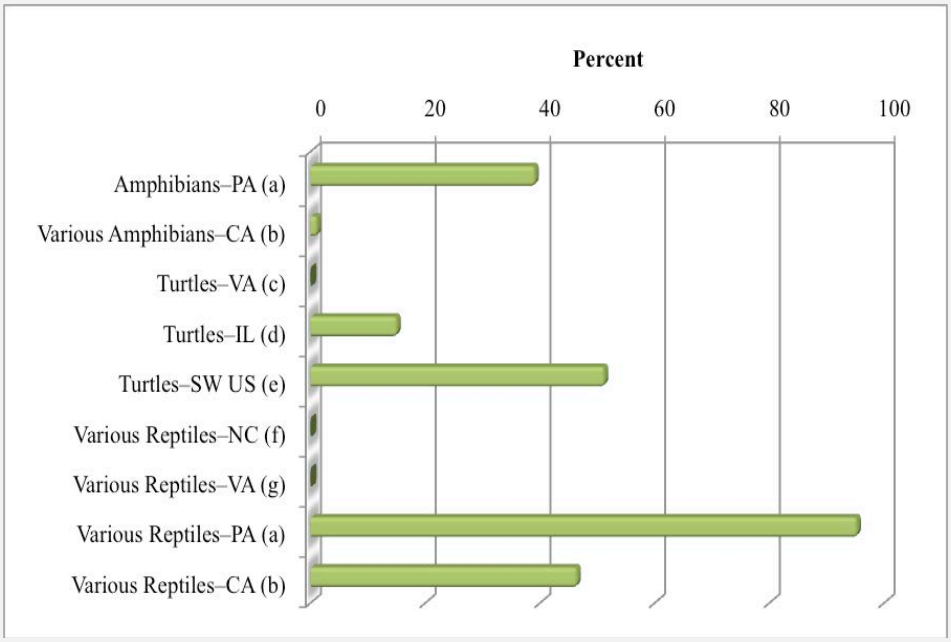
The data presented in this figure were included if the animals were in the United States; the number of animals sampled was at least 25; the samples were taken from the animal itself, not off the ground; the animals did not die of a disease; and the animals were not farm-raised or in a zoo.

Salmonella *Pathogens in Amphibians and Reptiles*

The amphibian and reptile research data in Figure 6 is shown separately from the other wildlife research in Figure 5 because it is not known how many of the "cold-blooded animal" *Salmonella* serotypes presented in this data are harmful to humans. All are assumed to be a risk, even though most cases of human illness arise from one "warm-blooded" type—*Salmonella enterica* subsp. *enterica.*

In nature, free-ranging amphibians were found with much more *Salmonella* in Pennsylvania than in California. Wild turtles in Virginia were absent of *Salmonella*, whereas those in Illinois and especially in the Southwest had higher prevalences. Various free-ranging reptiles in North Carolina and Virginia were not found with *Salmonella*, but others in Pennsylvania were. Various reptiles in California were detected with *Salmonella*. The large range of prevalence may be indicative that the higher occurrences of this pathogen are related to other contamination in the landscape. Reptiles are usually asymptomatic carriers, although once other diseases take hold, *Salmonella* can be a significant opportunistic pathogen contributing to their demise.

Figure 6: *Percent of U.S. Native Amphibian and Reptile Cloacal/Skin Swab/Tissue Samples with* Salmonella *Pathogens That May Have the Potential to Infect Humans*



From: (a) Chambers and Hulse 2006; (b) Gorski et al. 2013; (c) Brenner et al. 2002; (d) Readel et al. 2010; (e) Gaetner et al. 2008; (f) Saelinger et al. 2006; (g) Richards et al. 2004.

The data presented in this figure were included if the animals were in the United States; the number of animals sampled was at least 25; the samples were taken from the animal itself, not off the ground; the animals did not die of a disease; and the animals were not farm-raised or in a zoo.

Campylobacter, Cryptosporidium *and* Listeria *Pathogens*

Figure 7 depicts the prevalence of *Campylobacter* and *Cryptosporidium* pathogens in native and non-native animals in the United States. *Campylobacter* was detected in both the gastrointestinal tract and the oral cavity of feral pigs in produce fields and on rangeland with cattle in California Coastal Counties. In this same area (not shown in the figure), additional feral pigs and some native wild animals (birds, raccoons, coyotes), cattle, and goats were reported with *Campylobacter,* but not other wildlife (deer, skunks, squirrels, and deer mice). Migratory waterfowl was found with *Campylobacter* in Colorado, and Canada geese were detected with antibiotic resistant *Campylobacter* in North Carolina.

It is worth mentioning that deer, raccoons, elk, skunks, squirrels, and California gulls have been found with *Campylobacter*, although they were not shown in Figure 7 because of unacceptable data collection parameters. Most of *Campylobacter* serotypes found in the gulls in the last study were not closely related to species commonly associated with human illness. A direct relationship between ill persons who consumed peas in Alaska and *Campylobacter* pathogens found in sandhill crane feces was established with DNA fingerprinting techniques (not shown; see Table 3 Recorded Outbreaks Associated with Wildlife). *Campylobacter* was detected in flies, slugs, and ruminant feces that were collected from a single farm in Scotland over a 19-week period (not shown).

Feral pigs tested positive for *Cryptosporidium* in the California Coastal Counties, as did deer mice in two other studies (Figure 7). A thorough analysis was conducted in the deer mice study by calculating the environmental loading rate of the animals using the number of positive animals, daily fecal shedding rate, and the estimated population. This type of analysis can be most helpful with determining risk. As previously mentioned, most studies are only determining the prevalence in the animals.

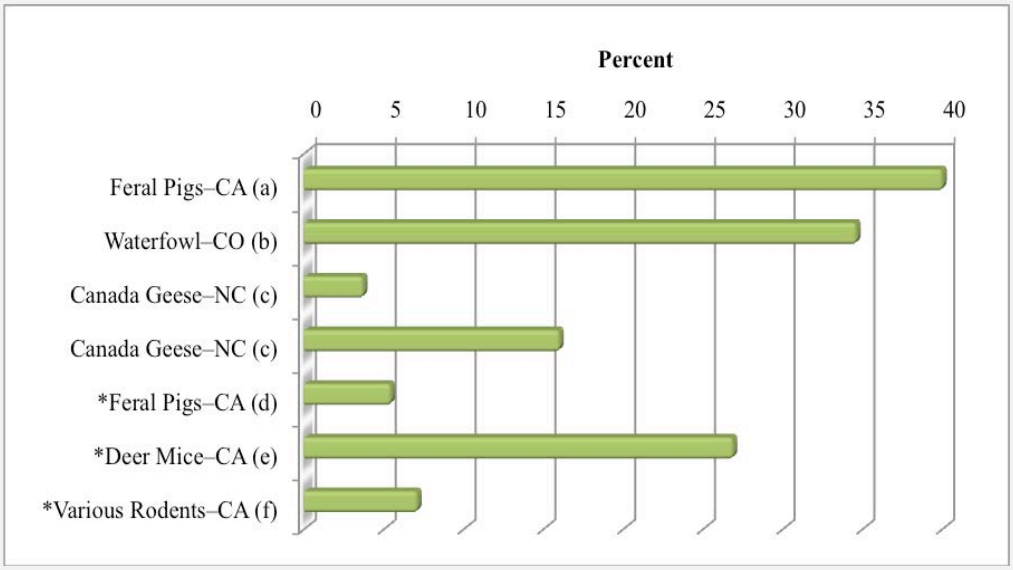
D. Cappareet, Michigan State University, Bugwood.org

A study conducted in California suggests that a reduction in rodent species diversity may cause increased pathogen prevalence in the individuals that remain.

In the California 'various rodents' study (Figure 7), it was suggested that control efforts that potentially reduce biodiversity, such as non-crop vegetation clearing and indiscriminate poison baiting, might also decrease the diversity of rodent species. When diversity decreases, interaction between individuals of the remaining species increases, which may cause an increase in pathogen prevalence in those individuals.

Not shown in Figure 7 were incidences of *Listeria* detected in Roosevelt elk in California, fox in Illinois, raccoon in Connecticut, skunk in North Dakota, and a preliminary report of wildlife with *Listeria* in New York. Deer, moose, voles, mice, muskrats, shrews, otters, raccoons, and geese and other wild birds have been found with *Listeria* in Canada. Rooks were detected with *Listeria* in Sweden, Finland, and Germany, and crows in Japan.

Figure 7: *Percent of U.S. Native and Non-Native Mammal Colon and Avian Cloacal Swab/Tissue Samples with* Campylobacter *and* Cryptosporidium* *Pathogens*



*** Indicates *Cryptosporidium* studies.**

From: (a) Jay-Russel et al. 2012; (b) Luechtefeld et al. 1980; (c) Rutledge et al. 2010; (d) Atwill et al. 1997; (e) Li et al. 2012; (f) Kilonzo et al. 2013.

The data presented in this figure were included if the animals were in the United States; the number of animals sampled was at least 25; the samples were taken from the animal itself, not off the ground; the animals did not die of a disease; and the animals were not farm-raised or in a zoo.

A.II.2 Prevalence of Pathogens in Livestock

Food-borne pathogens can be present in livestock, often at higher rates than in wildlife. While the research regarding food-borne pathogens in livestock is extensive, Tables 14, 15 and 16 present snapshots of prevalence. These examples include *E. coli*, *Salmonella*, and *Campylobacter* in dairy and beef cattle, swine, and chicken layers and broilers. Some of the data looks at prevalence between livestock operations, and other data reports prevalence in the animals themselves.

Table 14: Examples of Research Investigation *E. coli* Prevalence in Cattle and Cattle Feces in Different Cattle Management Systems

Location	What the Research Examined	Cattle Management System	Prevalence Data
Wisconsin (a)	Prevalence of *E. coli* O157:H7 in calves (< 4 months) in dairy operations.	dairy	7.1% (5 of 70) of dairy farms tested positive and 1.8% of fecal samples from calves tested positive (10 in 560 calves).
Northwest United States (b)	Prevalence of *E. coli* O157 in fresh cattle fecal pats.	feedlots & dairies	100% (12 of 12) farms had herds tested positive for *E. coli* O157. Within the herds, 1.1%–6.1% of fecal samples tested positive.
The Netherlands (c)	Prevalence of *E. coli* O157 in dairy cattle feces. Samples obtained by rectal retrieval in dairy operations.	dairy	70% (7 of 10) of dairy farms tested positive for verocytotoxin producing *E. coli* O175. Within positive herds, the proportion of infected cattle varied from 0.8% to 22.4%.
California (d)	Prevalence of *E. coli* O157 in cattle feces. Samples collected from the animals or from the interior of freshly deposited feces.	cow-calf ranches	62.5% (5 of 8) ranches tested positive for *E. coli* O157. Within positive ranches, 0.7%–10.1% of fecal samples tested positive.
Switzerland (e)	Prevalence of *E. coli* O157:H7 in cattle.	dairy	25% (15 of 60) organic dairy farms and 17% (10 of 60) conventional dairy farms tested positive for *E. coli* O157:H7.
Midwestern United States (f)	Prevalence of *E. coli* O157 in lots of beef cattle originating from a single ranch or feed lot. Samples were obtained from colorectal tissues collected during processing.	beef processing facility	72% (21 of 29) of cattle lots tested positive for enterohemorrhagic *E. coli* O157. Within the positive lots, 7.7–100% of fecal samples tested positive.
Canada (g)	Prevalence of *E. coli* O157 in fecal samples from lots of beef cattle originating from a single ranch or feedlot, or from auction. Samples were obtained from the bagged off rectum collected during processing.	abattoir	19.5% of lots had at least one positive *E. coli* O157:H7 culture. The median within lot prevalence for *E. coli* O157:H7 was 0%.

From: (a) Faith et al. 1996; (b) Hancock et al. 1998b; (c) Heuvelink et al. 1998; (d) Benjamin et al. 2014; (e) Kuhnert, et al. 2005; (f) Elder et al. 2000; (g) Van Donkersgoed et al. 1999.

Table 15: Examples of Research Investigating *Salmonella* Prevalence in Livestock and Livestock Operations

Location	Animal	What the Research Examined	Prevalence Data
United States (a)	dairy cattle	Prevalence of *Salmonella* in dairy herds.	31% (30 of 97) of herds had at least one positive culture.
United States (b)	chickens—layers	*Salmonella* prevalence in layer houses.	7.10% of houses.
California (c)	chickens—layers	*Salmonella* prevalence in manure piles in layer houses.	68% of houses.
Multiple States (United States) (d)	swine, poultry, dairy and beef cattle	*Salmonella* prevalence in diverse environmental samples taken from diverse farming operations (swine, poultry, dairy and beef).	4.7% of the 2,496 environmental samples tested positive for *Salmonella*. Of the positive samples, 57.3% came from swine farms, 17.9% from dairy farms, 16.2% from poultry farms, and 8.5% from beef cattle farms.

From: (a) APHIS 2005; (b) NAHMS 2000; (c) Riemann et al. 1998; (d) Rodriguez et al. 2006.

Table 16: Examples of Research Investigating *Campylobacter* Prevalence in Livestock and Livestock Operations

Location	Animal	What the Research Examined	Prevalence Data
United States (f)	dairy cattle	Prevalence of *Campylobacter jejuni* in dairy cattle fecal samples obtained by direct rectal retrieval.	37.7% (786 of 2085) of samples tested positive.
United States (b)	diary cattle	Prevalence of *Campylobacter* spp. in dairy cattle fecal samples obtained by rectal retrieval.	51% (735 of 1435) of samples tested positive.
Washington State (a)	diary and beef cattle	Prevalence of *Campylobacter jejuni* in cattle fecal samples obtained by rectal retrieval or free fecal droppings.	34.1% (234 of 686) of samples tested positive.
California (c)	beef cattle	Prevalence of *Campylobacter* spp. in rectal fecal samples from adult beef cattle.	5% (20 of 401) of samples tested positive.
Not Specified (e)	chickens—broilers	Prevalence of *Campylobacter* spp. in broiler cecal droppings.	100% (20 of 20) of samples tested positive.
Not Specified (d)	chickens—broilers	Prevalence of *Campylobacter* spp. in broiler cecal material at broiler farms.	90% (9 of 10) of farms tested positive.

From: (a) Bae et al 2005; (b) Englen et al. 2006; (c) Hoar et al. 1999; (d) Stern et al. 1995; (e) Suslow et al 2003; (f) Wesley et al. 2000.

Appendix III: Factors that Influence Pathogen Reduction in Water, Soil and Air

Major environmental factors and conservation practices that influence the fate and transport of pathogens in agricultural landscapes are listed in Tables 17 and 18 for water, Tables 19 and 20 for soil, and Tables 21 and 22 for air resources.

Table 17: Environmental Factors that Influence Pathogen Reduction in Water

Factors	Resource Concern: Pathogens in Surface Water Fate and Transport of Pathogens in Surface Water
Sunlight/UV Exposure	**Exposure of water to UV radiation damages pathogens and typically leads to quick reduction.** • High intensity sunlight radiation decreased levels of cultivable fecal indicator bacteria in water. (Schultz-Fademrecht et al. 2008) • A study conducted in an outdoor laboratory setting found that inactivation rates of pathogens in water were higher in sunlight than in the dark. Pathogen inactivation was directly related to the amount of in solution (i.e., dose of sunlight). (Sinton et al. 2007) • In a simulated environment laboratory study, *E. coli* exhibited a strong sensitivity to sunlight. (Fujioka & Yoneyama 2002) • When subjected to strong natural sunlight, the exposure time required for the complete inactivation of pathogens suspended in water and stored in plastic bottles was 20 minutes for *Campylobacter jejuni*, 45 minutes for *Staphylococcus epidermis*, 90 minutes for enteropathogenic *E. coli*, and 150 minutes for *Yersinia enterocolitica*. (Boyle et al. 2008) • In surface waters, sunlight is the most important inactivating factor in determining the survival of *E. coli*, *Salmonella typhimurium,* and other bacteria. (Pachepsky et al. 2011)
	Turbid water may be associated with increased levels of pathogens, as compared to non-turbid water. • In coastal creeks, turbidity was positively correlated with the abundance of enteric bacteria. (Mallin et al. 2000) • During times of higher water turbidity, there was a general tendency toward higher densities of pathogens. (Wilkes et al. 2011)
	Shady conditions created by wetland vegetation may protect pathogens from UV effects. • Due to the shade created by emergent wetland plants, it is likely that sunlight plays a less important role in pathogen inactivation in wetlands than in animal waste lagoons. (Hill 2003)
Predation/ Competition	**Predation and competition by native microbial communities in water may increase pathogen reduction rates.** • Predation was thought the likely mechanism for the high removal of *C. parvum* in canal water. (Diallo et al. 2009) • Plankton may predate upon *C. jejuni* in aquatic environments. (McElhany & Pillai 2011) • Predation and/or competition for nutrients may affect the survival of *C. jejuni* and *E. coli* in aquatic environments. (Korhonen & Martlkalnen 1991)
Harborage	**Some protozoa and algae may host pathogens.** • *Campylobacter* spp. typically survived longer when co-cultured with golden algae *D. cartularies*, as well as three amoebas from the genus *Acanthamoeba.* (Axelsson-Olsson et al. 2010a) • When co-incubated with *Acanthamoeba polyphaga*, *C. jejuni* cells tolerated pHs far below their normal range. (Axelsson-Olsson et al. 2010b) • The water underlying mats of *Cladophora* (a green algae) had a significantly greater concentration of *E. coli* than the surrounding lake water. (Heuvel et al. 2010) • While it is documented that aquatic organisms a can aid in pathogen survival, the relative importance of their role in serving as a reservoir for pathogens is not currently known. (Pachepsky et al. 2011)

Table 17 (continued)	
Harborage	**Some biofilms may harbor pathogens.** • A laboratory experiment found that natural microbial assemblages [biofilms] occurring in a Pennsylvania stream showed seasonal differences in the retention of *Cryptosporidium* oocysts. (Wolyniak et al. 2010) • While river biofilms displayed indicator bacteria at two orders of magnitude higher than the surrounding water, the indicator bacteria made up only a minor fraction of the whole biofilm community. (Balzer et al. 2010)
Nutrients	**Nutrient availability is a factor in determining bacteria survival in water.** • *E. coli* could grow in autoclaved water taken from below a sewage outfall, but not in the water taken from above the outfall. Differences in nutrient content were considered the reason for the difference. (Pachepsky et al. 2011)
	Nutrients may influence competition with and predation of pathogenic bacteria. • Nutrients can cause an increase in competition and predation of pathogenic bacteria in water. (Pachepsky et al. 2011)
Temperature	**Lower temperatures tend to extend pathogen survival. Warmer temperatures, conversely, tend to decrease pathogen survival.** • Pathogen survival in water was enhanced by cooler temperatures. (Berry & Wells 2010) • While higher temperatures can prolong bacteria survival, these temperatures also favor the growth of organisms that predate upon bacteria. (Vymazal 2005)
Re-suspension	**Re-suspended sediments in irrigation water can be a source of pathogens.** • Activities that re-suspend sediments into the water, such as irrigation water intake from ponds, can elevate the concentrations of *E. coli* in water. (Pachepsky et al. 2011)
Biological Movement	**Livestock feces deposited on land may increase pathogens in surface water runoff.** • Higher concentrations of *E. coli* were found in irrigation tailwater when cattle were present in the pasture during irrigation than when cattle were not present. (Knox et al. 2008) • Water running off open livestock systems can contain contaminants including *E. coli*. (Koelsch et al. 2006) • Samples taken from lakes, streams, rivers, and ponds on California's Central Coast showed that areas of higher elevation where cattle were frequently observed grazing near the watershed were "hot-spots" for pathogen prevalence. (Cooley et al. 2014)
	Wildlife may degrade the water quality of irrigation water storage ponds. • Inputs by birds or other wildlife can degrade the quality of water in storage ponds. (Pachepsky, 2011)
	Human activity may degrade water quality, as runoff from urban areas a can be contaminated with pathogens. • A study looking at pathogens in runoff water found that urban runoff had the greatest percentage of total potential pathogens, when compared to agricultural and natural-area runoff. (Ibekwe et al. 2013)

Table 18: Conservation Practices That Influence Pathogen Reduction in Water	
Factors	**Resource Concern: Pathogens in Surface Water**
	Fate and Transport of Waterborne Pathogens in Water
Constructed (656), Created (658), Enhanced (659), and Restored (657) Wetlands	
Plant Emissions/ Exudates	**Wetland vegetation may create undesirable conditions for pathogens by increasing oxygen levels and secreting root exudates.** • Aquatic plants and algae may increase oxygen levels in the water, making undesirable conditions for pathogens. (Vymazal 2005) • Root exudates from aquatic plants may be toxic to some pathogens. (Vymazal 2005)
Water Movement/ Interception	**Wetlands greatly reduce the movement of bacteria in surface water, though some bacteria may still be present in wetland outflow.** • A two-year study showed that constructed wetlands were effective at removing various microbial populations from wastewater. The presence of vegetation slightly enhanced (approximately 0.5 log) the removal efficiency for most microbial groups. (Hench et al. 2003) • A small wetland used to treat runoff from a large agricultural area was able to retain ~70% of indicator bacteria with a hydraulic loading time of less than a day. (Diaz et al. 2010) • Looking at *E. coli* concentrations in irrigation tailwater above and below a wetland, it was found that the wetland decreased *E. coli* concentrations by approximately 40%. (Knox et al. 2007)
	Long residence time and low loading rates may improve wetland function, which may result in increased pathogen reduction rates. Conversely, short residence time and high loading rates decrease wetland function, which results in decreased pathogen reduction rates. • Hydraulic residence time (HRT) appeared to have the greatest effect on the removal efficiency of indicator bacteria. Longer HRTs tended to be more efficient in removing indicator bacteria than shorter HRTs. (Diaz et al. 2010) • A review of literature on constructed wetlands with emergent vegetation found that hydraulic loading rate (HLR), resultant hydraulic residence time (HRT), and the presence of vegetation are the primary factors that influence the efficiency of enteric microbe removal in constructed wetlands. (Vymazal 2005) • Natural wetlands often have channelized flow paths. When compared to a non-degraded reference wetland, a channelized wetland had shorter residence times and lower *E. coli* retention efficiency. (Knox et al. 2008)
Wildlife Consider-ations	**Wildlife may increase the concentration of pathogens in a wetland.** • Resident and visiting wildlife may play an important role in elevating levels of pathogens in wetland effluents. (Graczyk et al. 2009)
Field Border (386), Filter strip (393), Conservation Cover (327), Riparian Forest Buffer (391)	
Water Movement/ Interception	**Pathogens moving as free cells or attached to manure, soil, or other debris in concentrated and sheet flow can be greatly reduced by vegetative treatment systems such as field borders, filter strips, conservation cover, and riparian forest buffers when conditions are right.** • The likelihood of *Salmonella* and *L. monocytogenes* isolation in fields was significantly decreased if growers reported presence of a vegetative buffer zone, defined as a zone of at least 5 m separating the edge of produce fields from potential environmental pathogen reservoirs (e.g., forests, roads, waterways, livestock operations). (Strawn et al. 2013) • A review of vegetative treatment systems (VTS) used for managing runoff from open lot livestock systems determined that pollutant reduction is based upon two primary mechanisms: a) sedimentation, typically occurring within the first few meters of a VTS, and b) infiltration of runoff into the soil profile. Critical design factors include pre-treatment, sheet flow, discharge control, siting, and sizing. (Koelsch et al. 2006) • Grass filter strips measuring 9 meters in width trapped most of the fecal bacteria in surface runoff but did not reduce pathogen load enough to meet existing water quality standards. (Coyne et al. 1998) • Grass vegetated buffer strips reduced the total number of *Cryptosporidium parvum* oocysts discharged in overland and subsurface flow. An increase in rainfall application rate reduced the effectiveness of the buffers. (Tate et al. 2004)

Table 18 (continued)	
Water Movement/ Interception	• Each additional meter of vegetative buffer reduced *E. coli* discharge by 0.3 to 3.1 log (10). (Tate et al. 2006) • Reduction in the concentration of fecal coliforms, *E. coli*, and fecal streptococci in runoff were positively correlated to vegetative filter strip: drainage area ratio and negatively correlated to the depth of the rainfall event. (Mankin et al. 2006) • Vegetated filter strips reduced the amount of water running off test plots. The reduced runoff in turn reduced the surface transport of fecal coliform bacteria, while increasing the vertical transport of bacteria into the soil. (Roodsari et al. 2005) • Modeled scenario analysis suggests potential reduction (3–82%; median 35%) of *E. coli* concentrations in stream waters with riparian buffer strips by eliminating livestock defecation in and near streams, and by trapping of bacteria in the riparian vegetation. (Collins & Rutherford 2004) • Riparian buffer strips function similarly to vegetative treatment areas, but are more critical because they are the last control point before the pathogens enter streams. (Oliver et al. 2007) • A 24% reduction in fecal coliforms was documented for every ten meters of buffer length. (Lewis et al. 2010) • Vegetated buffers, ranging in width from 1 to 25 meters, generally reduced the median fecal coliform concentration in runoff water by more than 99%. (Sullivan et al. 2007) • Grassland buffers of 1.1 to 2.1 m width, with residual dry vegetation matter between 225 and 4,500 kg/ha, and land slopes of 5 to 35%, generated between 3.2 and 8.8 log retention of *Cryptosporidium parvum.* (Atwill et al. 2006) • One positive *E. coli* 0157:H7 result was found out of 60 freshly-cut hay samples from a 4.5 ha vegetative treatment system that received pond storage water from a cattle feedlot. Neither *E. coli* 0157:H7 nor *Campylobacter* spp. were recovered from hay following baling and storage. (Berry et al. 2007)
Size of Runoff Event	**Large runoff events can reduce the efficacy of vegetative buffer strips.** • To reduce the delivery of fecal microbes to waterways during large runoff events, grass buffer strips need to exceed 5 meters in length. It was also found that some of the microbes previously trapped by grass strips were remobilized and washed out during a later runoff event. (Collins et al. 2004) • Large storm events can flush *E. coli* from the soil. (Fenlon et al. 2000) • Excessive hydraulic loading rates and inadequate retention times may lead to poor filter strip performance. (Schellinger & Clausen 1992) • Manure slurry containing coliforms was applied to a 6-m vegetated filter strip (VFS) and bare ground plots. The VFS efficiency was found to be <95% in 25%, < 75% in 23%, and <25% in 20% of cases. The partial failure of VFS to retain coliforms was due to relatively long high-intensity rainfalls and low hydraulic conductivities. (Guber et al. 2009)
Temperature / Moisture	**The cool, moist, nutrient rich conditions of accumulated vegetation and litter in filter strips may increase pathogen survival.** • High levels of residual dry matter (4500 kg/h) in filter strips may provide a moist, cool, nutrient rich environment preferable for *E. coli* survival and multiplication. These conditions may have been the cause of increased discharges of *E. coli* in runoff water from filter strips with high levels of residual dry matter, compared to filter strips with lower levels of residual dry matter (225–900 kg/h). (Tate et al. 2006)
Maintenance	**Proper maintenance may be required to maintain vegetative buffer efficacy.** • Several maintenance issues are critical in VTA [Vegetative Treatment System] function: 1) a good stand of dense vegetation, 2) management practices that contribute to strong fall growth and well-established winter vegetative cover, 3) regular harvesting and removal (animal grazing does not represent an acceptable harvesting option), 4) prevention of channel flow, 5) minimizing solids accumulation, 6) uniform flow conditions, and 7) minimal animal traffic and limiting of vehicle traffic to dry conditions are critical. (Koelsch et al. 2006)

Table 19: Environmental Factors that Influence Pathogen Reduction in Soil	
Factors	**Resource Concern: Soil Contamination, Pathogens** **Fate and Transport of Pathogens in Soil**
Sunlight/UV Exposure	**Higher intensity UV radiation reduces survival of pathogens in soil.** • Pathogens near the soil surface died off quicker than what was reported in other studies that examined survival deeper in the soil, presumably because of solar radiation. (Gessel et al. 2004) • After dairy manure was amended to the soil, fecal bacteria numbers usually declined to pre-application levels in 2 to 3 months depending on soil temperature and potential exposure to desiccation and ultra violet light. (Stoddard et al. 1998) • Survival of *Escherichia coli* and a fecal streptococcus was studied in shaded and exposed outdoor soil plots. During summer and fall, the organisms survived twice as long in the shaded area. During winter and spring, survival in shade and exposed areas were very similar, which may be a reflection of the cool, wet weather, but it may also be partially explained by the reduced solar radiation from heavy cloud cover, shortened days, and low solar angle. (Van Donsel et al. 1967)
Predation/Competition	**Competition and antagonistic interactions decrease pathogens in soil.** • Death to *E. coli* occurs in soil by competition. (Bogosian et al. 1996) • Pathogen populations decline more rapidly in manure-amended un-autoclaved soil than in autoclaved soil likely due to antagonistic interactions with indigenous soil microorganisms. (Jiang et al. 2002) • Indigenous *Pseudomonads flourescens* (found in decaying organic matter) isolated in soil was very effective at inhibiting growth of *E. coli* O157:H7 at 25 degrees Celcius and was somewhat effective at suppressing it at 10 and 15 degrees Celcius. (Johannessen et al. 2005) • Survival of *E. coil* in soil was significantly influenced by the complexity of the microbial community. Survival of *E. coli* progressively increased with the reduction of microbial community diversity. (Liang et al. 2011) • Microbial community diversity affects survival of the human pathogen *Pseudomonas aeruginosa* in the wheat rhizosphere. (Matos et al. 2005) • Coliform populations often decreased faster when *E. coli* O157:H7 was added indicating possible competition between microflora. (Gagliardi and Karns 2002)
	Reduced competition in soil by fumigation increases long-term pathogen survival. • If soil is contaminated by *E. coli* pathogens, fumigation alone may not eliminate the pathogen, but it may cause a decrease in microbial diversity, which may enhance the survival of the pathogen. (Ibekwe et al. 2011 and Ibekwe and Ma 2011) • Fumigated soils foster *E. coli* O157:H7 growth. Soil systems with reduced biological complexity offer enhanced opportunities for invading microbial species to establish and persist. (van Elsas et al. 2007)
	Protozoa predation reduces pathogen survival in soil. • Decrease of *Salmonella* was related to growth of protozoa in the soil. (Garcia et al. 2010) • The survival of *Salmonella* has been shown to be influenced by predation by soil protozoans amongst others. (Jacobsen and Bech 2012) • The role of protozoan predation in *E. coli* population decline was demonstrated by the simultaneous increase of the indigenous amoeba counts and the decline of *E. coli* cell number. (Recorbet et al. 1992) • When the soil was inoculated with *E. coli* K12 strain, there was an increase of the protozoan numbers, and when the soil was amended with a eukaryotic inhibitor (which kills protozoa), the period of *E. coli* K12 survival was increased. (Sorensen et al. 1999) • Protozoans can decrease the number of pathogens present in soil. (Tate 1978)
Temperature/ Moisture	**High temperature and low moisture reduce pathogen survival in soil.** • Elevated temperatures, especially combined with drying conditions, will effectively increase die-off rates of enteric (human) bacteria. Lower temperatures appear to increase survival time. (Crane and Moore 1985) • Mortality of fecal coliform bacteria at the 0 to 5, 5 to 15, and 15 to 30 cm soil depths also correlated with decreasing moisture and increasing temperature in a curvilinear relationship. (Entry et al. 2000) • The rates of *E. coli* O157 decline in the susceptible sub-population were more rapid under higher temperature and low moisture conditions. The rates of decline in the resistant population were not significantly different across the range of temperature and moisture contents applied to soil cores during the study. (Ogden et al. 2001) • After the sunlight reduced the numbers of non-fecal coliforms in the soil, there was growth in numbers as a result of temperature and rainfall variations. (Van Donsel et al. 1967)

Table 19 (continued)	
Temperature/ Moisture	**Freeze-thaw cycles reduce pathogen survival in soil.** • Freeze-thaw cycles reduce bacterial populations. (Crane and Moore 1985) • Freezing and thawing of soil decreases survival of *Salmonella.* A late fall manure application will not increase the risk of contaminating vegetables planted the next spring, since further experiments showed that repeated freeze-thaw cycles were detrimental to the survival of *Salmonella* and *E. coli* in manure-fertilized soil. (Natvig et al. 2002)
pH	**Higher and lower pH reduces pathogen survival in soil.** • *E. coli* and *Salmonella* die-off increased with decrease in soil moisture and was minimum in a pH range of 6–7. Survival was adversely affected outside the pH range of 5.8–8.4. (Reddy et al. 1981) • Survival of *E. coil* appears to be better in more neutral to alkaline soil than in more acidic soil. (Sjogren 1994)
Soil Texture	**Heavy soil texture increases pathogen survival in soil.** • Survival of *Salmonella* and *E. coli* in farm fields depends on the soil, including the clay content (more clay, longer survival vs. more sand, shorter survival). (Barak and Schroeder 2012) • Presence of higher amount of clay in a clay loam, versus loam soils, may favor the survival of STEC (*E. coli*) O26. (Fremaux et al. 2008) • Data suggests that clay increases persistence and activity of *E. coli* O157:H7 and other coliforms. (Gagliardi 2002) • The time needed to reach the detection limit for *E. coli* O157:H7 for loamy sand, sandy loam, and silty clay was 32, 80, and 110 days, respectively. (Ma et al. 2011) • *E. coli* O157:H7 tainted irrigation water applied to various soil textures persisted longest in clay soils. (Ibekwe et al. 2004) • Compared with sandy soil, clay soil is of a finer texture and thus has smaller pore spaces that may protect adhered cells against predation or niche competition. (Barak and Schroeder 2012)
Nutrients	**Nutrient-rich environment increases pathogen survival.** • Excess nutrients foster *E. coli* growth in soil. (Byappanahalli and Ishii 2011) • High assimilable organic carbon and total nitrogen correlate with high survival of *E. coli* O157:H7 in soil. (Ma et al. 2012) • Survival of *E. coli* O157 was found to be greatest in soil cores containing rooted grass compared to just manure or slurry. (Maule 2000) • *Salmonella* can swarm around active root zone areas where there is a nutrient-rich environment from the root's exudates. These areas are also colonized by diverse bacterial communities. To survive, *Salmonella* may need to avoid defensive antimicrobials produced by the plant and compete with rival microbes for nutrients. (Barak and Schroeder 2012) • Diseased plant tissue may provide a nutrient rich and protected ecological niche for enteric (human) pathogens. However, this opportunity for growth is dictated by the nature of the pathogen's interactions with the resident plant microflora. (Brandl 2006) • Members of the *Enterobacteriaceae,* including *Salmonella* and *E. coli,* are facultative anaerobes, fermenting sugars to produce lactic acid and various other end products. Most also are able to use nitrate as an alternate respiratory chain acceptor under anaerobic conditions. (Brenner 1984)
Salt	**High salt levels reduce pathogen survival in soil.** • Higher electrical conductivity levels may produce shorter survival time of *E. coli* O157:H7 in soil. (Ma et. al 2012)
Harborage	**Some types of pathogens may be harbored by protozoa in soil.** • Ingestion of *Salmonella* by soilborne protozoa resulted in a large number of vesicles being released containing viable *Salmonella,* while ingestion by *Listeria* resulted mostly in death, with only infrequent *Listeria* being released. (Brandl et al. 2005)
Harborage	**Pathogens may be harbored by biofilms in soil.** • Biofilms enhance survival of *E. coli* in soil. (Abu-Lail and Camesano 2003) • Biofilm formation is one multi-cellular, aggregative behavior used by bacteria to successfully colonize plants. *Salmonella* strains with stronger biofilm-forming ability in vitro, have stronger adhesion and persistence on lettuce leaves. Biofilm formation is equally important for root colonization. (Barak and Schroeder 2012) • *E. coli* strains can create biofilms on soil that help restrict them from being transported in water. (Salvucci et al. 2009) • Bacteria frequently live in biofilms, which are surface-associated communities encased in a hydrated extracellular polymeric substance matrix that is composed of polysaccharides, proteins, nucleic acids, and lipids. Bacteriophages have been used for controlling biofilms on stainless steel. (Viazis and Diez-Gonzalez 2011)

Table 19 (continued)

Antibiotic Resistance	**Antibiotic resistance can be transferred from manure to soil microbes.** • The environmental spread of antibiotic resistance can occur in soil bacterial populations. (Jechalke et al. 2013) • Evidence of increasing resistance to antibiotics in soil and other natural isolates highlights the importance of horizontal transfer of resistance genes in bacteria. The selective pressure for the spread of resistance genes correlates strongly with the clinical and agricultural overuse of antibiotics. (Nwosu 2001)

Table 20: Conservation Practices That Influence Pathogen Reduction in Soil	
Factors	**Resource Concern: Soil Contamination**
	Fate and Transport of Pathogens in Soil
Cover Crop (340)	
Species	**The relative length of pathogen survival in relation to cover crops.** • *E. coli* O157:H7 persisted a short time (up to 40 days) in soil with hairy vetch or with clover, and in soil with no plants; whereas it persisted more than twice as long (3 months) on alfalfa roots and on rye roots. (Gagliardi and Karns 2002) • Rye cover crops are usually grown in the winter for more than 3 months (Smith 2013) and alfalfa for a couple of years.
Anti-microbial Effects	**Compounds in some cover crops are harmful to pathogens.** • Glucosinolate compounds derived from cover crops in the Brassica family have an antimicrobial affect on *Salmonella* and to a somewhat lesser degree to *E. coli* O157:H7. (Patel 2013)
Microbial Diversity	**Soil Microbial Communities** • Cover crops can have a large impact on the size and activity of soil microbial communities. (Bolton et al. 1985; Fraser et al. 1988; Kirchner et al. 1993; and Powlson et al. 1987)
Compost Facility (317)*	
Sunlight/ UV Exposure	**Higher intensity UV radiation reduces survival of pathogens in compost.** • Higher light intensity in the summer was a contributing factor on the decreased survival of pathogens in compost versus lower light intensity in the winter, which increased survival. (Kim and Jiang 2010)
Competition/ Predation	**Competition decreases pathogens in compost.** • Bacteriophages (a type of virus) added to un-autoclaved dairy manure compost inoculated with *Salmonella* resulted in a greater reduction of the pathogen as compared to autoclaved compost due to competition. (Heringa et al. 2010) • Competition in non-autoclaved compost did not allow pathogens to grow, whereas autoclaved compost did. (Kim and Jiang 2010) • Indigenous microorganisms are critical for suppressing *E. coli* O157:H7 growth in compost. (Kim et al. 2011) • Pathogens did not survive when inoculated into stabilized compost but showed minimal die-off in sterilized compost. (Paniel et al. 2010)
	Protist predation reduces pathogens in compost. • Protist populations (protozoa and algae), not fungal populations, have the most dramatic effect on *E. coli* O157:H7 reduction. *E. coli* O157:H7 declined faster in untreated compost than in compost treated with cycloheximide. The chemical treatment was thought to kill the protists while leaving the fungal community unharmed. (Puri and Dudley 2010)
Microbial Diversity	**Soil Microbial Communities** • The use of compost has a long-term effect on soil microbial activity. (Ros et al 2006)
Moisture	**With enough moisture, unfinished compost can increase pathogens.** • If there is a small number of *E. coli* O157 cells present and enough moisture, the pathogen can re-grow in the compost. (Kim et al. 2009)

Table 20 (continued)	
Temperature	**While high temperature reduces pathogen survival in compost, it doesn't necessarily destroy all.** • Elevated temperatures may not be lethal for all microorganisms, but may affect their efficiency and further contribute to the decrease in microbial activity. Some microorganisms form spores in response to excessive heating, and when more favorable conditions exist those spores can germinate. (USDA Part 637)
Nutrients	**A low carbon: nitrogen ratio in compost resulted in quicker reduction of pathogens.** • Compost preparations with an initial C:N ratio of 20:1 required a maximum of 4 days of storage before *Salmonella* was inactivated, whereas preparations with C:N ratios of 30:1 and 40:1 required more than 5 and 7 days of storage, respectively. (Erickson et al. 2009)
Maturity	**Making quality compost is dependent on whether it has matured enough to kill human pathogens but not excessively so that antagonistic microorganisms are not able to re-colonize.** • Immature compost serves as food for pathogens and increases disease even when biocontrol agents are present. On the other hand, excessively stabilized organic matter does not support the activity of biocontrol agents. (Hoitink and Grebus 1994) • Plant disease suppression is the direct result of the activity of consortia of antagonistic microorganisms that naturally re-colonize the compost during the cooling phase of the process. (Hadar and Papadopoulou 2012)
Technique	**The windrow method of compost making consistently reduces pathogen survival.** • Composts produced with windrow methods were of higher microbiological quality than were those produced with static pile methods, and point-of-sale bagged composts scored very high. More effort is required to improve hygiene consistency in relation to management practices. (Brinton et al. 2009)

* The assumption has been made that the compost from the compost facility will be used in accordance with the Nutrient Management (590) practice standard.

Table 21: Environmental Factors that Influence Pathogen Reduction in Air	
Factors	**Resource Concern: Air Quality – Particulate Matter with Pathogens**
	Fate and Transport of Pathogens in Air
Sunlight/UV Exposure	**Exposure to UV radiation both damages and dries pathogens and typically leads to quick reduction on leaf surfaces.** • UV radiation limits microbes in the phyllosphere. (Beattie and Lindow 1995) • UV radiation influences populations on leaf surfaces. (Newsham et al. 1997) • Higher numbers of bacteria have been found on lower surfaces suggesting avoidance strategies necessary for surviving UV radiation. (Sundin 1999) • Biological control agents, such as *Bacillus thuringiensis, Beauveria bassiana,* and nematodes on leaves have also been found to be affected by UV radiation. (Ignoffo 1978)
	Pathogen reduction from UV exposure in the shady areas of the permanent vegetation is related to dosage. • Canopy structure, leaf area, and, to a lesser degree, the brightness of the sunlight were found to influence UV penetration into vegetation more than the sun's angle. (Shulski 2004) • A biological dosimeter system using attenuated *E. coli* was created to measure microorganism activity in the canopy of grass. The *E. coli* was placed in cell suspensions within small plastic packets at different locations in turf grass, along with a miniature UV-B radiometer. Die-off was linearly related to UV-B dosage. (Yuen 2002)
Predation/ Competition	**Some native microbial communities on leaf surfaces increase pathogen reduction rates through competition, predation, and antagonism.** • *Enterobacter asburiae* repressed the growth of the *E. coli* O157:H7 when sprayed on leaf lettuce. (Moyne et al. 2011) • The reduction of *E. coli* O157:H7 numbers on spinach leaves by natural epiphytic bacteria show that native plant microbiota can be used for bio-control of food-borne pathogens. Fifteen different genera, the majority belonging to *Firmicutes* and *Enterobacteriaceae,* reduced growth rates of *E. coil* O157:H7 in vitro by either nutrient competition or acid production. However, other epiphytes—phylloepiphytic bacteria belonging to eight different genera—increased numbers of *E. coil* O157: H7 and may promote the persistence of enteric pathogens on the phyllosphere. (Lopez-Velasco 2012)
Symbiosis	**Other native microbial communities on leaf surfaces may facilitate the growth of pathogen populations.** • *Wausteria paucula* promoted *E. coli* O157:H7 survival on leaf lettuce. (Moyne et al. 2011)

Table 22: Conservation Practices That Influence Pathogen Reduction in Air	
Factors	**Resource Concern: Air Quality – Particulate Matter with Pathogens**
	Fate and Transport of Pathogens in Air
Windbreak (380)	
Interception of Pathogens	**Preliminary indication shows that vegetative buffers may intercept pathogens**. • Vegetative buffers (that function like windbreaks) were placed between poultry houses sprayed with two attenuated live vaccine strains and coops with pathogen-free chickens. The proportion of virus-positive serum samples was significantly greater from birds in the control (without the veg. buffer) than with the vegetative buffer in the last of three trials. It was thought that once the buffers had grown to a fuller and greater height, they would have functioned better to reduce the spread of pathogens (Burley 2011).
Aerodynamics of Dust Near Windbreaks	**How Windbreaks Reduce Dust Downwind** • Windbreaks reduce dust downwind by both dropping particulates and lifting emissions into the upper air stream for greater dispersion and dilution (Malone 2004).
Interception of Dust by Buffers	**Vegetative buffers can be effective at reducing dust.** • Vegetative buffers can remove between 35%-55% of dust in the air (Luety 2004; Hernandez 2012; Malone 2004).
Plants Good at Interception	**Conifers are very good at interception.** • Conifers are better than deciduous trees for dense foliage (Straight 2007; Adrizal 2008) and interception. • The needle-like foliage of conifers captures two to four times more pesticide spray than broad-leaves because they don't alter their leaf alignment in high winds (Ucar 2003).

Appendix IV: Glossary and Acronyms

Glossary

amplify/amplification: increase in number/increased numbers due to growth and cell division, replication of viral nucleic acids and encapsulation, or multiplication of a parasite in a host and production of increased spore number.

antagonistic: having the ability to inhibit the growth of another organism.

autoclave/autoclaved: an apparatus that uses superheated steam to sterilize media, instruments, soil, and so on/to treat in an autoclave

bare-ground buffer: a strip of ground cleared of all vegetation to leave nothing but exposed soil to serve as a buffer between wildlife habitat and crop fields.

bio-available carbon: carbon that is freely available, or extracellularly converted, to cross an organism's cellular membrane from the medium the organism inhabits at a given time.

biofilm: a complex community of microorganisms attached to a surface or associated with an interface. Biofilms can be found on leaf surfaces, in aquatic environments, in the soil, and on equipment or in water conveyance canals and pipes.

biological control agents: natural enemies of pest insects, weeds, and diseases; may be predators, parasitoids, or pathogens of the pest.

brassica: a plant of the genus *Brassica* (family Brassicaceae), includes mustard, cabbage, and broccoli**.**

coliform(s): gram-negative, rod-shaped bacteria typically found in the intestine, such as *E. coli*.

Concentrated Animal Feeding Operation (CAFO): According to the U.S. Environmental Protection Agency, CAFOs are agricultural operations where (a) animals are kept and raised in confined situations for at least 45 days in a 12-month period, (b) there is no grass or other vegetation in the confinement area during the normal growing season, and (c) meet certain size criteria.

cultivable: capable of growing on routine culture media in a laboratory.

dosimeter: a device that measures doses of radiation.

enteric bacteria: bacteria that live naturally in the healthy gut of animals and people.

epiphyte: an organism that lives on the surface of plants. In this handbook, the term refers to bacteria and other microorganisms that live on leaf surfaces.

epiphytic: living on plant surfaces.

exudates: liquid released from within a source, such as the roots of plants.

facultative anaerobe: an organism, such as a bacterium, that can grow with or without free oxygen.

fecal: relating to feces.

fecal shedding rate: the rate at which organisms are released from the host through its feces.

Good Agricultural Practices (GAPs): guidelines used by the agricultural industry to minimize and prevent contamination of fresh fruits and vegetables on the farm.

gram-negative bacteria: bacteria that stain pink, instead of purple, due to the fact that they have a thin layer of peptidoglycan on their cell walls that retains little of the purple dye used in the Gram staining method.

gram-positive bacteria: bacteria that stain purple due to the fact that they have a thick layer of peptidoglycan on their cell walls that retains the purple dye used in the Gram staining method.

Gram staining method: a method of differentiating bacteria into two large groups (gram-positive and gram-negative) based on the structure of their cell walls. Gram-positive bacteria have cell walls with a thick layer of peptidoglycan and stain blue/purple. Gram-negative bacteria have cell walls with a thin layer of peptidoglycan and stain red/pink.

horizontal transfer: the transfer of genes between different species by means other than traditional reproduction.

inactivation: to cause a pathogen (or other infective agent) to lose its ability to produce disease.

indicator bacteria: organisms that indicate the presence of fecal contamination (e.g., thermotolerant coliforms or *E. coli*).

indigenous: occurring naturally in a particular environment.

invertebrate: an organism that lacks a spinal column.

Leafy Green Marketing Agreement or California Leafy Green Products Handler Marketing Agreement (LGMA): the LGMA is a membership organization of leafy-greens handlers. Member companies comply with a mandatory audit program that certifies the farming operations they purchase from are implementing a dictated set of food safety practices. All these farming operations are subject to government audits to verify that these food safety practices are being met.

loading rate: the total number of pathogens excreted by a defined cohort of animals or released from an environmental point-source for a specific period of time.

macrophyte: typically refers to an aquatic plant, such as *Potomageton* (pond weed), that is macroscopic in size.

microbiota: the microscopic flora and fauna that live at a particular site.

microflora: the microscopic algae, fungi, and/or bacteria that live in a particular site.

no-harvest buffer: a zone established around animal tracks, evidence of animal feeding, animal trampling or animal feces in which no crop is harvested due to potential pathogen contamination.

oocyst: the environmentally resistant stages of protozoan, such as *Cryptosporidium*. During this stage of development the zygote is protected by a thick-walled cyst that allows it to survive outside the host; this facilitates the transfer of the protozoan from one host to another.

pathogenic: causing disease.

persistence: the ability of any microorganism, including infectious agents, to remain viable in the environment, on crops, or on inert surfaces.

predation: the act of preying upon (killing and eating) other organisms.

phylloepiphytic: living on the surface of plant leaves.

phyllosphere: the microenvironment immediately surrounding the aerial parts of plants, such as the leaves.

prevalence: the dynamic proportion of a population with infection or disease, often expressed as a percentage.

protozoan: motile and heterotrophic unicellular organisms, such as amoebas and paramecia.

residence time: the period of time a substance remains in a particular place.

retention time: the average period of time for which water resides in a wetland, lake, reservoir, or other body of water.

rhizosphere: the microenvironment immediately surrounding the roots of a plant. The population of microorganisms in this area is greater than in the rest of the soil.

saprophytic: describing an organism that obtains nutrients from decaying matter.

serotype: a group of microorganisms distinguished by a common set of cell surface antigens.

streptococci: any bacterium from the genus *Streptococcus*—gram-positive bacteria that include many important human pathogens.

tailwater: water running off the lower end of a field resulting from normal irrigation practices.

tertiary treated wastewater: wastewater that has gone through a secondary treatment process, in which microorganisms degraded the dissolved organic material, and then a tertiary treatment process to remove inorganic nutrients, heavy metals, viruses, and so on from sewage by chemical and biological means.

thermophilic composting: a composting process in which one phase of the process takes place at temperatures exceeding 40°C (104°F).

thermophilic organism: an organism that requires/tolerates high temperature environments.

Ultraviolet (UV) radiation: electromagnetic energy with wavelengths that fall between those of visible light (violet) light and x-rays.

vector: any living organism that can carry a disease-causing organism.

vertebrate: an organism that possesses a spinal column, including mammals, reptiles, and birds.

virulence: the degree of pathogenicity of a microorganism as indicated by the severity of disease produced and the ability to invade the tissues of the host; by extension, the competence of any infectious agent to produce pathologic effects.

Acronyms

CAFO—Concentrated Animal Feeding Operation
CDC—Center for Disease Control
EHEC—Enterohemorrhagic *Escherichia coli*
FDA—United States Food and Drug Administration
FSMA—Food Safety Modernization Act
GAPs—Good Agricultural Practices
HLR—Hydraulic Loading Rate
HRT—Hydraulic Residence Time
LGMA—Leafy Greens Marketing Agreement (or California Leafy Green Products Handler Marketing Agreement)
NRCS—U.S. Department of Agriculture, Natural Resource Conservation Service
STEC—Shiga toxin–producing *Escherichia coli*
USDA—U.S. Department of Agriculture
VTS—Vegetative Treatment System
WFA—Wild Farm Alliance

Selected References

Informational Links on FDA's Produce Rule

National Sustainable Agriculture Coalition. Understanding FDA's New FSMA Rule for Produce Farms. http://sustainableagriculture.net/category/food-safety/

US Food and Drug Administration (FDA). Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption. http://www.fda.gov/Food/GuidanceRegulation/FSMA/ucm334114.htm

NRCS Technical Notes

Atwill, E. R, M. L. Partyka, R. F. Bond, X. Li, C. Xiao, and B. Karle. 2012. An introduction to *Waterborne Pathogens in Agricultural Watersheds.* Nutrient Management Technical Note No. 9.

Challender, R. 2008. *Food safety*—E. coli *O157:H7.* Food Safety Technical Note No. 1.

Rosen, B. H. 2000. *Waterborne pathogens in agricultural watersheds*. NRCS Watershed Institute, School of Natural Resources, University of Vermont, Burlington.

Scheeffe, L. 2007. *Reducing risk of* E. coli *O157:H7 contamination.* Nutrient Management Technical Note No. 7.

Good Agricultural Practices (GAPs) Materials/Links

Association of Food and Drug Officials. 2009. Model code for produce safety: An Association of Food and Drug Officials model code for produce safety for state and local regulatory agencies.

California Leafy Green Marketing Agreement. 2014. California Leafy Green Products Handler Marketing Agreement. http://www.caleafygreens.ca.gov.

Fresh Fruit and Vegetable Audit Programs. 2014. USDA Agricultural Marketing Service. www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&page=GAPGHPAuditVerificationProgram.

On Farm Food Safety Project. 2014. FamilyFarmed.org. http://onfarmfoodsafety.org/.

Produce GAPs Harmonization Initiative. United Fresh Produce Association. http://www.unitedfresh.org/newsviews/gap_harmonization.

Produce Safety Alliance. 2014. Cornell University Department of Food Science. http://producesafetyalliance.cornell.edu/psa.html.

UC Food Safety. 2014. University of California. www.ucfoodsafety.ucdavis.edu.

Wild Farm Alliance. 2014. Training scenarios for USDA and third party auditors on the co-management of food safety and conservation as well as small and mid-size farm concerns. www.wildfarmalliance.org

Additional Government Links

Centers for Disease Control and Prevention (CDC). 2014 (a). Surveillance for Food-borne Disease Outbreaks, United States, 2011, Annual Report. Atlanta, Georgia: US Department of Health and Human Services, CDC. Retrieved on July 25, 2014. http://www.cdc.gov/foodsafety/fdoss/data/annual-summaries/index.html.

Centers for Disease Control and Prevention (CDC). 2014 (b). Surveillance for Food-borne Disease Outbreaks, United States, 2012, Annual Report. Atlanta, Georgia: US Department of Health and Human Services, CDC. Retrieved on July 25, 2014. http://www.cdc.gov/foodsafety/fdoss/data/annual-summaries/index.html.

Centers for Disease Control and Prevention (CDC). 2013 (a). Surveillance for Food-borne Disease Outbreaks, United States—1998–2008. Atlanta, Georgia: US Department of Health and Human

Services, CDC. Retrieved on July 25, 2014. http://www.cdc.gov/foodsafety/fdoss/data/annual-summaries/index.html.
Centers for Disease Control and Prevention (CDC). 2013 (b). Surveillance for Food-borne Disease Outbreaks, United States, 2009–2010. Atlanta, Georgia: US Department of Health and Human Services, CDC. Retrieved on July 25, 2014. http://www.cdc.gov/foodsafety/fdoss/data/annual-summaries/index.html.
Painter, J. A., R. M. Hoekstra, T. Ayers, R. V. Tauxe, C. R. Braden, F. J. Angulo, et al. Attribution of food-borne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998–2008. *Emerg Infect Dis* March 2013. Retrieved on February 25, 2014. http://wwwnc.cdc.gov/eid/article/19/3/11-1866_article.
US Food and Drug Administration (FDA). Center for Food Safety and Applied Nutrition. http://www.fda.gov/AboutFDA/CentersOffices/OfficeofFoods/CFSAN/default.htm.
US Food and Drug Administration (FDA). Food Safety Modernization Act. http://www.fda.gov/Food/GuidanceRegulation/FSMA/default.htm.
US Food and Drug Administration (FDA). Guidance for industry: Evaluating the safety of flood-affected food crops for human consumption. http://www.fda.gov/food/guidanceregulation/guidancedocumentsregulatoryinformation/emergencyresponse/ucm287808.htm.
US Food and Drug Administration (FDA). Guidance for industry: Produce & plant products guidance documents & regulatory information. http://www.fda.gov/food/guidanceregulation/guidancedocumentsregulatoryinformation/produceplantproducts/default.htm.
US Food and Drug Administration (FDA). Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption. http://www.fda.gov/Food/GuidanceRegulation/FSMA/ucm334114.htm
US White House. Food Safety Working Group Report. http://www.whitehouse.gov/sites/default/files/fswg_report_final.pdf.
USDA-AMS National Organic Program Final Rule 7 CFR Part 205. http://www.ams.usda.gov/AMSv1.0/nop.

Selected Articles

Barak, J. D., and B. K. Schroeder. 2012. Interrelationships of food safety and plant pathology: The life cycle of human pathogens on plants. *Annual Review of Phytopathology*. N. K. VanAlfen, J. E. Leach, and S. Lindow. 50:241–266.
Baumgartner, J. A. 2013. *Food safety and conservation: Facts, tips, and frequently asked questions*. Wild Farm Alliance and Community Alliance with Family Farmers.
Baumgartner, J. A., and D. Runsten. Updated 2013. *Farming with food safety and conservation in mind.* Wild Farm Alliance and Community Alliance with Family Farmers.
Beretti, M. A., M. Martinez, D. Mountjoy, P. Robins, and D. Stuart. 2009. *Food safety considerations for conservation planners: A field guide for practitioners.* Resource Conservation District of Monterey County, California.
Berry, E. D., and J. E. Wells. 2010. *Escherichia coli* O157:H7: Recent advances in research on occurrence, transmission, and control in cattle and the production environment. In *Advances in Food and Nutrition Research,* Vol. 60. Ed. S. L. Taylor. Academic Press, Burlington. 67-118.
Bradford, S. A., V. L. Morales, W. Zhang, R. W. Harvey, A. I. Packman, A. Mohanram, and C. Welty. 2013. Transport and fate of microbial pathogens in agricultural settings. *Critical Reviews in Environmental Science and Technology* 43, no. 8: 775–893.

Burley, H. K., A. Adrizal, et al. 2011. The potential of vegetative buffers to reduce dust and respiratory virus transmission from commercial poultry farms. *Journal of Applied Poultry Research* 20, no. 2: 210–22.

Byappanahalli, M. N., and S. Ishii. 2011. Environmental sources of fecal bacteria. In *The Fecal Bacteria.* Ed. M. J. Sadowsky and R. L. Whitman. American Society for Microbiology Press, Washington, D.C. 93–110.

Cooley, M. B., B. Quiñones, D. Oryang, R. E. Mandrell, and L. Gorski. 2014. Prevalence of Shiga toxin producing *Escherichia coli*, *Salmonella enterica*, and *Listeria monocytogenes* at public access watershed sites in a California Central Coast agricultural region. *Fontiers in Cellular and Infection Microbiology* 4, no. 30.

Ferens, W. A., and C. J. Hovde. 2011. *Escherichia coli* O157:H7: Animal reservoir and sources of human infection. *Foodborne Pathogens and Disease* 8, no. 4: 465–87.

Fremaux, B., C. Prigent-Combaret, et al. 2008. Long-term survival of Shiga toxin-producing *Escherichia coli* in cattle effluents and environment: An updated review. *Veterinary Microbiology* 132, nos. 1–2: 1–18.

Gennet, S., J. Howard, J. Langholz, K. Andrews, M. Reynolds, and S. Morrison. 2013. Farm practices for food safety: An emerging threat to floodplain and riparian ecosystems. *Fronteirs in Ecology and the Environment*. 11: 236-242.

Jay, M. T., M. Cooley, et al. 2007. *Escherichia coli* O157:H7 in feral swine near spinach fields and cattle, central California coast. *Emerging Infectious Diseases* 13, no. 12: 1908–11.

Karp, D. S., S. Gennet, C. Kilonzo, M. Partyka, N. Chaumont, E. Atwill, and C. Kremen. 2015. Comanaging fresh produce for nature conservation and food safety. *Proceedings of the National Academy of Sciences* 112, no. 35: 11126-11131.

Langholz, J. A., and M. T. Jay-Russell. 2013. Potential role of wildlife in pathogenic contamination of fresh produce. *Human-Wildlife Interactions* 7:140–57.

Letourneau, D. K., Allen, S. G. B., Kula, R. R., Sharkey, M. J., & Stireman III, J. O. 2015. Habitat eradication and cropland intensification may reduce parasitoid diversity and natural pest control services in annual crop fields. *Elementa: Science of the Anthropocene* 3.1.

Li, X., R. Atwill, E. Vivas, T. Vodovoz, J. Carabez, C. Xiao, and M. Jay-Russell. 2012. Deer mouse (*Peromyscus maniculatus*) as a vector of foodborne protozoa adjacent to produce fields. Vertebrate Pest Control Conference.

Lowell, K., and J. Langholz. 2010. Safe and sustainable: Co-managing for food safety and ecological health in California's Central Coast region. The Nature Conservancy of CA and the Georgetown University Produce Safety Project. SF and DC. http://www.pewhealth.org/uploadedFiles/PHG/Content_Level_Pages/Issue_Briefs/PSP_Summary-SS.pdf.

Malone, B. 2004. Using trees to reduce dust and odour emissions from poultry farms. Proceedings 2004 Poultry Information Exchange. Surfers Paradise, Qld, AU.: 33–38.

McElhany, K. G., and S. D. Pillai. 2011. Prevalence and fate of gut-associated human pathogens in the environment. In *The Fecal Bacteria*. Ed. M. J. Sadowsky and R. L. Whitman. American Society for Microbiology Press, Washington, D.C. 217–37

Mermin, J., L. Hutwagner, et al. 2004. Reptiles, amphibians, and human *Salmonella* infection: A population-based, case-control study. *Clinical Infectious Diseases* 38: S253–S261.

Miller, W. G., and R. E. Mandrell. 2005. Prevalence of *Campylobacter* in the food and water supply: Incidence, outbreaks, isolation and detection. In Campylobacter jejuni: *New Perspectives in Molecular and Cellular Biology.* Ed. J. Ketley and M. E. Konkel. Horizon Scientific Press, Norfolk, UK. 101–63.

Pachepsky, Y. A., A. M. Sadeghi, et al. 2006. Transport and fate of manure-borne pathogens: Modeling perspective. *Agricultural Water Management* 86, nos. 1–2: 81–92.

Pachepsky, Y., D. R. Shelton, et al. 2011. Irrigation waters as a source of pathogenic microorganisms in produce: A review. *Advances in Agronomy* 113: 73–138.
Pedersen, K., and L. Clark. 2007. A review of Shiga toxin *Escherichia coli* and *Salmonella enterica* in cattle and free-ranging birds: Potential association and epidemiological links. *Human-Wildlife Conflicts* 1, no. 1: 68–77.
Vymazal, J. 2005. Removal of enteric bacteria in constructed treatment wetlands with emergent macrophytes: A review. *Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering* 40, nos. 6–7: 1355–67.
West, B. C., A. L. Cooper, and J. B. Armstrong. 2009. Managing wild pigs: A technical guide. Human-Wildlife Interactions Monograph 1:1–55. Available as a free download at: www.berrymaninstitute.org/publications.

References Used in Tables, Figures and Text

Abd-Elall, A. M. M., M. E. M. Mohamed, et al. 2009. Potential airborne microbial hazards for workers on dairy and beef cattle farms in Egypt. *Veterinaria Italiana* 45, no. 2: 275–85.
Abu-Lail, N. I., and T. A. Camesano. 2003. Role of lipopolysaccharides in the adhesion, retention, and transport of *Escherichia coli* JM109. *Environmental Science & Technology* 37, no. 10: 2173–83.
Adrizal, P. H. Patterson, et al. 2008. The potential for plants to trap emissions from farms with laying hens: 2. Ammonia and dust. *Journal of Applied Poultry Research* 17, no. 3: 398-411.
Alam, M. J., and L. Zurek. 2004. Association of *Escherichia coli* O157:H7 with houseflies on a cattle farm. *Applied and Environmental Microbiology* 70, no. 12: 7578–80.
APHIS. 2005. *Salmonella* on U.S. dairy operations: Prevalence and antimicrobial drug susceptibility. Retrieved on January 21, 2014. www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy02/Dairy02_is_Salmonella.pdf.
Atwill, E. R. et al. 2012. Introduction to waterborne pathogens in agricultural watersheds. Nutrient Management Technical Note No. 9.
Atwill, E. R., K. W. Tate, et al. 2006. Efficacy of natural grassland buffers for removal of *Cryptosporidium parvum* in rangeland runoff. *Journal of Food Protection* 69, no. 1: 177-184.
Atwill, E. R., R. A. Sweitzer, et al. 1997. Prevalence of and associated risk factors for shedding *Cryptosporidium* parvum oocysts and *Giardia* cysts within feral pig populations in California. *Applied and Environmental Microbiology* 63, no. 10: 3946–49.
Atwill, E. R., R. Phillips, et al. 2004. Seasonal shedding of multiple *Cryptosporidium* genotypes in California ground squirrels (*Spermophilus beecheyi*). *Applied and Environmental Microbiology* 70, no. 11: 6748–52.
Axelsson-Olsson, D., J. Olofsson, et al. 2010b. Amoebae and algae can prolong the survival of *Campylobacter* species in co-culture. *Experimental Parasitology* 126: 59–64.
Axelsson-Olsson, D., L. Svensson, et al. 2010a. Increase in acid tolerance of *Campylobacer jejuni* through coincubation with amoebae. *Applied and Environmental Microbiology* 76, no. 13: 4194–4200.
Bae et al. 2005. Prevalence and antimicrobial resistance of thermophilic *Campylobacter* spp. from cattle farms in Washington State. *Applied and environmental Microbiology* Jan.: 169–74.
Baertsch, C., T. Paez-Rubio, et al. 2007. Source tracking aerosols released from land-applied Class B biosolids during high-wind events. *Applied and Environmental Microbiology* 73, no. 14: 4522–31.
Baloda, S. et al. 2001. Persistence of *Salmonella enterica* serovar Typhimurium DT12 clone in a piggery and in agricultural soil amended with *Salmonella*-contaminated slurry. *Applied and Environmental Microbiology* 67: 2859–62.
Balzer, M., N. Witt, et al. 2010. Fecal indicator bacteria in river bioflms. *Water Science and Technology* 61, no. 5: 1105–11.

Barak, J. D., and B. K. Schroeder. 2012. Interrelationships of food safety and plant pathology: The life cycle of human pathogens on plants. *Annual Review of Phytopathology*. N. K. VanAlfen, J. E. Leach, and S. Lindow. 50: 241–66.

Beattie, G. A., and S. E. Lindow. 1995. The secret life of foliar bacterial pathogens on leaves. *Annual Review of Phytopathology* 33: 145–72.

Benjamin, L. A., and M. T. Jay-Russell, E. R. Atwill, M. B. Cooley, D. Carychao, R. E. Larsen and R. E. Mandrell. 2014. Risk factors for *Escherichia coli* O157 on beef cattle ranches located near a major produce production region. *Epidemiology and Infection*. 1–13.

Benjamin, L., E. R. Atwill, M. Jay-Russell, M. Cooley, D. Carychao, L. Gorski, R. E. Mandrell. 2013. Occurrence of generic *Escherichia coli*, *E. coli* O157 and *Salmonella* spp. in water and sediment from leafy green produce farms and streams on the Central California coast. *International Journal of Food Microbiology* 165: 65-76.

Berry, E. 2011–2012. *Escherichia coli* O157:H7 in bioaerosols from cattle production areas: Evaluation of proximity and airborne transport on leafy green crop contamination—Poster of proposed work. Center for Produce Safety.

Berry, E. D., and J. E. Wells. 2010. *Escherichia coli* O157:H7: Recent advances in research on occurrence, transmission, and control in cattle and the production environment. *Advances in Food and Nutrition Research* 60: 67–117.

Berry, E. D., B. L. Woodbury, et al. 2007. Incidence and persistence of zoonotic bacterial and protozoan pathogens in a beef cattle feedlot runoff control-vegetative treatment system. *Journal of Environmental Quality* 36, no. 6: 1873-1882.

Bogosian, G., L. E. Sammons, et al. 1996. Death of the *Escherichia coli* K-12 strain W3110 in soil and water. *Applied and Environmental Microbiology* 62, no. 11: 4114–20.

Bolton, D. et al. 1999. The survival characteristics of a non-toxigenic strain of *Escherichia coli* O157:H7. *Journal of Applied Microbiology* 86: 407–11.

Bolton, H., L. F. Elliott, et al. 1985. Soil microbial biomass and selected soil enzyme-activities—Effect of fertilization and cropping practices. *Soil Biology & Biochemistry* 17, no. 3: 297–302.

Boyle, M., C. Sichel, et al. 2008. Bactericidal effect of solar water disinfection under real sunlight conditions. *Applied and Environmental Microbiology* 74. no. 10: 2997–3001.

Brandl, M. T. 2006. Fitness of human enteric pathogens on plants and implications for food safety. *Annual Review of Phytopathology* 44: 367–92.

Brandl, M. T., B. M. Rosenthal, et al. 2005. Enhanced survival of *Salmonella enterica* in vesicles released by a soilborne *Tetrahymena* species. *Applied and Environmental Microbiology* 71, no. 3: 1562–69.

Branham, L. A., M. A. Carr, et al. 2005. *E-coli* O157 and *Salmonella* spp. in white-tailed deer and livestock. *Current Issues in Intestinal Microbiology* 6, no. 2: 25–29.

Brenner, D. J. e. 1984. *Enterobacteriaceaae*. Baltimore, MD: William and Wilkins Co.

Brenner, D., G. Lewbart, et al. 2002. Health survey of wild and captive bog turtles (*Clemmys muhlenbergii*) in North Carolina and Virginia. *Journal of Zoo and Wildlife Medicine* 33, no. 4: 311–16.

Brenner, F. W., R. G. Villar, et al. 2000. *Salmonella* nomenclature—Guest commentary. *Journal of Clinical Microbiology* 38, no. 7: 2465–67.

Brinton, W. F., P. Storms, et al. 2009. Occurrence and levels of fecal indicators and pathogenic bacteria in market-ready recycled organic matter composts. *Journal of Food Protection* 72, no. 2: 332–39.

Burley, H. K., A. Adrizal, et al. 2011. The potential of vegetative buffers to reduce dust and respiratory virus transmission from commercial poultry farms. *Journal of Applied Poultry Research* 20, no. 2: 210–22.

Byappanahalli, M. N., and S. Ishii. 2011. Environmental sources of fecal bacteria. In *The Fecal bacteria.* Ed. M. J. Sadowsky and R. L. Whitman. American Society for Microbiology Press, Washington, D.C. 93–110.

Byappanahalli, M. N., R. L. Whitman, et al. 2006. Population structure, persistence, and seasonality of autochthonous *Escherichia coli* in temperate, coastal forest soil from a Great Lakes watershed. *Environmental Microbiology* 8, no. 3: 504–13.

Cambre, R. C., D. E. Green, et al. 1980. Salmonellosis and Arizonosis in the reptile collection at the national-zoological-park. *Journal of the American Veterinary Medical Association* 177, no. 9: 800–803.

Carlson, J. C., A. B. Franklin, et al. 2011. The role of starlings in the spread of *Salmonella* within concentrated animal feeding operations. *Journal of Applied Ecology* 48, no. 2: 479–86.

Center for Disease Control. 2012. Foodborne outbreaks. http://www.cdc.gov/foodsafety/outbreaks/index.html. Retrieved on February 2012.

Centers for Disease Control and Prevention CD. 2008. Outbreak of *Salmonella* serotype Saintpaul infections associated with multiple raw produce items—United States 2008. MMWR 57, 929–934. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5734a1.htm.

Chambers, D. L., and A. C. Hulse. 2006. *Salmonella* serovars in the herpetofauna of Indiana County, Pennsylvania. *Applied and Environmental Microbiology* 72, no. 5: 3771–73.

Collins, R., A. Donnison, et al. 2004. Attenuation of effluent-derived fecal microbes in grass buffer strips. *New Zealand Journal of Agricultural Research* 47: 565–74.

Collins, R., and K. Rutherford. 2004. Modeling bacterial water quality in streams draining pastoral land. *Water Research* 38: 700–712.

Compton, J. A., J. A. Baney, et al. 2008. *Salmonella* infections in the common raccoon (*Procyon lotor*) in western Pennsylvania. *Journal of Clinical Microbiology* 469: 3084–86.

Converse, K., M. Wolcott, D. Docherty, and R. Cole. 1999. Screening for potential human pathogens in fecal material deposited by resident Canada geese on areas of public utility. USGS National Wildlife Heath Center.

Cooley, M. B., B. Quiñones, et al. 2014. Prevalence of Shiga toxin producing *Escherichia coli*, *Salmonella enterica*, and *Listeria monocytogenes* at public access watershed sites in a California central coast agricultural region. *Frontiers in Cellular and Infection Microbiology* 4, no. 30.

Cote, C., and S. Quessy. 2005. Persistence of *Escherichia coli* and *Salmonella* in surface soil following application of liquid hog manure for production of pickling cucumbers. *Journal of Food Protection* 68: 900–905.

Coyne, M. S., R. A. Gilfillen, et al. 1998. Fecal bacteria trapping by grass filter strips during simulated rain. *Journal of Soil and Water Conservation* 53, no. 2: 140–45.

Crane, S. R., and J. A. Moore. 1985. Modeling enteric bacterial die-off—A review. *Water Air and Soil Pollution* 27, no. 3–4: 411–39.

Crump, J. A., C. R. Braden, M. E. Dey, R. M. Hoekstra, J. M. Rickelman-Apisa, D. A. Baldwin, S. J. De Fijter, S. F. Nowicki, E. M. Koch, T. L. Bannerman, F. W. Smith, J. P. Sarisky, N. Hochberg, and P. S. Mead. 2003. Outbreaks of *Escherichia coli* O157 infections at multiple county agricultural fairs: A hazard of mixing cattle, concession stands and children. *Epidemiology and Infection* 131: 1055–62.

Czajkowska, D., H. Boszczyk-Maleszak, et al. 2008. Studies on the survival of enterohemorrhagic and environmental *Escherichia coli* strains in wastewater and in activated sludges from dairy sewage treatment plants. *Polish Journal of Microbiology* 57, no. 2: 165–71.

Desmarais, T. R., H. M. Solo-Gabriele, et al. 2002. Influence of soil on fecal indicator organisms in a tidally influenced subtropical environment. *Applied and Environmental Microbiology* 68, no. 3: 1165–72.

Diallo, M. B., A. J. Anceno, et al. 2009. GIS-based analysis of the fate of waste-related pathogens *Cryptosporidium parvum*, *Giardia lamblia* and *Escherichia coli* in a tropical canal network. *Journal of Water and Health* 7, no. 1: 133–43.

Diaz, F. J., A. T. O'Green, et al. 2010. Efficacy of constructed wetlands for removal of bacterial contamination from agricultural return flows. *Agricultural Water Management* 97: 1813–21.

Dunn, J. R., J. E. Keen, et al. 2004. Prevalence of *Escherichia coli* O157:H7 in white-tailed deer from Louisiana. *Journal of Wildlife Diseases* 40, no. 2: 361–65.

Elder, R. O., J. E. Keen, G. R. Siragusa, et al. 2000. Correlation of enterohemorrhagic *Escherichia coli* O157 prevalence in feces, hides, and carcasses of beef cattle during processing. *Proceedings of the National Academy of Sciences of the United States of America* 97, no. 7: 2999–3003.

Englen et al. 2006. Prevalence and antimicrobial resistance of *Campylobacter* in US dairy cattle. *Journal of Applied Microbiology* 102: 1570–77.

Entry, J. A., R. K. Hubbard, et al. 2000. The influence of vegetation in riparian filterstrips on coliform bacteria: II. Survival in soils. *Journal of Environmental Quality* 29, no. 4: 1215–24.

Erickson, M. C., J. Liao, et al. 2009. Inactivation of *Salmonella* spp. in cow manure composts formulated to different initial C:N ratios. *Bioresource Technology* 100, no. 23: 5898–5903.

Faith et al. 1996. Prevalence and clonal nature of *Escherichia coli* O157:H7 on dairy farms in Wisconsin. *Applied and Environmental Microbiology* 62, no. 5: 1519–25.

Fenlon, D. R., I. D. Ogden, et al. 2000. The fate of *Escherichia coli* and *E. coli* O157 in cattle slurry after application to land. *Journal of Applied Microbiology* Symposium Supplement 88: 149S–156S.

Fischer, J. R., T. Zhao, et al. 2001. Experimental and field studies of *Escherichia coli* O157:H7 in white-tailed deer. *Applied and Environmental Microbiology* 67, no. 3: 1218–24.

Fouks, B., and H. M. G. Lattorff. 2011. Recognition and avoidance of contaminated flowers by foraging bumblebees (*Bombus terrestris*). *Plos One* 6, no. 10.

Franz, E. et al. 2008. Modeling the contamination of lettuce with *Escherichia coli* O157:H7 from manure-amended soil and the effect of intervention strategies. *Journal of Applied Microbiology* 105: 1569–84.

Fraser, D. G., J. W. Doran, et al. 1988. Soil microbial-populations and activities under conventional and organic management. *Journal of Environmental Quality* 17, no. 4: 585–90.

Fremaux, B., C. Prigent-Combaret, et al. 2008. Persistence of Shiga toxin-producing *Escherichia coli* O26 in various manure-amended soil types. *Journal of Applied Microbiology* 104, no. 1: 296–304.

Fujioka, R. S., and B. S. Yoneyama. 2002. Sunlight inactivation of human enteric viruses and fecal bacteria. *Water Science and Technology* 46, no. 11–12: 291–95.

Gaertner, J. P., D. Hahn, et al. 2008. Detection of *Salmonellae* in captive and free-ranging turtles using enrichment culture and polymerase chain reaction. *Journal of Herpetology* 42, no. 2: 223–31.

Gagliardi, J. V., and J. S. Karns. 2002. Persistence of *Escherichia coli* O157:H7 in soil and on plant roots. *Environmental Microbiology* 4, no. 2: 89–96.

Garcia, R., J. Baelum, et al. 2010. Influence of temperature and predation on survival of *Salmonella enterica* serovar *typhimurium* and expression of invA in soil and manure-amended soil. *Applied and Environmental Microbiology* 76, no. 15: 5025–31.

Gaukler, S. M., G. M. Linz, et al. 2009. *Escherichia coli*, *Salmonella*, and *Mycobacterium avium* subsp *paratuberculosis* in Wild European Starlings at a Kansas cattle feedlot. *Avian Diseases* 53, no. 4: 544–51.

Gaukler, S. M., H. J. Homan, N. W. Dyer, G. M. Linz, and W. J. Beier. 2008. Pathogenic diseases and movements of wintering European starlings using feedlots in central Kansas. *Proceedings of Vertebrate Pest Conference*, no. 23: 280–82.

Gessel, P. D., N. C. Hansen, et al. 2004. Persistence of zoonotic pathogens in surface soil treated with different rates of liquid pig manure. *Applied Soil Ecology* 25, no. 3: 237–43.

Girardin, H. et al. 2005. Behavior of the pathogen surrogates *Listeria innocua* and *Clostridium sporogenes* during production of parsley in fields fertilized with contaminated amendments. *FEMS Microbiology Ecology* 54: 287–95.

Gordus, A., R. Mandrell, and E. R. Atwill. 2011. Wildlife survey for *E. coli* O157:H7 and *Salmonella* in the central coastal counties of California. Center for Produce Safety poster session.

Gorski, L., M. T. Jay-Russell, A. S. Liang, S. Walker, Y. Bengson, J. Govoni, and R. E. Mandrell. 2013. Diversity of pulsed-field gel electrophoresis pulsotypes, serovars, and antibiotic resistance among *Salmonella* isolates from wild amphibians and reptiles in the California central coast. *Foodborne Pathogens and Disease* 10, no. 6.

Graczyk, T. K., F. E. Lucy, et al. 2009. Propagation of human enteropathogens in constructed horizontal wetlands used for tertiary wastewater treatment. *Applied and Environmental Microbiology* 75, no. 13: 4531–38.

Gray, M. J., S. Rajeev, et al. 2007. Preliminary evidence that American bullfrogs (*Rana catesbeiana*) are suitable hosts for *Escherichia coli* O157:H7. *Applied and Environmental Microbiology* 73, no. 12: 4066–68.

Gray, M. L., and A. H. Killinger. 1966. *Listeria monocytogenes* and listeric infections. *Bacteriological reviews* 30, no. 2: 309-382.

Greene, S. K., E. R. Daly, E. A. Talbot, L. J. Demma, N. Holzbauer, N. J. Patel, T. A. Hill, M. A. Walderhaug, R. Hoekstra, M. F. Lynch, and J. A. Painter. 2008. Recurrent multistate outbreak of *Salmonella* Newport associated with tomatoes from contaminated fields, 2005. *Epicemiol. Infect*. 136, 157–65.

Guan, T. Y., and R. A. Holley. 2003. Pathogen survival in swine manure environments and transmission of human enteric illness: A review. *Journal of Environmental Quality* 32, no. 2: 383–92.

Guber, A. K., A. M. Yakirevich, et al. 2009. Uncertainty Evaluation of Coliform Bacteria Removal from Vegetated Filter Strip under Overland Flow Condition. *Journal of Environmental Quality* 38, no. 4: 1636-1644.

Guzewich, J., FDA Center for Food Safety and Applied Nutrition Presented by Robert Buchanan University of Maryland. 2011. Multi-state outbreak of human *E. coli* O145 infections linked to shredded romaine lettuce from a single processing facility. IAFP European Sysmposium, Ede, The Netherlands.

Hadar, Y., and K. K. Papadopoulou. 2012. Suppressive composts: Microbial ecology links between abiotic environments and healthy plants. *Annual Review of Phytopathology*. N. K. VanAlfen, J. E. Leach, and S. Lindow. Palo Alto, Annual Reviews. 50: 133–53.

Hancock et al. 1998b. Multiple sources of *Escherichia coli* O157 in feedlots and dairy farms in the Northwestern USA. *Preventive Veterinary Medicine* 35, no. 1: 11–19.

Hancock, D. D., T. E. Besser, et al. 1998. Multiple sources of *Escherichia coli* O157 in feedlots and dairy farms in the northwestern USA. *Preventive Veterinary Medicine* 35, no. 1: 11–19.

Hench, K. R., G. K. Bissonnette, et al. 2003. Fate of physical, chemical and microbial contaminants in domestic wastewater following treatment by small constructed wetlands. *Water Research* 37: 921–27.

Heringa, S. D., J. Kim, et al. 2010. Use of a mixture of bacteriophages for biological control of *Salmonella enterica* strains in compost. *Applied and Environmental Microbiology* 76, no. 15: 5327–32.

Hernandez, G. 2012. Odor mitigation with tree buffers: Swine production case study. *Agriculture, Ecosystems and Environment* 149: 154-163.

Heuvel, A. V, C. McDermott, et al. 2010. The green alga, *Cladophora*, promotes *Ecscherichia coli* growth and contamination of recreational waters in Lake Michigan. *Journal of Environmental Quality* 39: 333–44.

Heuvelink, A. E., F. L. A. M. Van Den Biggelaar, J. T. M. Zwartkruis-Nahuis, et al. 1998. Occurrence of verocytotoxin-producing *Escherichia coli* O157 on Dutch dairy farms. *Journal of Clinical Microbiology* 36, no. 12: 3480–87.

Hill, V. 2003. Prospects for pathogen reductions in livestock wastewaters: A review. *Critical Reviews in Environmental Science and Technology* 33, no. 2: 187–235.

Hilton, A. C., R. J. Willis, et al. 2002. Isolation of Salmonella from urban wild brown rats *Rattus norvegicus* in the West Midlands, UK. *International Journal of Environmental Health Research* 12, no. 2: 163–68.

Hoar et al. 1999. Comparison of fecal samples collected per rectum and off the ground for estimation of environmental contamination attributable to beef cattle. *American Journal of Veterinary Research* 60, no. 11: 1352–56.

Hoitink, H. A. J., and M. E. Grebus. 1994. Status of biological control of plant disease with composts. *Compost Science and Utilization* 2, no. 2: 6–12.

Holt, P. S., B. W. Mitchell, et al. 1998. Airborne horizontal transmission of *Salmonella enteritidis* in molted laying chickens. *Avian Diseases* 42, no. 1: 45–52.

Hugh-Jonesa, M., W. H. Allana, F. A. Darka, and G. J. Harpera. 1973. The evidence for the airborne spread of Newcastle Disease. *Journal of Hygiene* 71, no. 2: 325-339.

Hutchison, M. et al. 2005. Analyses of livestock production, waste storage, and pathogen levels and prevalences in farm manures. *Applied and Environmental Microbiology* 71: 1231–36.

Ibekwe, A. M., and J. Ma. 2011. Effects of fumigants on microbial diversity and persistence of *E. coli* O15:H7 in contrasting soil microcosms. *Science of the Total Environment* 409, no. 19: 3740–48.

Ibekwe, A. M., M. Leddy, et al. 2013. Potential human pathogenic bacteria in a mixed urban watershed as revealed by pyrosequencing. *PLoS One* 8, no. 11: 1–9.

Ibekwe, A. M., P. M. Watt, et al. 2004. Fate of *Escherichia coli* O157:H7 in irrigation water on soils and plants as validated by culture method and real-time PCR. *Canadian Journal of Microbiology* 50, no. 12: 1007–14.

Ibekwe, A. M., S. K. Papiernik, C. M. Grieve, and C. Yang. 2011. Quantification of persistance of *E. coli* O157:H7 in contrasting soils. *International Journal of Microbiology*.

Ignoffo, C. M., and C. Garcia. 1978. UV-photoinactivation of cells and spores of *Bacillus-thuringiensis* and effects of peroxidase on inactivation. *Environmental Entomology* 7, no. 2: 270–72.

Islam, M. et al. 2004. Persistence of *Salmonella enterica* serovar Typhimurium on lettuce and parsley and in soils on which they were grown in fields treated with contaminated manure composts or irrigation water. *Foodborne Pathogens and Disease* 1: 27–35.

Islam, M. et al. 2005. Survival of *Escherichia coli* O157:H7 in soil and on carrots and onions grown in fields treated with contaminated manure composts or irrigation water. *Food Microbiology* 22: 63–70.

Jacobsen, C. S., and T. B. Bech. 2012. Soil survival of *Salmonella* and transfer to freshwater and fresh produce. *Food Research International* 45, no. 2: 557–66.

Jay-Russell, M. T., A. Bates, L. Harden, W. G. Miller, and R. E. Mandrell. 2012. Isolation of *Campylobacter* from feral swine (*Sus scrofa*) on the ranch associated with the 2006 *Escherichia coli* O157:H7 spinach outbreak investigation in California. Zoonoses and Public Health.

Jay-Russell, M. T., E. R. Atwill, M. Cooley, D. Carychao, E. Vivas, S. Chandler, D. Orthmeyer, X. Li, and R. E. Mandrell. 2010. Occurrence of *Escherichia coli* O157:H7 in wildlife in a major produce production region in California. 110th General Meeting of the American Society for Microbiology. San Diego, California, USA, Western Center for Food Safety, Western Institute for Food Safety and Security.

Jay, M. T., M. Cooley, et al. 2007. *Escherichia coli* O157:H7 in feral swine near spinach fields and cattle, central California coast. *Emerging Infectious Diseases* 13, no. 12: 1908–11.

Jechalke, S., C. Kopmann, et al. 2013. Increased abundance and transferability of resistance genes after field application of manure from sulfadiazine-treated pigs. *Applied and Environmental Microbiology* 79, no. 5: 1704–11.
Jiang, X. et al. 2002. Fate of *Escherichia coli* O157:H7 in manure-amended soil. *Applied and Environmental Microbiology* 68: 2605–9.
Jiang, X. et al. 2004. Fate of *Listeria monocytogenes* in bovine manure-amended soil. *Journal of Food Protection* 8: 1676–81.
Jiang, X. P., J. Morgan, et al. 2002. Fate of *Escherichia coli* O157:H7 in manure-amended soil. *Applied and Environmental Microbiology* 68, no. 5: 2605–9.
Johannessen, G. S., G. B. Bengtsson, et al. 2005. Potential uptake of *Escherichia coli* O157:H7 from organic manure into crisphead lettuce. *Applied and Environmental Microbiology* 71, no. 5: 2221–25.
Johnson, Y., N. Gedamu, M. Salem, M. Colby, and B. Gebert. 2001. Application of a geographical information system database in the analysis of wind-associated transmission of laryngotrachetis. Proceedings of the 73rd Northeastern Conference on Avian Diseases, College Park, MD.
Kangas, S., J. Takkinen, et al. 2008. *Yersinia pseudotuberculosis* O:1 traced to raw carrots, Finland. *Emerging Infectious Diseases* 14, no. 12: 1959–61.
Keen, J. E., T. E. Wittum, et al. 2006. Shiga-toxigenic *Escherichia coli* O157 in agricultural fair livestock, United States. *Emerging Infectious Diseases* 12, no. 5: 780–86.
Kim, J., and X. Jiang. 2010. The growth potential of *Escherichia coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* in dairy manure-based compost in a greenhouse setting under different seasons. *Journal of Applied Microbiology* 109, no. 6: 2095–2104.
Kim, J., F. Luo, et al. 2009. Factors impacting the regrowth of *Escherichia coli* O157:H7 in dairy manure compost. *Journal of Food Protection* 72, no. 7: 1576–84. Kim, J., C. Miller, M. Shephard, X. Liu, and X. Jiang. 2011. Impact of indigenous microorganisms on *Escherichia coli* O157:H7 growth in cured compost. *Bioresource Technology* 102: 9619–25.
Kirchner, M. J., A. G. Wollum, et al. 1993. Soil microbial-populations and activities in reduced chemical input agroecosystems. *Soil Science Society of America Journal* 57, no. 5: 1289–95.
Kirk, J. H., C. A. Holmberg, et al. 2002. Prevalence of *Salmonella* spp in selected birds captured on California dairies. *Journal of the American Veterinary Medical Association* 220, no. 3: 359–62.
Knox, A. K., K. W. Tate, et al. 2007. Management reduces *E. coli* in irrigated pasture runoff. *California Agriculture* 61, no. 4: 159–65.
Knox, A. K., R. A. Dahlgren, et al. 2008. Efficacy of natural wetlands to retain nutrient, sediment and microbial pollutants. *Journal of Environmental Quality* 37, no. 5: 1837–46.
Koelsch, R. K., J. Lorimer, et al. 2006. Vegetative treatment systems for management of open lot runoff: Review of literature. *Applied Engineering in Agriculture* 22, no. 1: 141–53.
Korhonen, L. K., and P. J. Martlkalnen. 1991. Survival of *Escherichia coli* and *Campylobacter jejuni* in untreated and filtered lake water. *Journal of Applied Bacteriology* 71: 379–82.
Kudva, I. T., K. Blanch, et al. 1998. Analysis of *Escherichia coli* O157:H7 survival in ovine or bovine manure and manure slurry. *Applied and Environmental Microbiology* 64, no. 9: 3166–74.
Kuhnert, P., C. R. Dubossom, M. Roesch, et al. 2005. Prevalence and risk-factor analysis of Shiga toxigenic *Escherichia coli* in faecal samples of organically and conventionally farmed dairy cattle. *Veterinary Microbiology* 109, no. 1–2: 37–45.
Kullas, H., M. Coles, et al. 2002. Prevalence of *Escherichia coli* serogroups and human virulence factors in faeces of urban Canada geese (*Branta canadensis*). *International Journal of Environmental Health Research* 12, no. 2: 153–62.
Laidler, M., M. Tourdjman, G. Buser, T. Hosteler, K. Repp, R. Leman, M. Samadpour, and W. Keene. 2013. *Escherichia coli* O157:H7 infections associated with consumption of locally grown strawberries contaminated by deer. *Journals of the Royal Society of Tropical Medicine and Hygiene*.

LeJeune, J., J. Homan, G. Linz, and D. L. Pearl. 2008. Role of the European starling in the transmission of *E. coli* O157:H7 on dairy farms. Proceedings of the 23rd Vertebrate Pest Conference: 31–34.
Lewis, D. J., E. R. Atwill, et al. 2010. Management of microbial contamination in storm runoff from California coastal dairy pastures. *Journal of Environmental Quality* 39, no. 5: 1782–89.
Li, X., Rob Atwill, Eduardo Vivas, Tamara Vodovoz, Jennifer Carabez, Chengling Xiao, and Michele Jay-Russell. 2012. Deer mouse (*Peromyscus maniculatus*) as a vector of foodborne protozoa adjacent to produce fields. Vertebrate Pest Control Conference 2012.
Liang, Z. B., Z. L. He, et al. 2011. Survival of *Escherichia coli* in soil with modified microbial community composition. *Soil Biology & Biochemistry* 43, no. 7: 1591–99.
Lopez-Velasco, G., H. A. Tydings, et al. 2012. Characterization of interactions between *Escherichia coli* O157:H7 with epiphytic bacteria in vitro and on spinach leaf surfaces. *International Journal of Food Microbiology* 153, no. 3: 351–57.
Luechtefeld, N. A. W., M. J. Blaser, et al. 1980. Isolation of *Campylobacter-fetus* subsp *jejuni* from migratory waterfowl. *Journal of Clinical Microbiology* 12, no. 3: 406–8.
Luety, T. 2004. Using shelterbelts to reduce odors as- sociated with livestock production barns. Ministry of Agriculture, Food, and Rural Affairs. Ontario, CA http://www.omafra.gov.on.ca/english/crops/facts/info_odours.htm Accessed Mar 2012.
Lyautey, E., A. Hartmann, et al. 2007. Characteristics and frequency of detection of fecal *Listeria monocytogenes* shed by livestock, wildlife, and humans. *Canadian Journal of Microbiology* 53, no. 10: 1158–67.
Lyautey, E., D. R. Lapen, et al. 2007. Distribution and characteristics of *Listeria monocytogenes* isolates from surface waters of the South Nation River watershed, Ontario, Canada. *Applied and Environmental Microbiology* 73, no. 17: 5401–10.
Ma, J. C., A. M. Ibekwe, et al. 2012. Persistence of *Escherichia coli* O157:H7 in major leafy green producing soils. *Environmental Science & Technology* 46, no. 21: 12154–61.
Ma, J. et al. 2011. Persistence of *Escherichia coli* O157:H7 and its mutants in soils. *PLOS One* 6: no. 8: e23191. doi:10.1371/journal.pone.0023191
Mallin, M. A., K. E. Williams, et al. 2000. Effect of human development on bacteriological water quality in coastal watersheds. *Ecological Applications* 10, no. 4: 1047–56.
Malone, B. 2004. Using trees to reduce dust and odour emissions from poultry farms. Proceedings of 2004 Poultry Information Exchange Surfers Paradise, Qld, AU.: 33-38.
Mandrell, R. E., M. H. Chapman, M. Jay-Russell, E. R. Atwill, E. Yee, A. H. Bates, S. C. Chandler, D. L. Orthmeyer, A. Gordus, and W. G. Miller. 2010. Incidence of *Campylobacter* species in livestock, wildlife and watersheds in a major produce production region of California. American Society for Microbiology—conference abstract.
Mankin, K. P., P. L. Barnes, et al. 2006. Field evaluation of vegetative filter effectiveness and runoff quality from unstocked feedlots. *Journal of Soil and Water Conservation* 61, no. 4: 209–17.
Martyny, J. W., and R. G. Botzler 1975. *Listeria monocytogenes* isolated from wapiti (*Cervus canadensis roosevelti*). *Journal of Wildlife Diseases* 11: 330-334.
Matos, A., L. Kerkhof, et al. 2005. Effects of microbial community diversity on the survival of *Pseudomonas aeruginosa* in the wheat rhizosphere. *Microbial Ecology* 49, no. 2: 257–64.
Maule, A. 2000. Survival of verocytotoxigenic *Escherichia coli* O157 in soil, water and on surfaces. *Journal of Applied Microbiology* 88: 71S–78S.
McElhany, K. G., and S. D. Pillai. 2011. Prevalence and fate of gut-associated human pathogens in the environment. In *The Fecal Bacteria*. Ed. M. Sadowsky and R. Whitman. American Society for Microbiology Press, Washington, D.C. 217-37.
McLaughlin, J., and B. D. Gessner. 2008. *Campylobacteriosis* outbreak due to consumption of raw peas—Alaska, 2008. State of Alaska Epidemiology Bulletin, no. 20.

Mermin, J., L. Hutwagner, et al. 2004. Reptiles, amphibians, and human *Salmonella* infection: A population-based, case-control study. *Clinical Infectious Diseases* 38: S253–S261.
Milani, J. F., H. Wilson, M. Ziccardi, R. LeFebvre, and C. Scott. 2012. Hematology, plasma chemistry, and bacteriology of wild tundra swans (*Cygnus columbianus*) in Alaska. *Journal of Wildlife Diseases* 48, no. 1: 212–15.
Miller, M. F., G. H. Loneragan, et al. 2008. Environmental dust exposure as a factor contributing to an increase in *Escherichia coli* O157 and *Salmonella* populations on cattle hides in feedyards. *Journal of Food Protection* 71, no. 10: 2078–81.
Morishita, T. Y., P. P. Aye, et al. 1999. Survey of pathogens and blood parasites in free-living passerines. *Avian Diseases* 43, no. 3: 549–52.
Moyne, A. L., M. R. Sudarshana, et al. 2011. Fate of *Escherichia coli* O157:H7 in field-inoculated lettuce. *Food Microbiology* 28, no. 8: 1417–25.
Mukherjee, A. et al. 2006. Soil survival of *Escherichia coli* O157:H7 acquired by a child from garden soil recently fertilized with cattle manure. *Journal of Applied Microbiology* 101: 429–36.
NAHMS. 2000. *Salmonella enterica* serotype *enteritidis* in table egg layers in the U.S. Retrieved on January 21, 2014. http://www.aphis.usda.gov/animal_health/nahms/poultry/downloads/layers99/Layers99_dr_Salmonella.pdf.
Natvig, E. E., S. C. Ingham, et al. 2002. *Salmonella enterica* serovar *typhimurium* and *Escherichia coli* contamination of root and leaf vegetables grown in soils with incorporated bovine manure. *Applied and Environmental Microbiology* 68, no. 6: 2737–44.
Newsham, K. K., M. N. R. Low, et al. 1997. Ultraviolet-B radiation influences the abundance and distribution of phylloplane fungi on pedunculate oak (*Quercus robur*). *New Phytologist* 136, no. 2: 287–97.
Nicholson, F. A., S. J. Groves, et al. 2005. Pathogen survival during livestock manure storage and following land application. *Bioresource Technology* 96, no. 2: 135–43.
Nwosu, V. C. 2001. Antibiotic resistance with particular reference to soil microorganisms. *Research in Microbiology* 152, no. 5: 421–30.
Nyberg, K. A., B. Vinneråsa, J. R. Ottosona, P. Aronssond, and A. Albihna. 2010. Inactivation of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium in manure-amended soils studied in outdoor lysimeters. *Applied Soil Ecology* 46: 398–404.
Ogden, I. D., D. R. Fenlon, et al. 2001. The fate of *Escherichia coli* O157 in soil and its potential to contaminate drinking water. *International Journal of Food Microbiology* 66, nos. 1–2: 111–17.
Ogden, I. et al. 2002. Long-term survival of *Escherichia coli* O157 on pasture following an outbreak associated with sheep at a scout camp. *Letters in Applied Microbiology* 34: 100–104.
Oliver, D. M., A. L. Heathwaite, et al. 2007b. Mitigation and current management attempts to limit pathogen survival and movement within farmed grassland. *Advances in Agronomy* 93: 95–152.
Ongeng, D. et al. 2011. Survival of *Escherichia coli* O157:H7 and *Salmonella enterica* serovar Typhimurium in manure and manure-amended soil under tropical climatic conditions in Sub-Saharan Africa. *Journal of Applied Microbiology* 110: 1007–1022.
Oyarzabal, O. A., D. E. Conner, et al. 1995. Incidence of *Campylobacters* in the intestine of avian species in Alabama. *Avian Diseases* 39, no. 1: 147–51.
Pachepsky, Y., D. R. Shelton, et al. 2011. Irrigation waters as a source of pathogenic microorganisms in produce: A Review. *Advances in Agronomy* 113: 73–138.
Paniel, N. et al. 2010. Assessment of survival of *Listeria monocytogenes*, *Salmonella infantis* and *Enterococcus faecalis* artificially inoculated into experimental waste or compost. *Journal of Applied Microbiology* 108: 1797–1809.
Patel, J. 2013. Glucosinolate-derived compounds as a green manure for controlling *E. coli* O157:H7 and *Salmonella* in soil. *Center for Produce Safety Interim Report*.

Patel, J. et al. 2010. Persistence of enterohaemorrhagic and nonpathogenic *E. coli* on spinach leaves and in rhizosphere soil. *Journal of Applied Microbiology* 108: 1789–96.
Pedersen, K., L. Clark, et al. 2006. Prevalence of shiga toxin-producing *Escherichia coli* and *Salmonella enterica* in rock pigeons captured in Fort Collins, Colorado. *Journal of Wildlife Diseases* 42, no. 1: 46–55.
Peng, X. 2008. Evaluation of the effect of temperature on the die-off rate for *Cryptosporidium parvum* oocysts in water, soils, and feces. *Applied and Environmental Microbiology* 74: 7101–7.
Popescu, S., C. Borda, et al. 2011. Microbiological air quality in tie-stall dairy barns and some factors that influence it. *African Journal of Agricultural Research* 6, no. 32: 6726–34.
poster session.
Powlson, D. S., P. C. Brookes, et al. 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic-matter due to straw incorporation. *Soil Biology & Biochemistry* 19, no. 2: 159–64.
Puri, A., and E. G. Dudley. 2010. Influence of indigenous eukaryotic microbial communities on the reduction of *Escherichia coli* O157:H7 in compost slurry. *Fems Microbiology Letters* 313, no. 2: 148–54.
Readel, A. M., C. A. Phillips, et al. 2010. Prevalence of *Salmonella* in intestinal mucosal samples from free-ranging red-eared sliders (*Trachemys scripta elegans*) in Illinois. *Herpetological Conservation and Biology* 5, no. 2: 207–13.
Recorbet, G., C. Steinberg, et al. 1992. Survival in soil of genetically engineered *Escherichia-coli* as related to inoculum density, predation and competition. *Fems Microbiology Ecology* 101, no. 4: 251–60.
Reddy, K. R., R. Khaleel, et al. 1981. Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. *Journal of Environmental Quality* 10, no. 3: 255–66.
Renter, D. G., D. P. Gnad, et al. 2006. Prevalence and serovars of *Salmonella* in the feces of free-ranging white-tailed deer (*Odocoileus virginianus*) in Nebraska. *Journal of Wildlife Diseases* 42, no. 3: 699–703.
Renter, D. G., J. M. Sargeant, et al. 2001. *Escherichia coli* O157:H7 in free-ranging deer in Nebraska. *Journal of Wildlife Diseases* 37, no. 4: 755–60.
Renter, D. G., J. M. Sargeant, et al. 2003. Diversity, frequency, and persistence of *Escherichia coli* O157 strains from range cattle environments. *Applied and Environmental Microbiology* 69, no. 1: 542–47.
Richards, J. M., J. D. Brown, et al. 2004. Absence of detectable *Salmonella* cloacal shedding in free-living reptiles on admission to the wildlife center of Virginia. *Journal of Zoo and Wildlife Medicine* 35, no. 4: 562–63.
Riemann et al. 1998. A survey for *Salmonella* by drag swabbing manure piles in California egg ranches. *Avian Diseases* 42: 67–71.
Rodriguez et al. 2006. Prevalence of *Salmonella* in diverse environmental farm samples. *Journal of Food Protection* 69, no. 11: 2576–80.
Roodsari, R. M., D. R. Shelton, et al. 2005. Fecal coliform transport as affected by surface condition. *Transactions of the ASAE* 48, no. 3: 1055–61.
Ros, M., S. Klammer, et al. 2006. Long-term effects of compost amendment of soil on functional and structural diversity and microbial activity. *Soil Use and Management* 22, no. 2: 209–18.
Rosas, I., E. Salinas, et al. 1997. *Escherichia coli* in settled-dust and air samples collected in residential environments in Mexico City. *Applied and Environmental Microbiology* 63, no. 10: 4093–95.
Rutledge, M., R. M. Siletzky, W.. Gu, L. A. Degernes, C. E. Moorman, C. S. DePerno, and S. Kathariou. 2013. Characterization of *Campylobacter* from resident Canada geese in an urban environment. *Journal of Wildlife Diseases* 49, no. 1: 1–9.

Saelinger, C. A., G. A. Lewbart, et al. 2006. Prevalence of *Salmonella* spp in cloacal, fecal, and gastrointestinal mucosal samples from wild North American turtles. *JAVMA—Journal of the American Veterinary Medical Association* 229, no. 2: 266–68.

Salvucci, A. E., W. Zhang, et al. 2009. The impact of biofilm-forming potential and tafi production on transport of environmental *Salmonella* through unsaturated porous media. *Biologia* 64, no. 3: 460–64.

Samadpour, N., J. Stewart, et al. 2002. Laboratory investigation of an *E-coli* O157:H7 outbreak associated with swimming in Battle Ground Lake, Vancouver, Washington. *Journal of Environmental Health* 64, no. 10: 16–20.

Sanderson, M. W., J. M. Sargeant, et al. 2006. Longitudinal emergence and distribution of *Escherichia coli* O157 genotypes in a beef feedlot. *Applied and Environmental Microbiology* 72, no. 12: 7614–19.

Sargeant, J. M., D. J. Hafer, et al. 1999. Prevalence of *Escherichia coli* O157:H7 in white-tailed deer sharing rangeland with cattle. *Journal of the American Veterinary Medical Association* 215, no. 6: 792–94.

Schellinger, G. R., and J. C. Clausen. 1992. Vegetative filter treatment of dairy barnyard runoff in cold regions. *Journal of Environmental Quality* 21, no. 1: 40–45.

Schultz-Fademrecht, C., M. Wichern, et al. 2008. The impact of sunlight on inactivation of indicator microorganisms both in river water and benthic biofilms. *Water Research* 42, no. 19: 4771–79.

Shender, L. A., R. D. Glock, et al. 2009. Salmonellosis in a free-ranging population of javelinas (*Pecari tajacu*) in south central Arizona. *Journal of Wildlife Diseases* 45, no. 4: 941–51.

Shere, J. A., K. J. Bartlett, et al. 1998. Longitudinal study of *Escherichia coli* O157:H7 dissemination on four dairy farms in Wisconsin. *Applied and Environmental Microbiology* 64, no. 4: 1390–99.

Shulski, M. D., E. A. Walter-Shea, et al. 2004. Penetration of photosynthetically active and ultraviolet radiation into alfalfa and tall fescue canopies. *Agronomy Journal* 96, no. 6: 1562–71.

Sinton, L., C. Hall, et al. 2007. Sunlight inactivation of *Campylobacter jejuni* and *Salmonella enterica*, compared with *Escherichia coli*, in seawater and river water. *Journal of Water and Health* 5, no. 3: 357–65.

Sjogren, R. E. 1994. Prolonged survival of an environmental *Escherichia-coli* in laboratory soil microcosms. *Water Air and Soil Pollution* 75, no. 3–4: 389–403.

Smith, R. 2013. Personal communication about rye cover crop growth. April 1st. Salinas, CA.

Snelling, W. J., J. P. McKenna, et al. 2005. Survival of *Campylobacter jejuni* in waterborne protozoa. *Applied and Environmental Microbiology* 71, no. 9: 5560-5571.

Soderstrom, A., P. Osterberg, A. Lindquist, B. Jonsson, A. Lindberg, S. Blide Ulander, C. Welinder-Olsson, S. Lofdahl, B. Kaijser, B. De Jong, S. Kuhlmann-Berenzon, S. Boquist, et al. 2008. A large *Escherichia coli* O157 outbreak in Sweden associated with locally produced lettuce. *Foodborne Pathog Dis* 5: 339–348.

Sorber, C., and B. Moore. 1987. Project summary, survival and transport of pathogens in sludge-amended soil: A critical literature review.

Sorensen, S. J., T. Schyberg, et al. 1999. Predation by protozoa on *Escherichia coli* K12 in soil and transfer of resistance plasmid RP4 to indigenous bacteria in soil. *Applied Soil Ecology* 11, no. 1: 79–90.

Sproston, E. L., M. Macrae, et al. 2006. Slugs: Potential novel vectors of *Escherichia coli* O157. *Applied and Environmental Microbiology* 72, no. 1: 144–49.

Stern et al. 1995. *Campylobacter* spp. in broilers on the farm and after transport. *Poultry Sci* 74: 937–41.

Stoddard, C. S., M. S. Coyne, et al. 1998. Fecal bacteria survival and infiltration through a shallow agricultural soil: Timing and tillage effects. *Journal of Environmental Quality* 27, no. 6: 1516–23.

Straight, R., and J. Brandle (2007). *Windbreak Density: Rules Of Thumb For Design*. Agroforestry Note 36.

Strawn, L. K., Y. T. Grohn, et al. 2013. Risk factors associated with *Salmonella* and *Listeria monocytogenes* contamination of produce fields. *Applied and Environmental Microbiology* 79, no. 24: 7618–27.
Sullivan, T. J., J. A. Moore, et al. 2007. Efficacy of vegetated buffers in preventing transport of fecal coliform bacteria from pasturelands. *Environmental Management* 40: 958–65.
Sundin, G. W. and J. L. Jacobs. 1999. Ultraviolet radiation (UVR) sensitivity analysis and UVR survival strategies of a bacterial community from the phyllosphere of field-grown peanut (*Arachis hypogeae* L.). *Microbial Ecology* 38, no. 1: 27–38.
Talley, J. L., A. C. Wayadande, et al. 2009. Association of *Escherichia coli* O157:H7 with filth flies (Muscidae and Calliphoridae) captured in leafy greens fields and experimental transmission of *E. coli* O157:H7 to spinach leaves by house flies (Diptera: Muscidae). *Journal of Food Protection* 72, no. 7: 1547–52.
Tate, K. W., E. R. Atwill, et al. 2006. Significant *Escherichia coli* attenuation by vegetative buffers on annual grassland. *Journal of Environmental Quality* 35: 795–805.
Tate, K. W., M. Das Gracas, C. Pereira, et al. 2004. Efficacy of vegetated buffer strips for retaining *Cryptosporidium parvum*. *Journal of Environmental Quality* 33, no. 6: 2243–51.
Tate, R. L. 1978. Cultural and environmental-factors affecting longevity of *Escherichia-coli* in histosols. *Applied and Environmental Microbiology* 35, no. 5: 925–29.
Temiz, A., A. Sener, et al. 2011. Antibacterial activity of bee propolis samples from different geographical regions of Turkey against two foodborne pathogens, *Salmonella Enteritidis* and *Listeria monocytogenes*. *Turkish Journal of Biology* 35, no. 4: 503–11.
Ucar, T., F. R. Hall, et al. 2003. Wind tunnel studies on spray deposition on leaves of tree species used for windbreaks and exposure of honey bees. *Pest Management Science* 59, no. 3: 358-364.
US Food and Drug Administration (FDA) and CA Emergency Response Team. 2008. Investigation of the Taco John's *Escherichia coli* O157:H7 outbreak associated with iceberg lettuce. Department of Health, Sacramento, CA.
US Food and Drug Administration (FDA). 2012. *Bad bug book, foodborne pathogenic microorganisms and natural toxins.* Second Edition.
USDA NRCS. 2000. Part 637 *Env. Eng*. Chapter 2 Composting.
Van Donkersgoed, J., T. Graham, and V. Gannon. 1999. The prevalence of verotoxins, *Escherichia coli* O157:H7, and *Salmonella* in the feces and rumen of cattle at processing. *The Canadian Veterinary Journal* 40, no. 5: 332–38.
Van Donsel, D., E. Geldreich, and N. Clarke. 1967. Seasonal variations in survival of indicator bacteria in soil and their contribution to storm-water pollution. *Appl. Environ. Microbiol.* 15, no. 6.
van Elsas, J. D., P. Hill, et al. 2007. Survival of genetically marked *Escherichia coli* O157:H7 in soil as affected by soil microbial community shifts. *Isme Journal* 1, no. 3: 204–14.
Viazis, S., and F. Diez-Gonzalez. 2011. Enterohemorrhagic *Escherichia coli*: The twentieth century's emerging foodborne pathogen: A review. *Advances in Agronomy*. D. L. Sparks. San Diego, Elsevier Academic Press Inc. 111: 1–50.
Vucemilo, M., B. Vinkovic, et al. 2010. The influence of housing systems on the air quality and bacterial eggshell contamination of table eggs. *Czech Journal of Animal Science* 55, no. 6: 243–49.
Vymazal, J. 2005. Removal of enteric bacteria in constructed treatment wetlands with emergent macrophytes: A review. *Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering* 40, no. 6–7: 1355–67.
Weber, A., A. Prell, et al. 1993. Occurrence of *Listeria-monocytogenes* in snakes, tortoises, lizards and amphibia kept as pets. *Berliner Und Munchener Tierarztliche Wochenschrift* 106, no. 9: 293–95.
Wilkes, G., T. A. Edge, et al. 2011. Associations among pathogenic bacteria, parasites, and environmental and land use factors in multiple mixed-use watersheds. *Water Research* 45, no. 18: 5807–25.

Williams, M. L., D. L. Pearl, and J. T. LeJeune. 2011. Multiple-locus variable-nucleotide tandem repeat subtype analysis implicates European starlings as biological vectors for *Escherichia coli* O157:H7 in Ohio, USA. *Journal of Applied Microbiology* 111, no. 4: 982–88.

Wolyniak, E. A., B. R. Hargreaves, et al. 2010. Seasonal retention and release of *Cryptosporidium parvum* Oocysts by environmental biofilms in the laboratory. *Applied and Environmental Microbiology* 76, no. 4: 1021.

Yoshida, T., T. Sugimoto, et al. 2000. Incidence of *Listeria monocytogenes* in wild animals in Japan. *Journal of Veterinary Medical Science* 62, no. 6: 673–75.

You, Y. W., S. C. Rankin, et al. 2006. Survival of *Salmonella enterica* serovar Newport in manure and manure-amended soils. *Applied and Environmental Microbiology* 72, no. 9: 5777–83.

Yuen, G. Y., C. C. Jochum, et al. 2002. UV-B biodosimetry in turfgrass canopies. *Crop Science* 42, no. 3: 859–68.

Zhai, Q. et al. 1995. Mortality rates of fecal bacteria in subsoil amended with poultry manure. *Bioresource Technology* 54: 165–69.

References for Glossary/Acronyms

Ashbolt, N. J., W. O. K. Grabow, and M. Snozzi. 2001. Indicators of microbial water quality. In World Health Organization (WHO). *Water quality: Guidelines, standards and health.* Ed. L. Fewtrell & J. Bartman. IWA Publishing. London, UK.

Art, H. W. 1993. *The dictionary of ecology and environmental science.* 1993. New York, NY: Henry Holt and Company.

Atwill, E. R., R. Phillips, and F. Rulofson. 2003. Estimating environmental loading rates of the waterborne pathogenic protozoa, *Cryptosporidium parvum*, in certain domestic and wildlife species in California. *Recent Work*, Sierra Foothill Research and Extension Center, Agriculture and Natural Resources Research and Extension Centers, UC Davis. Retrieved on January 15, 2014. http://escholarship.org/uc/item/0c5054fm.

Centers for Disease Control and Prevention (CDC). 2010. Parasites—*Cryptosporidium*, Biology. ,ved January 15, 2014 from http://www.cdc.gov/parasites/crypto/biology.html.

Colorado State University Extension. Good agricultural practices webinar: Farm to table food safety for Colorado producers. Retrieved on March 27, 2014. http://farmtotable.colostate.edu/docs/GAPsWebinar1.pdf.

Davey, M. E., and G. A. O'Toole. 2000. Microbial biofilms: From ecology to molecular genetics. *Microbiology and Molecular Biology Reviews* 64, no. 4: 847–67. ,ved from March 27, 2014 from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC99016/.

The free dictionary. Retrieved on March 21, 2014. http://www.thefreedictionary.com.

Koonin, E.V., K.S. Makarova, and L. Aravind. 2002. Horizontal gene transfer in prokaryotes: Quantification and classification. *Annual Review of Microbiology* 55: 709–42. Retrieved on March 25, 2014. http://www.ncbi.nlm.nih.gov/books/NBK2228/pdf/ch12.pdf.

LGMA. About us. Retrieved on September 7, 2012. http://www.caleafygreens.ca.gov/about-us.

LGMA. Food safety practices. Retrieved on September 7, 2012. http://www.caleafygreens.ca.gov/food-safety-practices.

Maier, R. M., J. L. Pepper, and C. P. Gerba. 2000. *Environmental microbiology.* New Delhi: Elsevier.

McCarthy, E. M. (ed.). Online Biology Dictionary. Macroevolution.net. Retrieved on August 7, 2012. http://www.macroevolution.net/biology-dictionary-gagd.html#.UCFNaByoowY.

McSwane, D., N. R. Rue, and R. Linton. 2005. *Essentials of food safety and sanitation* (4th ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

Merriam Webster's collegiate dictionary (10th ed.). 1996. Merriam-Webster, Incorporated.

Merriam Webster Online. Dictionary. Retrieved on March 21, 2014. http://www.merriam-webster.com/dictionary/.

Nester, E. W. 2004. *Microbiology: A human perspective*. Boston: McGraw-Hill.
Rosen, B. H. 2000. *Waterborne pathogens in agricultural watersheds.* USDA, NRCS, Watershed Science Institute.
Oxford Dictionaries. Retrieved on March 21, 2014. http://www.oxforddictionaries.com/us/.
Oxford dictionary of biology (5th ed.). 2004. Oxford, UK: Oxford University Press.
Oliver, J. D. 2005. The viable but nonculturable state in bacteria. *Journal of Microbiology* Feb. 43, Spec. No.: 93–100.
Park, C. 2007. *A dictionary of environment and conservation* (1st ed). Oxford, UK: Oxford University Press. Accessed online on March 25, 2014.
Prescott, L. M., J. P. Harley, and D. A. Klein. 2002. *Microbiology*. Boston: McGraw-Hill.
Semple, K.T. et al. 2004. Defining bioavaiability and bioaccessibility of contaminated soil and sediment is complicated. *Environmental Science and Technology* 38, no. 12: 228A–231A.
Shasta Valley Resource Conservation District. Irrigation tailwater management in the Shasta Valley. Retrieved on March 24, 2014. http://www.waterboards.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/110726/110726_tailwatrpub_pamphlet3.pdf.
Shelton, A. Biological control. A guide to natural enemies in North America. Cornell University College of Agriculture and Life Science. Department of Entomology. Retrieved on March 21, 2014. http://www.biocontrol.entomology.cornell.edu/what.html.
Smith, A. C., and M. A. Hussey. 2005. Gram Stain Protocols. American Society for Microbiology MicrobeLibrary. Retrieved on January 15, 2014. http://www.microbelibrary.org/component/resource/gram-stain/2886-gram-stain-protocols
Stetzenbach, L. D., and M. V. Yates. 2003. *The dictionary of environmental microbiology.* San Diego, CA: Academic Press.
Suslow, T. 2014. Personal communication.
Trautmann, N. M., and M. E. Krasny. 1997. Composting in the classroom: Scientific inquiry for high school students. Cornell University. Retrieved on January 15, 2014. http://cwmi.css.cornell.edu/compostingintheclassroom.pdf.
USDA. NRCS. 2012. Nutrient management technical Note No. 9: Introduction to waterborne pathogens in agricultural watersheds. Retrieved on January 15, 2014. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=32935.wba.
U.S. Environmental Protection Agency. 2012. What is a CAFO? Retrieved on August 7, 2012. http://www.epa.gov/region7/water/cafo/index.htm.
Vorholt, J. A. 2012. Microbial life in the phyllosphere. *Nature reviews microbiology* 10: 828–40.

User's Note

This publication provides guidelines and practical tools for use by growers and conservation planners. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture. The information provided herein is offered by Wild Farm Alliance in good faith and believed to be reliable, but is made without warranty, express or implied, as to merchantability, fitness for a particular purpose, or any other matter. It is intended as an educational resource and not as technical advice tailored to a specific farming operation or as a substitute for actual regulations and guidance from FDA or other regulatory agencies. It is also not intended as legal advice. We will not be responsible or liable, directly or indirectly, for any consequences resulting from use of this document or any resources identified in this document.

WILD FARM ALLIANCE