Reconciling Food Safety and Environmental Protection: A Literature Review

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I. Executive Summary

The purpose of this literature review is to identify information from scientific studies that may aid in resolving current conflicts between food safety and environmental protection. Specifically, this review is concerned with pre-harvest conditions relevant to Monterey County, the Central Coast, and other regions where fresh-cut produce is grown. Issues concerning food safety have become increasingly prevalent: outbreaks of pathogenic bacteria, specifically *E. coli* 0157:H7, have increased pressure on the agriculture industry to address all possible sources of contamination. There are also increasing efforts, both voluntary and regulatory, to promote environmental quality in agricultural operations, especially regarding water resources. Food safety guidelines, developed with industry support, to reduce sources of pre-harvest contamination in some cases directly conflict with local, state, and federal guidelines intended to protect environmental quality. This report explores scientific literature concerning possible sources and vectors of pre-harvest contamination of crops, as well as how conservation practices to promote environmental quality may affect food safety.

As highlighted in the literature reviewed, food-borne pathogens such as *E. coli 0157:H7* are zoonoses, meaning they originate from animals. Cattle and domesticated animals have been identified as significant hosts for pathogens of concern in the fresh-cut produce industry. Pathogens can contaminate crops through exposure to contaminated soil, water, or through direct animal contact. Enriching soil with raw manure poses a high risk for crop contamination, however this is not a common practice in the Central Coast. Irrigation, run-off, and flood water contaminated with fecal matter may pose significant risks. It is important to know the sources of water and to avoid contact between crops and contaminated water. Direct contact with domestic cattle and/or their feces is another source of pre-harvest contamination. In cases where livestock are in close range to fields, substantial barriers should be used to reduce chances of contamination. Lastly, the prevalence of food-borne pathogens in wildlife was found to be generally very low, but is higher for wildlife that eat or live around human and livestock waste, such as gulls or rats.

Conservation practices to promote environmental quality are often installed in close proximity to cropped fields. These practices can include introducing non-crop vegetation and water bodies, along with the wildlife and possible flood impacts associated with these features. There is concern that aspects of conservation practices may increase possible risks of crop contamination. However, in many cases vegetation and waterways established for conservation have been shown to reduce the presence and transport of water-borne bacteria and pathogens that threaten human health. Studies indicate that certain conservation practices could be specifically designed to address food safety issues. Before current guidelines are further interpreted and considered for possible mandatory standards, it is critical to resolve current conflicts with conservation practices. More research is needed to explore how the design of specific practices could affect contamination risks as well as the specific relationships between wildlife and crops in the region. Given the compatibility of food safety and environmental goals in Europe and other regions, additional information may be able to resolve the conflict between food safety guidelines and conservation practices in California.

II. Introduction

Food Safety: A Rising Health Concern

In the past several decades, there has been an increase in the occurrence of food-borne illness linked to fresh fruits and vegetables. Whereas produce-associated outbreaks accounted for 0.7% of all food-borne outbreaks in the 1970s, they accounted for 6% in the 1990s (Sicapalasingam et al. 2004). This could be related to the overall increase in consumption of raw fruits and vegetables (Bureau of Census 1996, Beuchat 1996), changes in human demography (Beuchat 2002), microbial adaptation (Altekruse et al. 1997), and/or changes in farming or processing practices (Beuchat 2002). Most of the outbreaks are due to pathogens that have animal reservoirs or zoonoses (Tauxe 1997). Although there are many different types of bacteria associated with animals, only certain strains or serotypes are harmful if ingested by humans. For example, there are many types of *Escherichia coli* (*E. coli*) bacteria found in the intestines and feces of all animals. However, only specific types of *E. coli*, such as *E. coli* 0157:H7, are disease-causing, or pathogenic to humans. Documented outbreaks of *E. coli* 0157:H7 have occurred from the consumption of apples, cantaloupe, sprouts, and lettuce. These 'ready to use' foods are minimally processed and retain a large portion of their indigenous microflora (Francis et al. 1999).

Since 1995, there have been 20 outbreaks of food-borne illness from *E. coli* 0157:H7 on lettuce or leafy greens, and of these outbreaks nine were linked to produce from the Central Coast Region. It has been difficult to directly trace the cause of outbreaks, and attempts to identifying specific sources of contamination, ranging from the field to the kitchen, have been largely unsuccessful. In 1996, a significant outbreak of *E. coli* 0157:H7 inflicted over sixty people on the East Coast and was linked to lettuce from a San Benito County farm. Contamination of lettuce or spinach from Monterey County was linked to one major outbreak in 2002 and two other outbreaks in 2003. An outbreak in Minnesota in the fall of 2005 was also linked to salad mix grown in Monterey County. Most recently, in September 2006 an outbreak of *E. coli* 0157:H7 affected consumers in over 25 states, drawing national attention. Spinach from this outbreak was also traced back to Central Coast fields and processing plant.

Overall, food safety has become a critical issue to be addressed by all stages of industry in the region.

Guidelines for Food Safety

Although there have been no government mandated food safety guidelines, increased awareness of food safety by consumers, growers and processors has led to the development and implementation of voluntary commodity specific food safety guidelines and Good Agricultural Practices (GAP) programs throughout the industry. It is largely unknown at which stage from the field to table that microbial contaminants are introduced: farming, harvesting, packing, handling, processing, food preparation, and food service all have possible risks. Guidelines have been developed for farming practices, packing, handling, and processing. The U.S. Department of Health and Human Services through the U.S. Food and Drug Administration (FDA) has produced several publications including the “Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables” (1998) and the “Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/Elimination of Microbial Hazards on Fresh and Fresh-Cut Produce” (2001). In addition, a national Good Agricultural Practices (GAP) program was created in 1999 and is a cooperative effort between industry and government. The program offers GAP guidelines and educational material to encourage “safe” farming practices. Lastly, in response to outbreaks in September 2006, a group of produce associations have proposed additional short-term actions to address contamination which are specified in an “Immediate Technical Action Plan for the Spinach Industry of Monterey, San Benito, and Santa Clara Counties”.

In addition to the governmental and academic guidelines that have been developed for the agricultural industry, farming organizations and private food safety auditors have developed their own GAPs. There are also commodity specific guidelines for cantaloupe and more recently for lettuce and leafy green vegetables created by cooperative efforts in the industry. In April of 2006, the first edition of “Commodity Specific Food Safety Guidelines for the Lettuce and Leafy Greens Supply Chain”(Gombas et al. 2006) was released by a group of associations in the lettuce and leafy greens industry. Although current guidelines are voluntary and primarily market-driven, with increasing public concern there exists the possibility of mandatory or regulatory food safety standards in the near future. As the current guidelines are interpreted, applied, and possibly considered to become mandatory standards, it is critical that they are evaluated to understand the full implications of their widespread adoption, both for protecting consumer health as well as environmental quality.

Possible Conflicts between Environmental Protection and Food Safety

Current food safety guidelines can conflict with efforts to improve and protect water quality and wildlife habitat. California contains over 60 impaired priority watersheds and over 300 federally listed endangered and threatened species. In addition to pressure regarding food safety, California growers face increasing environmental regulations and are encouraged to be good environmental stewards. Growers on certain properties may face legal restrictions under the Endangered Species Act to protect wildlife in danger of extinction. Government programs and conservation organizations also encourage growers to provide habitat for wildlife that are not legally protected. More recently, growers also face developing non-point source (NPS) water quality regulations and compliance programs. Since the 1987 Clean Water Act amendments, California has been developing a NPS program which addresses agricultural water pollution. NPS pollution, including contaminants associated with agriculture, has been identified as a major contributor to impaired watersheds in California (US EPA 2000). NPS pollution efforts have been focused on education and the adoption of management practices to reduce pollution and runoff. In California, under the Porter Cologne Act of 1969, water resources are managed through the State Water Resources Control Board and nine Regional Water Quality Control Boards. Regional boards throughout the state are currently developing and enforcing Total Maximum Daily Load (TMDL) regulations stated in the Clean Water Act. The Central Coast Regional Water Quality Control Board has adopted a "Conditional Waiver Program" under Porter Cologne. The conditional waiver requires growers to enroll in the program, attend water quality training sessions, adopt farm water quality management plans, complete management practice checklists, and participate in water quality monitoring.

Many of the currently used GAP and food safety guidelines contradict and directly conflict with US Department of Agriculture (USDA) guidelines for conservation practices to promote clean water and wildlife habitat. To address environmental concerns and to conserve natural resources, programs for growers are offered by the USDA under the Farm Security and Rural Investment Act of 2002. These programs include the Environmental Quality Incentive Program (EQIP), the Wetlands Reserve Program (WRP), the Conservation Security Program (CSP), and the Wildlife Habitat Incentive Program (WHIP). Through technical and financial assistance, these programs encourage growers to adopt conservation practices to improve water quality and wildlife habitat including creating field borders, grassed waterways, riparian buffers, tailwater recovery systems, and wetlands. Many governmental and non-governmental organizations have been working with California growers for years to increase the adoption of conservation practices both on and adjacent to agricultural fields. In addition, these practices have become a key component of the Central Coast regional water quality improvement strategies through the "Conditional Waiver Program."

Information in food safety guidelines with respect to non-crop vegetation, wildlife, and water bodies has caused growers in the Central Coast to be increasingly wary of conservation practices. These concerns are enforced by lost points for the presence of some conservation practices during ranch food safety audits. Some growers have declined to install and in some cases have removed conservation projects. The following are examples of excerpts from food safety and GAP guidelines which conflict with the goals of conservation organizations to protect waterways, habitat, and wildlife:

"In addition, high concentrations of wildlife (such as deer or waterfowl in a field) may increase the potential for microbial contamination. Control of wild animal populations in the field may be difficult, especially where crop production areas are adjacent to wooded areas, open meadows, and waterways. . . . . . where high concentrations of wildlife are a concern, growers should consider establishing good agricultural practices to deter or redirect wildlife to areas with crops that are not destined for the fresh produce market." [1]

"Key areas of concern are prior land use, adjacent land use, field slope and drainage, soil properties, crop inputs and soil fertility, water quality and use practices, equipment and container sanitation, worker hygiene and sanitary facilities, harvest implement and surface sanitation, pest and vermin control, effects of domesticated animal and wildlife on the crop itself or packing area, post-harvest water quality and use practices, post-harvest handling, transportation and distribution, and documentation and record-keeping." [2]

"Evaluate the need for bare soil buffers to adjacent land that may encourage high populations of reptiles, amphibians, rodents, birds or other potential sources of contamination." [3]

"Is there a routine maintenance program for canals or ditches that includes removal of all inappropriate materials (e.g. plant material, trash, animal carcasses, etc.)?" [4]

"Are any measures taken to minimize microbial contamination of canals or ditches (e.g. visual inspection, periodic chlorination, filtration, rodent control program, etc.)?" [5]

"Monitor and minimize domestic and wildlife activity in lettuce/leafy greens fields and production environments (e.g. reduce potential cover and harborage, eliminate standing water, utilize animal repellants and attractants)." [6]

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[1] U.S. Department of Health and Human Services, Food and Drug Administration, Center for Food Safety and Applied Nutrition Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables (October, 1998)

[2] U.S. Department of Health and Human Services, Food and Drug Administration, Center for Food Safety and Applied Nutrition Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/Elimination of Microbial Hazards on Fresh and Fresh-Cut Produce (September 2001)

[3] National GAP (Good Agricultural Practices) Program
A Self-Audit Report for Growers and Handlers

[4]Primus Labs Food Safety Self Audit

[5] Primus Labs Food Safety Self Audit

Although individuals may read food safety guidelines, such as those listed above, and feel that growers should not pursue conservation practices, other parts of the same guidelines indicate benefits from the implementation of conservation practices. For example, to separate crop production from animal production measures can be adopted and "might include physical barriers, such as ditches, mounds, grassed/sod waterways, diversion berms, and vegetative buffer areas." [7] It is clear from existing food safety guidelines that conservation practices can be regarded as positive or negative depending on the circumstances, setting, and the individual interpreting and applying the guidelines. Further investigations need to clarify how conservation practices such as grassed waterways, wetlands, and vegetative buffer zones affect food safety.

Purpose of Report

This paper will review scientific literature on pre-harvest contamination of fresh produce (focusing on leafy greens, lettuce, and vegetables) with microbial pathogens and how conservation practices may affect contamination. Food safety issues with leafy greens and raw vegetables are not a problem unique to California or the United States. In addition to studies on microbial pathogens and food safety in the United States, literature from the European Union was reviewed and is also included in this paper. This review will cover major sources and vectors of prominent pathogens associated with leafy greens and fresh vegetables and explore the possible connections between the adoption of conservation practices and food safety.

III. Scientific Literature Review

Possible Sources of Pre-Harvest Microbial Contamination

Contamination of food can take place at any point between the fields where food is grown and food consumption. Most microbial contamination of leafy greens and fresh

[6] Commodity Specific Food Safety Guidelines for the Lettuce and Leafy Greens Supply Chain (March 2006)

[7] U.S. Department of Health and Human Services, Food and Drug Administration, Center for Food Safety and Applied Nutrition Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables (October, 1998)

vegetables is stated to be associated with improperly composted manures, irrigation water containing manure or sewage, contact with domestic animals, contact with wild animals, contaminated wash water, human handling, contaminated ice during storage, or contamination during packaging, slicing or shredding, and food preparation (Beuchat and Ryu 1997, Beuchat 2006, Tauxe 1997, Francis et al. 1999, Rangel et al. 2005). This review focuses on the possible pre-harvest sources and vectors of contamination and will not include harvesting, washing, processing, packaging, and food service; however, in many cases these are considered likely sources of contamination. For example, approximately half of all US *E. coli* 0157:H7 outbreaks from produce between 1982 and 2002 were due to kitchen-level contamination during food preparation, the other half were due to produce contamination either from the field or during handling and processing (Rangel et al. 2005). In fact, there is a lack of evidence clearly linking any specific pre-harvest practices to food-borne illness (Suslow et al. 2003). However, this review will explore possible sources of *E. coli* 0157:H7 contamination including animal feces from the applications of manure, cattle and domesticated animal operations, contaminated irrigation or flood water, and direct contact with domesticated or wild animals. This report will evaluate possible risks as well as potential ways to reduce risks of crop contamination in the field through soil, water, and animal contact.

Soil: Risks of Contamination

Generic and pathogenic forms of *E. coli* are found in fecal material which can contaminate soil in cropped fields (Francis et al. 1999). The most important reservoir of cerocytoxin producing *E. coli* (such as *E. coli* 0157:H7) is ruminants, primarily cattle (Nielsen et al. 2004). Due to the vast quantities of manure created by cattle in the United States and subsequent issues with disposal, applying manure to fertilize soil has traditionally been a common method of disposal. Manure is a source of macro and micronutrients and is an effective fertilizer, often used as an alternative or supplement to applying synthetic fertilizers to soil. However, manure can incubate pathogens and subsequently contaminate crops in the field (Natvig et al. 2002). Pathogens have been shown to be transferred from manure to the surface of crops on contaminated soil particles. Once on the surface of the crop, pathogens may persist for long periods of time. Islam et al. (2005) found that *E. coli* 0157:H7 could survive on planted carrots contaminated by manure for over 150 days. Beuchat (1999) inoculated harvested lettuce with bovine manure and found that *E. coli* 0157:H7 persisted for over 15 days during cold storage. It is important to note that raw manure application in the Central Coast Region has already been largely phased out. However, manure transported from nearby or upland cattle operations could significantly increase risks of crop contamination.

Studies indicate that the composition of cattle diets may affect the amount and composition of bacteria in cattle manure. Diez-Gonzalez (1998) found that cattle fed grain had significantly higher levels of acid-resistant *E. coli* than cattle fed hay or grazed on grass pastures. Franz et al. (2005) explored the effects of cattle feeding regimes on *E. coli* 0157:H7 and *Salmonella* on manure from dairy cattle. They found that manure from cattle with a pure straw diet (high fiber content) had reduced levels of *E. coli* 0157:H7 and *Salmonella* compared to manure from cattle fed a mixture of grass silage and maize silage (lower fiber content). They conclude that a high starch/grain diet favors the growth and survival of pathogenic bacteria. Because feeding grain to cattle (especially dairy cows) has become a common practice, manure may now have higher concentrations of pathogenic bacteria than with previous traditional feeding regimes. Diez-Gonzalez (1998) and Franz et al. (2005) both suggest that increasing fiber in the diet, through feeding hay, could reduce pathogen excretion from cattle.

Pathogenic bacteria can also be transferred through the air attached to dry manure, dry soil, or dust. Many studies have looked at the bacterial content of air in confined animal operations and have found significant levels of airborne pathogenic bacteria (Chang et al. 2001, Lee et al. 2006, Whyte et al. 2001). These studies and others focused on the impacts of airborne pathogens on worker respiratory health. Spaan et al. (2006) looked at airborne pathogenic bacteria found in three different agricultural sectors: the grains, seeds and legumes sector, the horticulture sector, and the animal production sector. They found that workers in the grains, seeds, and legumes sector were exposed to the highest levels of airborne pathogens. Lee et al. (2006) also looked at airborne pathogens in grain operations and found that exposure to dust and microorganisms after grain harvest exceeded levels found in animal confinements. All of these studies focused on the health effects on humans through direct inhalation. No studies were found that looked at the transport of airborne pathogens onto cropped fields. However, these studies do indicate that pathogens may be airborne and could reach crops if they are in close proximity to confined animal operations or grain harvesting operations.

Soil: Preventing Contamination

There are several ways to reduce the possible contamination of crops from soil via manure. Composting is an effective way to treat manure and decrease risks to food safety. The heat that occurs during composting kills bacteria, including harmful pathogens (Jiang et al. 2003). Non-composted or improperly composted manures are much more likely to harbor pathogens. Another more passive way to reduce pathogen populations is to store or age manure before application (Ingham et al. 2004), or to wait substantial lengths of time before harvesting from fields where manure was applied. The National Organic Standards require at least 120 days between non-composted manure application and crop harvest for crops where edible portions are in direct contact with soil (NOP 2006). Islam et al. (2004) and Islam et al. (2005) explored how long pathogens from non-composted manure can survive in the fields of different vegetable crops in Georgia. They found that depending on the type of crop planted, *E. coli*. 0157:H7 can survive for more than six months in the soil. Because this variation exists, the 120-day interval may need to be reevaluated to incorporate regional climate and the type of crop planted (Islam et al. 2005). Ingham et al. (2005) also studied fertilization-to-harvest intervals and recommended that the interval should not be shortened less than 120 days. Extreme caution should be used when using non-composted manure. Again, the use of uncomposted manure has been largely phased out of the lettuce and leafy greens sector in the Central Coast.

A review of studies indicates that diverse microbial organisms in soil may reduce the potential for pathogen contamination (Suslow et al. 2003). Suppression of pathogens can occur through the antagonistic capacity of the resident microbial flora. Johannessen et al. (2005) illustrate how naturally occurring bacteria in soil reduce the abundance in *E. coli* 0157:H7 and inhibit the pathogen from uptake into lettuce tissue through the roots. Soil with diverse microorganisms may contain *Pseudomonas fluorescens*, a bacterium known to compete with and inhibit the growth of *E. coli*. 0157:H7. In their study, Johannessen et al. (2005) discovered that transmittance of *E. coli*. 0157:H7 from inoculated soil to lettuce did not occur and suggest that the presence of *Pseudomonas fluorescens* in the soil or on the plant roots may be responsible for preventing transmittance. This study indicates that microbial pathogens may flourish in soils that lack a balance of natural microbial diversity, and that soil management should aim to encourage the diversity of microbial organisms. Organic fields have been shown to host higher diversity and biomass of soil microbial and faunal communities and have been correlated with higher suppression of soil-borne plant pathogens (Van Bruggen 1995). This pattern may also hold for the suppression of pathogens such as *E. coli* 0157:H7.

Although less is known about the risks of airborne contamination through dry manure, soil, and dust, measures may be taken to reduce the likelihood of airborne pathogen transport. Plastic covers or concrete blocks may be used to contain sources of airborne contamination, such as drying manure piles. Constructing barriers or windbreaks with fences or vegetation could also prevent possible transport of pathogens through wind and dust. Additional research may be needed to identify the risks of airborne crop contamination and the best methods to reduce possible risks.

Water: Risks of Contamination

While crop contamination can result directly from manure application and feces from domestic livestock operations, water may be a more likely vehicle of contamination (Suslow et al. 2003). Rivers, creeks, and streams can contain pathogenic bacteria from upstream activities, such as livestock operations, and diverting these waterways for irrigation could lead to crop contamination. However, growers in the Central Coast typically use well water and not surface water diversions. Still, wells should be inspected for possible contamination, especially older and shallow wells (Suslow et al. 2003). Water draining from open lot cattle/grazing operations or concentrated animal feeding operations can contain contaminated runoff (Koelsch et al. 2006). In some cases, runoff from open lot cattle grazing areas has been shown to result in more contamination than runoff from concentrated cattle facilities with slurry application (Vinton et al. 2004). Abu-Ashour and Lee (2000) show that pathogenic *E. coli* can migrate through run-off on sloped surfaces, potentially increasing risks to crops down slope. Collection ponds, diversion berms, or vegetated buffers can be used to divert contaminated run-off away from other water sources (Suslow et al. 2003). However, due to the possibility of water contamination from run-off, it is recommended that food crops not be irrigated with water of unknown sources and microbial content (Solomon et al. 2002b). Lastly, flooding of nearby contaminated water bodies onto fields could also result in contamination of crops.

The majority of studies indicate that contamination most likely occurs through direct contact between crops and contaminated water; however, recent studies have investigated the possibility for *E. coli* 0157:H7 to enter plant tissue through the root system. While these studies used *E. coli* 0157:H7 concentrations far exceeding any that would be found on an agricultural field, they did show that if concentrations are very high, it is possible for *E. coli* 0157:H7 to enter plant tissue through the root system. Solomon et al. (2002a) inoculated irrigation water with extremely high concentrations of *E. coli* 0157:H7. In this situation, lettuce was contaminated without direct surface exposure to the pathogen, but rather by uptake of the pathogen through the root system. However, the authors of the study do concede that the concentrations of *E. coli* 0157:H7 used far exceed any that would be found on an agricultural field. Wachtel et al. (2002a) also found that contamination can occur through plant roots at exceedingly high concentrations. They state that the ability for contamination to occur through the root system is dose dependent, although the specific thresholds are unclear. Again, the authors state that the presence of such high levels of contamination on agricultural fields is very unlikely. In a more realistic scenario, Wachtel et al. (2002b) investigated cabbage that was irrigated with creek water contaminated with sewage from a recent spill. Here, they found that although the roots were contaminated with serotypes of *E. coli*, the edible portions of the plant were not. In the absence of experimental inoculation of water with very high concentrations of pathogens, root uptake is an unlikely route of contamination.

Studies have also investigated the effects of different methods of irrigation as well as how long fields can remain contaminated after exposure to pathogens. Methods of irrigation have been shown to affect the chances of contamination. Solomon et al. (2002b) found that lettuce exposed to *E. coli*. 0157:H7 were more likely to test positive for pathogen presence if they were sprayed by sprinklers with the inoculated water than if they were exposed through surface irrigation. Solomon et al. (2003) also found that repeatedly spraying crops with contaminated irrigation water increases chances of crop contamination. Fields which have been exposed to contaminated water may result in the contamination of the soil for extended periods of time. Islam et al. (2005) treated fields of vegetable crops with irrigation water contaminated with *E. coli* 0157:H7. While the levels of *E. coli* 0157:H7 used in the study were far greater than any that would be likely to exist on an agricultural field, the researchers found that *E. coli* 0157:H7 survived for at least 154 days in the soil.

Water: Preventing Contamination

Certain practices may reduce the spread of microbial pathogens through water. Settling basins and collection ponds near concentrated livestock operations may be used to contain contaminated runoff (Koelsch et al. 2006). Contamination in overland flow may also be reduced by filtration through perennial forage and/or grasses. Tate et al. (2006) tested the effectiveness of *E. coli* filtration through vegetated buffers on cattle grazing lands in California. They used known quantities of *E. coli* and measured transport in surface water run-off. Although the efficiency of filtration depends on water flow, soil type, and slope, they found that vegetative buffers are an effective way to reduce inputs of waterborne *E. coli* into surface waters. Although this study did not focus specifically on *E. coli* 0157:H7, generic *E. coli* is an indicator of potential pathogen contamination (Suslow et al. 2003, Tate et al. 2006).

Vegetated Treatment Systems (VTS) have also been shown to reduce the presence of pathogens. A Vegetated Treatment System is a planted area that water is directed through to improve water quality. Common practices in these systems include grassed waterways, vegetated ponds or basins, and constructed wetlands. Koelsch et al. (2006) reviewed studies and found approximately 40 field trials indicating that vegetative systems with a settling basin can achieve significant pollution reductions, including pathogenic bacteria. Other studies indicate that fecal coliform reductions greater than 90% are regularly observed from vegetated treatment systems (Kadlec and Knight 1996). Fecal coliform is readily used as an indicator of possible pathogenic bacteria. These practices can reduce the presence of pathogenic bacteria in waterways near fields and significantly reduce the possibility of contamination if flooding occurs. In general, the literature stresses the importance of knowing the sources of irrigation and flood water and to be aware of possible sources of contamination.

Constructed wetlands have been shown to effectively reduce the presence of pathogenic bacteria and are used in sewage and agricultural wastewater treatment. In a wetland, pathogens are removed through filtration in dense vegetation, sedimentation of particles carrying pathogens, microbial competition and predation, high temperatures, and UV disinfection (Hench et al. 2003, Nokes et al. 2003, Greenway et al. 2005). Nokes et al. (2003) show that large, as well as small-scale, constructed wetlands in Arizona can reduce fecal coliforms by up to 97%. Hench et al (2003) tested the effectiveness of constructed wetlands in West Virginia at removing specific pathogenic bacteria. They show that within a 23-52 hour wetland residence time *Salmonella* can be reduced by 93-96%. They also found that wetlands which contain vegetation remove significantly more pathogens than un-vegetated wetlands. Hill and Sobsey (2001) also report a 96% reduction in *Salmonella* in wastewater from a pig farm after passing through a constructed wetland in North Carolina. Decamp and Warren (1999) found that wetlands reduced between 96-99% of *E. coli* in the influent water. Lastly, studies in Australia show that constructed wetlands can remove 95% of pathogens and indicator organisms (Greenway 2005). Through their literature review, Greenway et al. (2005) conclude that surface-flow constructed wetlands with a high diversity of macrophytes can reclaim water and produce effluent meeting microbial standards for agricultural irrigation. Again, although most of these studies did not test for *E. coli* 0157:H7 specifically, they did test for common indicator bacteria associated with pathogens. With the development of additional design standards specifically targeted to reduce pathogenic bacteria, constructed wetlands may provide a highly effective and reliable means to reduce water-borne pathogens.

Animal Contact: Risks of Contamination

Microbial pathogens such as *E. coli* 0157:H7 are zoonoses, meaning they originate from animals. Due to the animal origins of zoonoses pathogens, contamination can occur through direct animal contact. Domestic cattle are the primary source of microbial pathogens associated with food-borne illness. Prevalence can be highly variable among cattle depending on the environment and the time of year. Hancock et al. (1998) studied cattle in the Pacific Northwest and found that 3.6% of feedlot cattle and 2.3% of dairy cattle tested positive for *E. coli*. 0157:H7. Chapman et al. (1997) tested cattle at a slaughter facility in England over an entire year. Overall, 13.4 % of beef cattle and 16.1% of dairy cattle tested positive for *E. coli*. 0157:H7. However, depending on the time of year (highest in spring and summer), up to 36.8% of total cattle tested positive for *E. coli*. 0157:H7.

Concern over the role of wild animals as sources of food-borne illness has also been generated. Many studies have investigated the potential for different organisms to serve as vectors of food-borne pathogens. This review presents all the information found on species that may be relevant to issues in the Central Coast. Studies exploring relationships between wildlife and food safety have not yet been conducted for many species. In one recent study, Sproston et al. (2006) explored the potential for slugs to transfer *E. coli*. 0157:H7 from animal feces to salad vegetables in Scotland. They found that slugs can carry *E. coli*. 0157:H7 on their external surface for up to 14 days. Many other invertebrates such as beetles, mealworms, houseflies, and fruit flies have also been investigated in their role as potential vectors of disease. However, the prevalence of pathogens in invertebrates is very low: the literature indicates that only 2% of flies and only 0.21% of slugs were found to carry *E. coli*. 0157:H7 (Spronston et al. 2006).

Wild mammals have also been investigated as possible vectors of *E. coli* 0157:H7. The studies below investigated the feces or rectal contents of wild animals for the presence of *E. coli* 0157:H7 and other pathogens. Results from studies on rodents vary: Hancock et al. (1998) did not find any *E. coli*. 0157:H7 from 300 samples of rodents on cattle farms in the Pacific Northwest, whereas Nielsen et al. (2004) found 2 out of 10 rat samples to carry other pathogenic forms of *E. coli* on farms in Denmark. Nielsen et al. (2004) also indicate that these rats were living in close proximity to cattle and feces. According to Meerburg et al. (2004), rodents can be divided into two groups: field rodents and commensal rodents, such as house mice and rats. Where as commensal rodents may be in closer contact with human and livestock waste, field rodents that are kept separated from these sources of contamination may have a much lower prevalence of pathogens. Field rodents should be managed to minimize their exposure to livestock (Meerburg et al. 2004). Several studies have explored the role of wild deer as vectors. In a study of white-tailed deer sharing a rangeland with cattle in Kansas, *E. coli*. 0157:H7 was isolated from 2.4% of deer (Sargeant et al. 1999). Fischer et al (2001) found that 0-0.6% of wild white-tailed deer sharing a range with cattle showed signs of *E. coli*. 0157:H7 and concluded that wild deer are not a major reservoir of *E. coli*. 0157:H7 in the southeastern United States. Feral pigs may also come into contact with cropped fields. Although they may carry other bacteria, such as *Cryptosporidium parcum* and *Giardia*, studies have not indicated that feral pigs in California carry or spread *E. coli*. 0157:H7 (Atwill et al. 1997, Witmer et al. 2003).

Many more studies have looked at birds as a source of food-borne illness. The studies below investigated the feces and/or intestinal contents of numerous bird species for the presence of *E. coli* 0157:H7 and other pathogens. In a survey of wild birds in England, mostly gulls, an average of 2% of isolates from birds contained *E. coli*. 0157:H7 (Wallace et al.1997). In another study in Sweden, Palmgren et al. (1997) found that, of 50 gulls sampled, 4% contained *Salmonella* isolates and of 151 wild passerines and gulls none contained *E.*

coli. 0157:H7 islolates. In England, Fenlon (1981) showed that of 1,241 seagull feces samples, 12.9% contained *Salmonella*, most likely from nearby sewage outfalls. Although most studies have looked at pathogens carried by gulls, which are often associated with a dependence on human waste for food, fewer studies have looked at other types of wild birds. Converse et al. (1999) sampled feces from Canada Geese in New Jersey and Virginia and found no signs of *E. coli*. 0157:H7. Brittingham et al. (1988), studied passerines and woodpeckers in Wisconsin, finding that of 364 birds 0% showed signs of *Salmonella* and 1% showed signs of *E. coli* 0157:H7. Hancock et al. (1998) found that 0% of wild birds tested on cattle farms in the Pacific Northwest showed signs of *E. coli* 0157:H7. These studies indicate that, although the overall prevalence of microbial pathogens associated with food-borne illness is low among wild birds, the presence of pathogens may be higher for birds associated with human waste, such as gulls. As shown by Brittingham et al. (1988) and Hancock et al. (1998), other birds such as woodpeckers, chickadees, and nuthatches, more closely associated with pastoral environments, are very unlikely to carry pathogens and contaminate crops.

Animal Contact: Preventing Contamination

Domesticated animals in livestock operations are the most prominent known source of microbial pathogens associated with food-borne illness (Nielsen et al. 2004). In cases where domesticated animals or livestock reside in close proximity to cropland, measures to prevent wandering animals are highly recommended in food safety guidelines. Physical barriers such as fences and vegetated buffers may be effective barriers to prevent movement of livestock onto fields. Efforts could also be made to reduce the prevalence of pathogens in cattle herds. As stated earlier, changes in livestock diets to a more traditional feeding regime may reduce the presence of microbial pathogens in cattle operations. More research is needed to specifically identify effective means to reduce risks of crop contamination from nearby livestock.

Wild animals are much less likely to carry *E. coli*. 0157:H7 than domesticated animals such as livestock. Whereas up to 36.8% of cattle can carry *E. coli*. 0157:H7

(Chapman et al. 1997), on average around 1% of all wild animals in these studies (excluding those in close contact of animal and human waste) carried *E. coli*. 0157:H7. The prevalence of pathogens in animals, such as rats and seagulls, that eat or live around human and livestock waste, is higher: closer to 12%. This indicates that limiting access to crops by these waste-associated animals and also limiting the access these animals have to sources of waste (such as manure piles and garbage dumps) would greatly reduce the probability of contamination from direct animal contact. Accordingly, evidence suggests that other animals such as invertebrates, field rodents, deer, and birds associated with natural environments should pose a minimal risk to food safety.

Although this review indicates that the risk of wildlife spreading disease is very low, growers may still be concerned about the presence of wildlife on and around cropped fields. Growers may wish to limit the access wildlife have to crops to insure crop quality and to make sure that no small animals are harvested and processed along with crops. However, there are currently no known/publicly documented cases of such accidental harvest events in the region. To ease concerns, mitigation measures can be adopted to avoid wildlife presence during harvest. Barriers and buffers can be used to deter small vertebrates from crossing from non-crop vegetation onto cropped fields. In addition, adapted technology on harvesting equipment can also be used to herd wildlife away from crops before or during harvest. Some growers are already using such methods, but they are not widespread and their effectiveness is undocumented.

Potential Impacts of Conservation Practices on Food Safety

Conservation practices used on or adjacent to cropped fields to improve environmental quality include but are not limited to: hedgerows, grassed waterways, filter strips, contour buffer strips, and constructed wetlands. According to the USDA Natural Resources Conservation Service Field Office Technical Guide standards (NRCS 2002), hedgerows are created by planting woody plants or perennial bunchgrasses that are at least 3 feet tall in a linear design. Possible functions of hedgerows are to create living fences, provide food and habitat for wildlife, barriers for odors and dust, and to improve the landscape appearance. Improvements in water quality may also occur through reduced erosion and sediment trapping (NRCS 2002a). Grassed waterways are natural or constructed channels with established vegetation. The purpose of grassed waterways is to convey runoff, to reduce overall erosion, and to improve water quality (NRCS 2002b). Filter strips are areas of vegetation for removing sediment, pollutants, and organic matter from run-off water. This occurs through filtration, deposition, infiltration, and decomposition of materials before they enter the effluent water flow. Filter strips are recommended along field edges, waterways, and around livestock areas to reduce pollution (NRCS 2000a). Contour buffer strips are narrow strips of permanent vegetation on sloped cropland aimed to reduce erosion, reduce the transport of contaminants, and provide wildlife habitat (NRCS, 2000b). Constructed wetlands are also a recommended conservation practice to improve water quality. They can be used to treat surface runoff and wastewater from livestock operations and agricultural fields. Constructed wetlands are applied to reduce the concentrations of metals, pesticides, nutrients, fertilizers, and animal wastes in effluent waters and also provide wildlife habitat (NRCS 2002c).

Despite contradictions in current food safety and environmental guidelines, the literature in this review indicates that certain conservation practices may be useful in addressing current food safety problems. Although the goal of many conservation practices is to reduce erosion and pollution from fertilizers and pesticides, these practices can also remove and control harmful microbes. Many of the ways to address waterborne pathogens described earlier are conservation practices already being promoted to improve water quality and protect wildlife. As detailed earlier, vegetated buffers, vegetative treatment systems, and constructed wetlands have been found to be effective ways to reduce waterborne pathogens. These practices may be designed specifically to increase effectiveness in reducing certain bacteria. For example, constructed wetlands can be designed to maximize the removal of pathogens (Greenway et al. 2005). Although most of these studies did not test *E. coli*. 0157:H7 specifically, bacteria such as fecal coliform and generic *E. coli,* which were tested, are often used as indicators for pathogens. With further research, design standards tailored specifically to pathogen removal, including *E. coli*. 0157:H7, could be created for several conservation practices. Also, ways to make the adoption of these practices more feasible can also be explored. For example, Nokes et al. (2003) show that small-scale vegetated wetlands can be equally effective and efficient in the removal of harmful bacteria as large-scale constructed wetlands. With current land values in California and the costs associated with construction, these small-scale wetlands as well as vegetation buffers and treatment systems may be easier to apply throughout the region.

Many of the same conservation practices have multiple objectives and include enhancing the abundance and diversity of wildlife in agricultural settings. With significant numbers of endangered and threatened species in California and over a third of the total land in agriculture, integrating wildlife habitat onto agricultural landscapes (especially in riparian zones) may be critical for species preservation. Planting non-crop vegetation and creating waterways is likely to attract wildlife. There are concerns that adopting conservation practices will therefore increase the spread of food-borne pathogens. Food safety guidelines often recommend removing non-crop vegetation or anything that may attract wildlife. Given suggested conservation practices and Endangered Species Act requirements, growers are therefore receiving conflicting messages regarding wildlife. However, as the studies reviewed in this paper indicate, wildlife associated with natural environments have a very low likelihood (around 1%) of carrying pathogens such as *E. coli*. 0157:H7. Efforts to keep animals which are associated with human waste (such as gulls) and especially cattle away from croplands are more likely to reduce risks of contamination. Conservation practices aim to attract the types of wildlife that studies indicate are unlikely to cause contamination. In addition, habitat provided by conservation practices could also attract and harbor natural predators, such as birds of prey, which can function to control the growth of small wildlife populations.

There is a concern that conservation practices will increase the chances of flooding on agricultural fields and contaminate crops with pathogens. Whether water bodies introduced or modified through conservation projects will affect the likelihood of flooding depends on site specific conditions and project design. Some conservation practices could actually reduce the chances of flooding. According to Zedler (2003), wetlands not only provide water quality improvement but also provide flood abatement. When designed properly, wetlands can moderate and prevent floods: flood peaks are reduced and delayed due to temporary water storage in the wetlands and either downstream or groundwater drainage (Potter 1994). However, how well water bodies function to mitigate flood events can be limited if capacity is constrained. Although having ponds or canals around fields could result in flooding, if mitigation measures are taken, flooding can be avoided. The USDA standards for grassed waterways state that "all grassed waterways shall have an outlet with adequate capacity to prevent ponding or flooding damages." (NRCS, CA 2002b). Flooding is a valid concern regarding food safety and should be avoided when possible. If flooding of agricultural waterways does occur, the studies presented in this review indicate that highly vegetated waterways should have lower levels of microbial pathogens than non-vegetated waterways. Again, it is the source of flood water that determines whether a flood event presents a significant contamination risk.

IV. Areas for Further Research

Based on the findings of this review, several areas may need to be further investigated in order to confidently resolve the apparent conflicts between pre-harvest food safety concerns and conservation practices:

- Effectiveness and Extent of Pathogen Reduction

Although the studies in this review indicate that constructed wetlands, vegetated buffers, and vegetated waterways can reduce the presence of pathogenic bacteria, studies to explore the extent of this reduction specific to landscapes in the Central Coast Region, or similar settings, would produce results relevant to local conditions.

- Designs to Reduce Risks of Contamination

It is unclear under what scenarios adopting specific conservation practices reduces, increases, or affects the chances of flooding. It is also necessary to consider mitigation measures for flooding and pathogen transport when designing conservation practices.

Research on how specific conservation practice designs affect risks would be useful to the development of guidelines and design standards to reduce risks when applying conservation practices.

- Local Wildlife

Concerning wildlife as possible vectors of food-borne pathogens, none of the studies cited in this review were conducted in California. Although studies conducted elsewhere were generally consistent, studies that are specific to California wildlife and the crops grown in the Central Coast may more clearly illustrate the relative risks of local wildlife regarding food safety.

V. Conclusion

From the field to the table, there are many possible sources of microbial contamination. With every outbreak there is an attempt to identify the source of contamination, which is a difficult task. The most commonly cited sources are from the washing of produce and human handling in the food preparation process. Of pre-harvest sources, un-composted manure application is the most commonly cited source. Since this is not a common practice in the Central Coast, other sources such as contaminated water need to be further investigated. Also, the role of conservation practices needs to be further explored. Although food safety guidelines imply that the wildlife attracted by conservation practices can increase risks of contamination, the literature in this review indicates that wildlife associated with natural environments should not pose a large threat. Conservation practices may also have an unknown affect on the chances of flooding. More studies on the installation of conservation practices and their impacts on flooding may elucidate possible designs to mitigate flooding risks. Studies should also be conducted in the region to determine any potentially negative impacts that conservation practices could have on the flow capacities of rivers, creeks, and streams which have the potential to flood agricultural farmland. Despite concerns about conservation practices, the literature in this review indicates that in many cases they may actually be a useful a tool in addressing current food safety problems. Further studies may reveal more about the ability for vegetation introduced through conservation practices to reduce the presence and transport of pathogens such as *E. coli*. 0157:H7.

Lastly, it is interesting to compare the food safety and good agricultural practice guidelines between the United States and the European Union. Although there have been similar problems with outbreaks of food-borne illness in Europe, their guidelines do not call for the removal of non-crop vegetation and wildlife from the agricultural environment. "Good farming practices" according to the European Union Department of Agriculture, Food, and Rural Development (2001) include measures for both hygiene and environmental quality. With additional research and communication between involved parties, the apparent conflict in California between environmental and food safety guidelines may be something that can be confidently resolved.

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