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Chapter 8 Keeping Wildlife Out of Your Food: Mitigation and Control Strategies to Reduce the Transmission Risk of Food-Borne Pathogens

Alan B. Franklin
USDA-APHIS-WS National Wildlife Research Center, alan.b.franklin@aphis.usda.gov

Kurt C. VerCauteren
USDA-APHIS-Wildlife Services, kurt.c.vercauteren@usda.gov

Chapter 8
Keeping Wildlife Out of Your Food: Mitigation and Control Strategies to Reduce the Transmission Risk of Food-Borne Pathogens

Alan B. Franklin and Kurt C. VerCauteren

Abstract In this chapter, we provide a general framework for developing strategies to mitigate the contamination of agricultural operations with pathogens carried by wildlife. As part of this framework, we present adaptive management as a viable approach to developing these strategies to reduce the uncertainty over time as to whether management methods are being effective. We provide the general steps to developing an adaptive management strategies as well as generic mitigation methods that can be applied to agricultural operations as part of an adaptive management strategy.

Keywords Adaptive management • Agriculture • Food safety • Habitat modification • Human-wildlife conflict • Mitigation • Population control • Risk assessment • Wildlife • Wildlife damage management

Introduction

In the past few decades, wildlife has been increasingly recognized as a threat to food safety because of their ability to transmit pathogens to agricultural crops and livestock (Langholz and Jay-Russell 2013; Miller et al. 2013). Although the risk and extent of this problem still need to be clarified, increased regulation of agricultural producers has been predicated on the assumption that wildlife has a high probability of contaminating produce fields and livestock, primarily with their feces (U.S. Department of Health and Human Services 2013), which may or may not contain pathogens posing a risk to humans consuming agricultural products.

A.B. Franklin (✉) • K.C. VerCauteren
USDA-APHIS Wildlife Services National Wildlife Research Center, Fort Collins, CO, USA
e-mail: alan.b.franklin@aphis.usda.gov

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Our intent in this chapter is not to provide a litany of methods that can be used to keep wildlife from contaminating agricultural operations, but to provide an overview that agricultural producers can use as a starting point in developing strategic programs to deal with the issue of wildlife contamination of agricultural operations with food-borne pathogens. While we provide some broad categories of tools that can be used, it is not an exhaustive list. An important caveat in the use of some of these tools is that most were developed to prevent or mitigate physical wildlife damage. Thus, the effectiveness of many wildlife damage management methods in preventing or mitigating contamination of agricultural operations with food-borne pathogens has not been evaluated, primarily because this problem has only become a focus in recent years (Langholz and Jay-Russell 2013).

General Strategies

We advocate strategies that are proactive, including a number of what we consider to be essential components and allow for adaptive management (Fig. 8.1). Adaptive management is a programmatic approach, which was originally developed in natural resource management to deal with problems where uncertainty was present in a system (Walters 1986; Walters and Holling 1990; Nichols et al. 1995). Our general strategy (Fig. 8.1) includes the following key components, each of which we will cover in more detail further on:

1. Identifying the problem—Are wildlife a problem in contaminating agricultural operations with food-borne pathogens?

Fig. 8.1 General flowchart for developing and applying methods to mitigate contamination of agricultural operations by food-borne pathogens carried by wildlife

2. Assessing the risk—If wildlife are a problem, what is the level of risk and consequences (i.e., what is the magnitude of the problem)?
3. Developing a strategy—If wildlife pose a risk, how will the problem be dealt with?
4. Implementing mitigation methods—In conjunction with developing a strategy, what are the specific options available for mitigating contamination by wildlife?
5. Evaluation of management effort (testing methods)—Once the general strategy and mitigation methods are implemented, are they working as expected in mitigating or eliminating the problem?

Adaptive Management

The feedback loop in the bottom of Fig. 8.1 represents part of the adaptive management component of the process. Although the use of adaptive management has been proposed for use in wildlife damage management (Reidinger and Miller 2013), it has rarely been applied to management of wildlife-borne pathogens (Miller et al. 2013). One exception that closely resembles adaptive management is an ongoing program to reduce transmission of bovine tuberculosis from wildlife to cattle in Michigan (Box 8.1).

Box 8.1: Example of a Strategic Process Resembling Adaptive Management to Minimize Transmission of Bovine Tuberculosis from Wildlife to Cattle in Michigan

In Michigan, state and federal agencies and universities have been challenged with assisting producers in modifying their practices to reduce potential for exposure to *Mycobacterium bovis* from wildlife to cattle. First, they identified the problem and monitored wildlife and cattle herds to determine its pathways and magnitude (Bruning-Fann et al. 2001; Kaneene et al. 2002; Palmer et al. 2004a, b; Walter et al. 2014). Second, they conducted research to learn about the ecology of the pathogen (Palmer and Whipple 2006; Fine et al. 2011) and wildlife species involved (Atwood et al. 2009; Walter et al. 2013). Finally, they developed methods for addressing the issues (VerCauteren et al. 2012b; Phillips et al. 2012; Vercauteren et al. 2010) and then implemented a cooperative adaptive management program that was tailored for each specific producer. This program has been ongoing and monitoring and adjustment is under way (Walter et al. 2012).

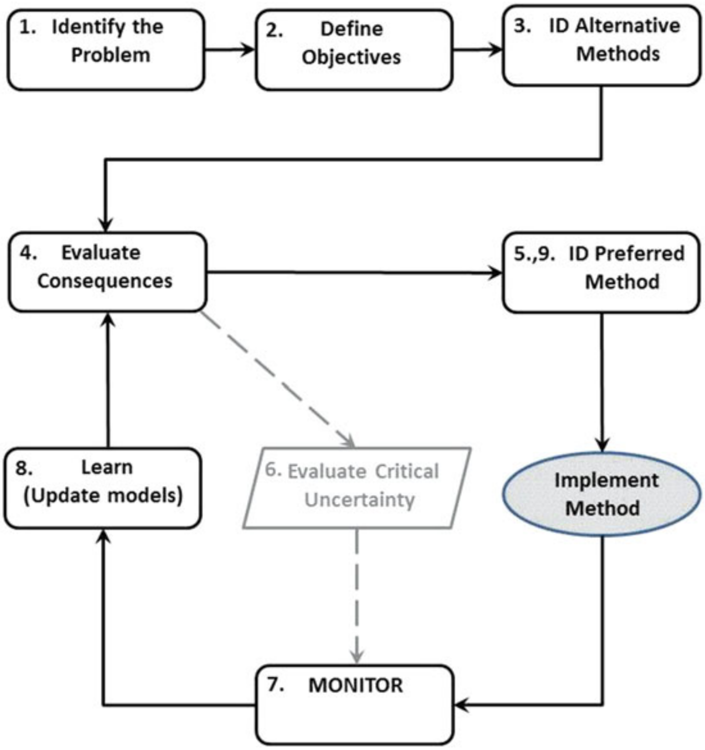

Fig. 8.2 Conceptual framework of adaptive management for managing wildlife contamination of agricultural operations (modified from Runge 2011)

Adaptive management is a formal, learning-based approach for dealing with wildlife management problems (Knutson et al. 2010). It is a formal framework in the sense that it incorporates a structured process of iterative decision making, which is often mathematical in nature (Runge 2011). This is in contrast to management by trial and error where management options are attempted, and if unsuccessful then some other management option is implemented, with no systematic mechanism of "learning by doing" to guide alternative options (Williams and Brown 2012). The adaptive management process includes the steps we outlined previously but puts certain aspects into a more formal framework (Fig. 8.2), which we will discuss further.

Some may argue that the adaptive management process is too time consuming, complicated, costly, and slow (i.e., we need to act now). However, this argument needs to be balanced against the effects of product recalls, restrictive policies for agricultural producers, and other economic costs accrued by not adequately addressing and solving the problem. Thus, we argue that an adaptive management framework is ideal for solving problems of pathogen contamination of agricultural operations by wildlife.

Strategic Processes

Identifying the Problem

The first step in any management issue is to address the following:

1. Is there a problem?
2. If there is a problem, what is the degree and magnitude of the problem?

Wildlife have recently become a concern for spread of food-borne pathogens to agricultural operations, such as produce fields (Langholz and Jay-Russell 2013), concentrated animal feeding operations (Carlson et al. 2011b), and dairy operations (LeJeune et al. 2008). While outbreaks of human illness have been attributed to wildlife contaminating produce fields with food-borne pathogens (Erickson and Doyle 2012), few studies have adequately documented the magnitude of wildlife contamination. Thus, the first step for any agricultural operation is to identify whether wildlife are a potential risk for contaminating their product. This includes identifying which wildlife species are involved, what is the magnitude of their visitation rates to the operation, and what pathogens they are carrying that might affect human food safety.

Most wildlife populations around agricultural operations are synanthropic (peridomestic) species, which are those species that easily coexist with humans. Examples of native synanthropic species (those species indigenous to a particular area) include white-tailed and mule deer, raccoons, skunks, coyotes, cottontail rabbits, and foxes (Clark 2014; Rice 2014). Thus, the first identification of wildlife problems will probably focus initially on these types of wildlife species.

Assessing the Risk

Risk of contamination of agricultural operations from wildlife is a function of:

1. The species of wildlife visiting the facility.
2. The pathogens these wildlife species are infected with.
3. The prevalence of pathogens of concern in these wildlife species.
4. The amount of pathogens they can shed (either orally or through feces) when visiting agricultural facilities (pathogen loads).
5. How often they visit (visitation rates).
6. How many animals visit.
7. What time of year they visit.
8. The contact rates (direct or indirect) between wildlife and agricultural products.
9. The vulnerability of the products to microbial contamination based on type of processing (raw, minimally processed, treated with a kill step) and the production/harvest methods (hand vs. mechanical).
10. Whether there is substantial long-term variation in characteristics 1–8 above.

Understanding the characteristics outlined above requires understanding both the ecology and transmission mechanisms of the wildlife species that may impact a particular agricultural operation. For example, European starlings have been associated with *Salmonella* contamination of livestock feedlots (concentrated animal feeding operations, or CAFOs) (Carlson et al. 2011b) and *Escherichia coli* O157 on dairy farms (Cernicchiaro et al. 2012). In particular, the extent of contamination on CAFOs and dairy farms has been associated with numbers of starlings visiting facilities (Carlson et al. 2011b; Cernicchiaro et al. 2012), which diminished once starling numbers were controlled on a facility (Carlson et al. 2011a). However, control of starlings on single facilities may not always be a cost-effective approach; starlings occupy roost areas away from facilities and often visit multiple facilities (Cernicchiaro et al. 2012; Homan et al. 2013; Gaukler et al. 2008). Thus, understanding the ecology of starlings beyond their impacts on individual operations is important because effective control will depend on the degree of their site fidelity to agricultural operations, their use of other agricultural operations, and roosting behavior (Homan et al. 2013).

In addition, each of the characteristics described above cannot be considered in isolation. For example, prevalence of *Escherichia coli* O157 is relatively low (3 %) in European starlings (LeJeune et al. 2008). However, the number of starlings visiting facilities can be very high, up to ~50,000 daily (Carlson et al. 2011b), which translates to a potential of 1500 starlings infected with *Escherichia coli* O157 visiting such a facility every day at certain times of the year.

Developing Strategies

Developing a strategy to deal with contamination of agricultural operations with pathogens can range from simple guidelines, such as those published by the Colorado State University Extension (2012), to more complex, adaptive strategies. Although adaptive management strategies have not been used specifically for addressing issues of wildlife contaminating agricultural facilities with food-borne pathogens, adaptive management has been attempted in other wildlife damage issues (Parkes et al. 2006; Bryce et al. 2011).

One drawback of adaptive management is that it requires a level of technical expertise to develop the framework of the strategy and the required monitoring effort (Doherty and McLean 2011; Parma 1998). In its truest form, adaptive management is couched in a formal statistical and sampling framework that requires statistical expertise to establish and implement (see Williams et al. 2002). However, the gains in knowledge in dealing with the problem far outweigh the requirement of statistical and scientific rigor required in designing and implementing the strategy. For example, Parkes et al. (2006) argued that adaptive management decreased uncertainty in complex problems or decreased the risk of failure by making uncertainty explicit when dealing with invasive species management.

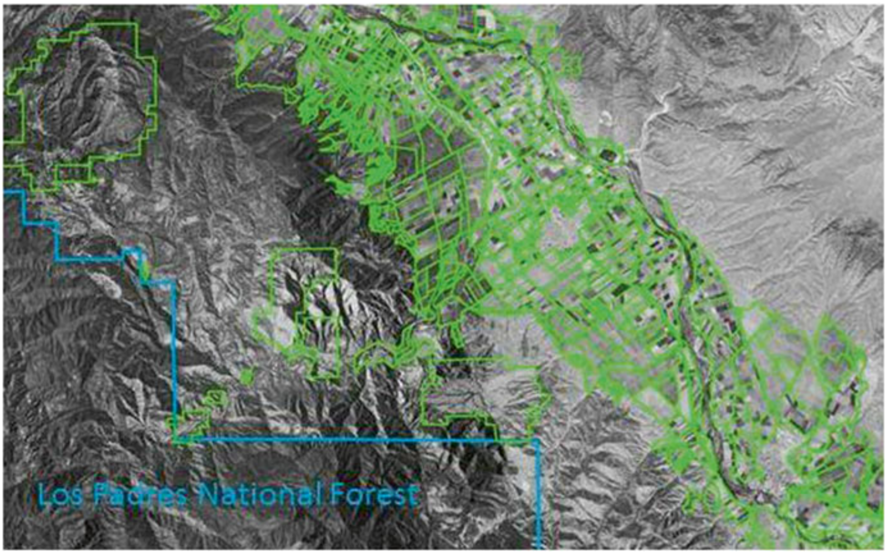

Fig. 8.3 Portion of the Salinas Valley, California, showing different farm and ranch ownerships (*green boundaries*) in proximity to large expanses of public lands (*blue boundaries*)

Of critical importance in developing a strategy for dealing with pathogen contamination by wildlife is the scale of the plan. Few agricultural producers will likely be able to effectively develop an adaptive management plan for their single facilities. However, scales to be considered for effective management can range from local (e.g., county) scales to regional (e.g., state or combination of states) to national scales. The scale to be considered is dependent on the nature of the problem and the uniqueness of the situation. For example, the Salinas Valley in California is the top producer of leafy greens in the USA (Cooley et al. 2007), has a number of independent producers, and is relatively isolated from other similar growing regions (Fig. 8.3). Rather than having separate strategies for each agricultural operation, a common strategy encompassing the entire valley across all producers would probably be most effective, both economically and strategically.

Part of the strategy may include understanding the ultimate source (i.e., a resource that is responsible for contaminating wildlife) of contamination if pathogen contamination by wildlife is suspected as only a proximate source (i.e., is immediately responsible for the contamination). For example, deer were considered the ultimate source of contamination of strawberry fields with *Escherichia coli* O157 (Laidler et al. 2013), which subsequently infected humans consuming the strawberries. However, other ultimate sources, such as water, were not reported as potential causative factors that could have contaminated both the fields and the deer

using those fields. In contrast, contamination of spinach fields with *Escherichia coli* O157 was more thorough but less clear with several ultimate sources implicated, including feral swine as a proximate source (Jay et al. 2007).

Implementing Mitigation Measures

Mitigation measures used in wildlife damage management have direct implications for managing pathogen transmission from wildlife and may often dovetail with issues where wildlife are involved in both damage and pathogen contamination. For example, feral swine cause considerable crop damage as well as pose a risk for pathogen transmission to agriculture (Bevins et al. 2014; Jay and Wiscomb 2008), suggesting that mitigation strategies could simultaneously deal with these two problems.

Mitigation measures can be classified into two primary categories, population control where wildlife populations are reduced or eliminated, and exclusionary measures where wildlife are excluded from agricultural operations (e.g., farm fields, dairies, and livestock facilities).

Population Control

The primary goal in population control is to reduce wildlife populations that represent a contamination threat around agricultural operations. There are three broad categories of population control: lethal control, reproductive control, and habitat modification.

Lethal Control

Lethal control is always an option in wildlife damage management but it has become increasingly difficult to justify with some native wildlife species in terms of ecological effects and has become much less politically and socially palatable (Bergstrom et al. 2014). In addition, we currently lack the ability to alleviate many wildlife damage problems in effective and economical ways using only nonlethal techniques (Conover 2001). For invasive species, such as European starlings and feral swine, the use of lethal control is considered more justifiable because it simultaneously resolves ecological and damage issues beyond just agricultural contamination by wildlife-borne pathogens and is, thus, more politically palatable.

For example, feral swine are effectual reservoirs of an array of diseases (Williams and Barker 2001) that could be transmitted to crop fields and domestic swine herds through interactions that have been documented to occur between wild and domestic

populations (Wyckoff et al. 2012). Feral swine also wallow in and around water sources, thereby increasing potential for pathogen contamination (Atwill et al. 1997; Jay et al. 2007). For these reasons and other wildlife damage issues, a national program to eradicate feral swine throughout most of the USA has been recently implemented (Bevins and Franklin 2014). However, to be effective in the long term, we argue that the use of lethal control to remove some invasive species is ultimately a regional and national problem (e.g., feral swine, European starlings) with reduced effectiveness when control is solely at local levels.

Two examples of lethal control methods with relevance to wildlife in agricultural operations are regulated hunting with ungulates and Integrated Pest Management (IPM) with rodents. Regulated, managed hunting in rural settings is the most practical and effective method of managing overabundant ungulate populations and controlling damage. It is also the most ecologically, socially, and fiscally responsible method. Some states have special depredation permits that can be issued to landowners to remove deer in areas where they are causing damage or threatening to transmit pathogens to agricultural crops or livestock outside the normal hunting season, if sufficient control cannot be achieved during the hunting season. An IPM approach (Witmer 2007) is recommended for control of rodents and other small mammals. The IPM concept favors timely and strategic incorporation of a combination of cost-effective control techniques (lethal and nonlethal) to reduce the impact of species on valuable resources (Newman et al. 2012).

Reproductive Control

Reproductive control is where reproduction is inhibited in free-ranging wildlife populations through sterilization, contraceptives, or immune-contraceptive vaccines. There is a large body of literature on reproductive control and wildlife. However, except for a few species, it has largely been untested as a definitive management tool and is currently not being used effectively in managing wildlife species relative to agricultural production. Considerable effort has been expended to develop fertility control agents (contraceptives) and methods of delivery for primarily wild ungulates, geese, and feral pigeons (Fagerstone et al. 2002; Rhyan et al. 2013). Contraceptives for wildlife have the potential to be a complementary tool for population management in scenarios where current nonlethal management techniques are ineffective or unacceptable. In addition, Killian et al. (2007) argue that reproductive control should be used rather than lethal control to prevent pathogen transmission from wildlife because animals removed through lethal control may be replaced by others infected with pathogens. There are several contraceptive strategies, including chemosterilants, immunocontraceptives, intrauterine devices, and surgical procedures, that can all effectively result in decreased reproduction by individuals (Fagerstone et al. 2002, 2010). Orally delivered contraceptives as well as live vector (bacterial or viral) delivery are being explored further (Fagerstone et al. 2002; Conner et al. 2007). However, it is unlikely that fertility control will become

a viable stand-alone management strategy (Dolbeer 1998; DeNicola et al. 2000) until better and more consistent delivery systems are developed, and research and registration of compounds to use with species other than deer, geese, and pigeons have been completed.

Habitat Modification

All animals are dependent on food and shelter. Therefore, elimination of one or both of these requirements may force wildlife to move from the immediate area. Habitat modification as a mitigation tool has been extensively criticized for its effects on wildlife conservation (Gennet et al. 2013). Using agricultural practices in the Salinas Valley as an example, Gennet et al. (2013) argue that habitat modification, especially in riparian systems, was based on reactive strategies resulting from sporadic outbreaks of food-borne pathogens in produce associated with wildlife (Jay et al. 2007). In addition, the proximity of large blocks of wildlife habitat (Fig. 8.3) precludes the effectiveness of localized habitat modification at smaller scales for wide-ranging wildlife species, such as wild ungulates and feral swine.

Given the above caveat, habitat modification can be useful when used judiciously and at small scales. For example, habitat modification can be implemented in many situations to make roosting, loafing, or feeding sites less attractive to birds, such as European starlings. Although the initial investment of time and money may be high, these modifications often provide long-lasting relief. Thinning or pruning vegetation can cause roosting birds such as blackbirds and starlings to move, often increasing the commercial or ecological aspects at the same time (Leitch et al. 1997). However, there is considerable uncertainty in ecological consequences from large-scale habitat modifications around agricultural facilities. For example, reduction of habitats supporting insectivorous birds and bats could result in increased pest insect populations with subsequent increases in crop damage.

Exclusionary Methods

Here, we view nonlethal, exclusionary methods as including physical barriers, scare devices, and repellants. VerCauteren et al. (2012a) and Reidinger and Miller (2013) provide an extensive review of exclusionary methods that can be used to keep wildlife away from agricultural operations. While many of these methods have been developed to mitigate wildlife damage, they also have direct applications toward mitigating contamination from pathogens carried by wildlife. Methods that prevent wildlife from entering agricultural facilities and crops, such as those evaluated by Johnson et al. (2014), are the most relevant to mitigating contamination with pathogens from wildlife.

Limited effectiveness and high cost of some nonlethal strategies frequently make them economically impractical, even when used in conjunction with lethal strategies. Frequently, the efficacy of nonlethal techniques is directly correlated to

the level of motivation of the targeted individuals. For example, a simple frightening device employing sound and lights or a single strand of electric fence may be a sufficient deterrent to minimize deer use of a minimally desired resource. However, when stressed for food, deer can breech a 2.1-m-high woven-wire mesh fence to feed on and potentially contaminate stored crops, imposing risk for pathogen transmission to livestock (VerCauteren et al. 2003). Thus, the management technique chosen for a scenario under one level of motivation may have a different degree of success in dissimilar scenarios, so the level of motivation of the targeted wildlife must be considered prior to implementation of any nonlethal technique.

Frequently, fencing is the only long-term, nonlethal method to effectively minimize exposure of agricultural facilities and crops to wildlife. Many fence designs are available, although an effective yet low-cost design that keeps out multiple wildlife species has yet to be perfected. Fencing provides protection as a physical barrier, as a psychological barrier, or as a combination of the two. The standard deer fence, a 2.4-m-high woven-wire fence, is a physical barrier and greatly reduces the possibility of an animal passing through, over, or under. Conversely, a single- or double-strand electric poly-tape fence acts as a psychological barrier through aversive conditioning. Conditioning occurs when an animal attempts to breach the fence and receives a powerful electric shock. This training can be expedited with the use of bait such as peanut butter applied directly to the fence (Porter 1983). Plastic netting has been used as a cost-effective method to exclude birds from individual fruit trees or high-value crops such as blueberries or grapes (Fuller-Perrine and Tobin 1993), but is probably infeasible for large expanses of crops or feed bunks at large livestock facilities.

Scare devices, such as propane cannons, flashing lights, shell crackers, and other sonic devices, used near an agricultural facility can provide temporary relief from wildlife intrusions (Gilsdorf et al. 2002). Blackbird roosts containing up to several million birds can be moved by using a combination of devices, particularly recorded distress calls, shell crackers, rockets, and propane cannons (Mott 1980). Strobe lights placed in the roost are also helpful. However, some species, such as wild ungulates, adjust or habituate to frightening devices quickly, and these devices are generally not effective for an entire crop-growing season. Recent research has evaluated the efficacy of animal-activated frightening devices, revealing mixed results (Gilsdorf et al. 2004a, b; Belant et al. 1998; Beringer et al. 2003). Often these devices are most effective when used in combination with other methods rather than as a sole exclusionary method (Gilsdorf et al. 2002).

While repellants may minimize or prevent wildlife from damaging crops, they will not necessarily prevent potential contamination from pathogens in feces unless there is a strong negative habituation from repellants in the use of areas by wildlife. As with other nonlethal techniques, factors such as ungulate population density, availability of alternate foods, target plant species, weather, repellent concentration, and duration of the problem can influence the effectiveness of repellents.

One underutilized, but potentially effective, exclusionary method to eliminate or reduce wildlife intrusion into agricultural crop fields and facilities is the use of

guard dogs. Guard dogs have been effectively used to minimize contact between wildlife and field crops (VerCauteren et al. 2005) and wildlife and livestock (VerCauteren et al. 2008, 2012b). Despite the initial cost and effort of training, guard dogs may be a long-term and cost-effective method for keeping wildlife, and hence pathogen transmission, out of livestock facilities and agricultural fields.

Testing Methods Through Monitoring

The last, but most important, step in implementing any strategy is monitoring to test whether the strategy is working and, if not, where it is failing. This is also an integral component of adaptive management and provides the "learning-by-doing" component (Knutson et al. 2010). Nichols and Williams (2006) distinguish between surveillance monitoring and targeted monitoring, where targeted monitoring has the advantage of being designed and includes rigorous monitoring that produces scientifically credible results. Monitoring alone does not make a strategy fit with adaptive management; adaptive management also involves the implementation and integration of multiple components in both assessment and adaptation (Fig. 8.2) (Williams and Brown 2012).

Monitoring is a critical step in the adaptive management process; the failure of most adaptive management programs is because the monitoring component has not been adequately supported (Knutson et al. 2010; Nichols and Williams 2006). Under adaptive management, the monitored attributes must be directly related to management objectives or else it will be difficult to ascertain whether the management objectives were met (Knutson et al. 2010).

Monitoring wildlife populations and their impacts is often problematic because wildlife are not completely detectable. This issue of incomplete detectability has generated considerable effort to develop population estimators that account for lack of complete detectability through estimation of detection probabilities (Thompson et al. 1998). The statistical and sampling issues surrounding detection of pathogens in wildlife in a monitoring program are further described conceptually by Doherty and McLean (2011) and analytically by McClintock et al. (2010).

Conclusions

Throughout this chapter, we have argued that an adaptive management approach is an appropriate, objective, scientifically based approach for mitigating or eliminating pathogen contamination of agricultural operations by wildlife. In addition, the flexibility of adaptive management allows for multiple objectives and also allows for balancing competing objectives (Knutson et al. 2010; Parma 1998; Williams

and Brown 2012). For example, mitigating pathogen contamination and maintaining wildlife habitat are two seemingly competing objectives that can be evaluated and potentially balanced using an adaptive management approach (Gennet et al. 2013). In developing an adaptive management strategy, we suggest that agricultural producers:

1. Form localized coalitions among independent producers and groups to efficiently share resources.
2. Partner with university, state, and federal scientists familiar with adaptive management to develop effective strategic approaches.
3. Consider multiple methods for mitigating wildlife intrusion into agricultural facilities, which may include a combination of population control and exclusionary measures.

All of these points should be considered in terms of the scope and scale of the problem. For example, developing strategies for leafy green crops in the Salinas Valley may not be completely relevant to other leafy green production areas because of differences in landscapes, wildlife species, and pathogens of concern. However, the general framework of the strategy may be very similar, with only the specifics needing modification.

In considering population control as an option, we argue that lethal control should generally be used only when dealing with invasive species because it resolves both ecological and agricultural problems and, thus, is more palatable to the general public. Habitat modification is also difficult to justify without more scientific evidence in terms of its effectiveness (Gennet et al. 2013).

In summary, we argue that adaptive management strategies coupled with existing methods for preventing and mitigating wildlife damage have the greatest promise for achieving cost-effective and long-term practices that balance the needs of wildlife conservation while preventing their intrusion and subsequent contamination of agricultural facilities and crops.

References

Atwill ER, Sweitzer RA, Pereira MG et al (1997) Prevalence of and associated risk factors for shedding *Cryptosporidium parvum* oocysts and *Giardia* cysts within feral pig populations in California. Appl Environ Microbiol 63:3946–3949

Atwood TC, Deliberto TJ, Smith HJ et al (2009) Spatial ecology of raccoons related to cattle and bovine tuberculosis in northeastern Michigan. J Wildl Manage 73:647–654

Belant JL, Seamans TW, Tyson LA (1998) Evaluation of electronic frightening devices as white-tailed deer deterrents. In: Baker RO, Crabb AC (eds) Proceedings of the eighteenth vertebrate pest conference. University of California, Davis, CA, pp 107–110

Bergstrom BJ, Arias LC, Davidson AD et al (2014) License to kill: reforming federal wildlife control to restore biodiversity and ecosystem function. Cons Lett 7:131–142

Beringer J, VerCauteren KC, Millspaugh JJ (2003) Evaluation of an animal-activated scarecrow and a monofilament fence for reducing deer use of soybean fields. Wildl Soc Bull 31:492–498

Bevins SN, Franklin AB (2014) One Health in action: reducing feral swine damage and disease. One Health Newsl 7(2):4–6
Bevins SN, Pedersen K, Lutman MW et al (2014) Consequences associated with the recent range expansion of nonnative feral swine. Bioscience 64:291–299
Bruning-Fann CS, Schmitt SM, Fitzgerald SD et al (2001) Bovine tuberculosis in free-ranging carnivores from Michigan. J Wildl Dis 37:58–64
Bryce R, Oliver MK, Davies L et al (2011) Turning back the tide of American mink invasion at an unprecedented scale through community participation and adaptive management. Biol Conserv 144:575–583
Carlson JC, Engeman RM, Hyatt DR et al (2011a) Efficacy of European starling control to reduce *Salmonella enterica* contamination in a concentrated animal feeding operation in the Texas panhandle. BMC Vet Res 7:9
Carlson JC, Franklin AB, Hyatt DR et al (2011b) The role of starlings in the spread of Salmonella within concentrated animal feeding operations. J Appl Ecol 48:479–486
Cernicchiaro N, Pearl DL, McEwen SA et al (2012) Association of wild bird density and farm management factors with the prevalence of *E. coli* O157 in dairy herds in Ohio (2007–2009). Zoonoses Public Health 59:320–329
Clark L (2014) Disease risks posed by wild birds associated with agricultural landscapes. In: Matthews KR, Sapers GM, Gerba CP (eds) The produce contamination problem: causes and solutions, 2nd edn. Academic Press, San Diego, CA, pp 139–165
Colorado State University Extension (2012) Fundamentals of creating a Colorado farm food safety plan: food safety plan guide. Colorado State University, Fort Collins, CO
Conner MM, Baker DL, Wild MA et al (2007) Fertility control in free-ranging elk using gonadotropin-releasing hormone agonist leuprolide: effects on reproduction, behavior, and body condition. J Wildl Manage 71:2346–2356
Conover MR (2001) Resolving human-wildlife conflicts: the science of wildlife damage management. CRC Press, Boca Raton, FL
Cooley M, Carychao D, Crawford-Miksza L et al (2007) Incidence and tracking of *Escherichia coli* O157:H7 in a major produce production region in California. PLoS One 2(11), e1159
DeNicola AJ, VerCauteren KC, Curtis PD et al (2000) Managing white-tailed deer in suburban environments: a technical guide. Cornell Cooperative Extension, Ithaca, NY
Doherty PF, McLean RG (2011) Conceptual and practical issues in monitoring disease in wild animal populations: A review of avian influenza programs. In: Majumdar SK, Brenner FJ, Huffman JE et al (eds) Pandemic influenza viruses: science, surveillance and public health. The Pennsylvania Academy of Science, Easton, PA, pp 130–142
Dolbeer RA (1998) Population dynamics: The foundation of wildlife damage management for the 21st century. In: Baker RO, Crabb AC (eds) Proceedings of the 18th vertebrate pest conference. University of California, Davis, Davis, CA, pp 2–11
Erickson MC, Doyle MP (2012) Plant food safety issues: production agriculture with One Health. In: Institute of Medicine (ed) Improving food safety through a One Health approach. The National Academies Press, Washington, DC, pp 140–175
Fagerstone KA, Coffey MA, Curtis PD et al (2002) Wildlife fertility control. Wildlife society technical review. The Wildlife Society, Bethesda, MD
Fagerstone KA, Miller LA, Killian G et al (2010) Review of issues concerning the use of reproductive inhibitors, with particular emphasis on resolving human-wildlife conflicts in North America. Integr Zool 5:15–30
Fine AE, Bolin CA, Gardiner JC et al (2011) A study of the persistence of *Mycobacterium bovis* in the environment under natural weather conditions in Michigan, USA. Vet Med Int 2011:12
Fuller-Perrine LD, Tobin ME (1993) A method for applying and removing bird-exclusion netting in commercial vineyards. Wildl Soc Bull 21:47–51
Gaukler SM, Homan HJ, Dyer NW et al (2008) Pathogenic diseases and movements of wintering European starlings using feedlots in central Kansas. In: Timm RM, Madon MB (eds) 23rd vertebrate pest conference, University of California, San Diego, CA, pp 280–282

Gennet S, Howard J, Langholz J et al (2013) Farm practices for food safety: an emerging threat to floodplain and riparian ecosystems. Front Ecol Environ 11:236–242

Gilsdorf JM, Hygnstrom SE, VerCauteren KC (2002) Use of frightening devices in wildlife damage management. Integr Pest Manage Rev 7:29–45

Gilsdorf JM, Hygnstrom SE, VerCauteren KC et al (2004a) Propane exploders and electronic guards were ineffective at reducing deer damage in cornfields. Wildl Soc Bull 32:524–531

Gilsdorf J, Hygnstrom SE, VerCauteren KC et al (2004b) Evaluation of a deer-activated bioacoustic frightening device for reducing deer damage in cornfields. Wildl Soc Bull 32:515–523

Homan HJ, LeJeune JT, Pearl DL et al (2013) Use of dairies by postreproductive flocks of European starlings. J Dairy Sci 96:4487–4493

Jay MT, Wiscomb GW (2008) Food safety risks and mitigation strategies for feral swine (*Sus scrofa*) near agriculture fields. In: Timm RM, Madon MB (eds) Proceedings of the 23rd vertebrate pest conference. University of California, Davis, CA, pp 21–25

Jay MT, Cooley M, Carychao D et al (2007) *Escherichia coli* O157:H7 in feral swine near spinach fields and cattle, Central California Coast. Emerg Infect Dis 13:1908–1911

Johnson HE, Fischer JW, Hammond M et al (2014) Evaluation of techniques to reduce deer and elk damage to agricultural crops. Wildl Soc Bull 38:358–365

Kaneene JB, Bruning-Fann CS, Granger LM et al (2002) Environmental and farm management factors associated with tuberculosis on cattle farms in northeastern Michigan. J Am Vet Med Assoc 221:837–842

Killian G, Fagerstone K, Kreeger T et al (2007) Management strategies for addressing wildlife disease transmission: The case for fertility control. In: Nolte DL, Arjo WM, Stalman D (eds) Proceedings of the 12th wildlife damage management conference. National Wildlife Research Center, Fort Collins, CO, pp 265–271

Knutson M, Laskowski H, Moore C et al (2010) Defensible decision making: harnessing the power of adaptive resource management. Wildl Prof 4:58–62

Laidler MR, Tourdjman M, Buser GL et al (2013) *Escherichia coli* O157:H7 infections associated with consumption of locally grown strawberries contaminated by deer. Clin Infect Dis 57:1129–1134

Langholz JA, Jay-Russell MT (2013) Potential role of wildlife in pathogenic contamination of fresh produce. Hum Wildl Interact 7:140–157

Leitch JA, Linz GM, Baltezore JF (1997) Economics of cattail (*Typha* spp.) control to reduce blackbird damage to sunflower. Agric Ecosyst Environ 65:141–149

LeJeune J, Homan J, Linz G et al (2008) Role of the European starling in the transmission of *E. coli* O157 on dairy farms. In: Timm RM, Madon MB (eds) Proceedings of the 23rd vertebrate pest conference, University of California, San Diego, California. University of California Press, San Diego, CA, pp 31–34

McClintock BT, Nichols JD, Bailey LL et al (2010) Seeking a second opinion: uncertainty in disease ecology. Ecol Lett 13:659–674

Miller RS, Farnsworth ML, Malmberg JL (2013) Diseases at the livestock–wildlife interface: status, challenges, and opportunities in the United States. Prev Vet Med 110:119–132

Mott DF (1980) Dispersing blackbirds and starlings from objectionable roost sites. In: Clark JP, Marsh RE (eds) Proceedings of the 9th vertebrate pest conference. University of California, Davis, CA

Newman P, Salmon TP, Gorenzel WP (2012) Food safety and rodent control in leafy green crops. In: Timm RM, Madon MB (eds) Proceedings of the 25th vertebrate pest conference. University of California-Davis, Davis, CA, pp 107–112

Nichols JD, Williams BK (2006) Monitoring for conservation. Trends Ecol Evol 21:668–673

Nichols JD, Johnson FA, Williams BK (1995) Managing North American waterfowl in the face of uncertainty. Annu Rev Ecol Syst 26:177–199

Palmer MV, Whipple DL (2006) Survival of *Mycobacterium bovis* on feedstuffs commonly used as supplemental feed for white-tailed deer (*Odocoileus virginianus*). J Wildl Dis 42:853–858

Palmer MV, Waters WR, Whipple DL (2004a) Investigation of the transmission of *Mycobacterium bovis* from deer to cattle through indirect contact. Am J Vet Res 65:1483–1489

Palmer MV, Waters WR, Whipple DL (2004b) Shared feed as a means of deer-to-deer transmission of *Mycobacterium bovis*. J Wildl Dis 40:87–91

Parkes JP, Robley A, Forsyth DM et al (2006) Adaptive management experiments in vertebrate pest control in New Zealand and Australia. Wildl Soc Bull 34:229–236

Parma AM (1998) What can adaptive management do for our fish, forests, food, and biodiversity? Integr Biol 1:16–26

Phillips GE, Lavelle MJ, Fischer JW et al (2012) A novel bipolar electric fence for excluding white-tailed deer from stored livestock feed. J Anim Sci 90:4090–4097

Porter WF (1983) A baited electric fence for controlling deer damage to orchard seedlings. Wildl Soc Bull 11:325–327

Reidinger RF, Miller JE (2013) Wildlife damage management: prevention, problem solving and conflict resolution. Johns Hopkins University Press, Baltimore, MD

Rhyan JC, Miller LA, Fagerstone KA (2013) The use of contraception as a disease management tool in wildlife. J Zoo Wildl Med 44:S135–S137

Rice DH (2014) Produce contamination by other wildlife. In: Matthews KR, Sapers GM, Gerba CP (eds) The produce contamination problem: causes and solutions, 2nd edn. Academic Press, San Diego, CA, pp 139–165

Runge MC (2011) An introduction to adaptive management for threatened and endangered species. J Fish Wildl Manage 2:220–233

Thompson WL, White GC, Gowan C (1998) Monitoring vertebrate populations. Academic Press, San Diego, CA

U. S. Department of Health and Human Services (2013) Proposed rule for standards for the growing, harvesting, packing, and holding of produce for human consumption. Fed Reg 78:3504–3646

VerCauteren K, Pipas M, Peterson P et al (2003) Stored-crop loss due to deer consumption. Wildl Soc Bull 31:578–582

VerCauteren KC, Seward NW, Hirchert DL et al (2005) Dogs for reducing wildlife damage to organic crops: a case study. In: Nolte DL, Fagerstone KA (eds) Proceedings of the 11th wildlife damage management conference, Fort Collins, CO, pp 286–293

VerCauteren KC, Lavelle MJ, Phillips GE (2008) Livestock protection dogs for deterring deer from cattle and feed. J Wildl Manage 72:1443–1448

Vercauteren KC, Vandeelen TR, Lavelle MJ et al (2010) Assessment of abilities of white-tailed deer to jump fences. J Wildl Manage 74:1378–1381

VerCauteren KC, Dolbeer R, Gese E (2012a) Identification and management of wildlife damage. In: Silvy NJ (ed) The wildlife techniques manual, 7th edn. John Hopkins University Press, Baltimore, MD, pp 232–269

VerCauteren KC, Lavelle MJ, Gehring TM et al (2012b) Cow dogs: use of livestock protection dogs for reducing predation and transmission of pathogens from wildlife to cattle. Appl Anim Behav Sci 140:128–136

Walter WD, Anderson CW, Smith R et al (2012) On-farm mitigation of transmission of tuberculosis from white-tailed deer to cattle: Literature review and recommendations. Vet Med Intern 2012:15.

Walter WD, Smith R, Vanderklok M et al (2014) Linking bovine tuberculosis on cattle farms to white-tailed deer and environmental variables using Bayesian hierarchical analysis. PLoS One 9, e90925

Walters C (1986) Adaptive management of renewable resources. Macmillan Publishing Company, New York, NY

Walters CJ, Holling CS (1990) Large-scale management experiments and learning by doing. Ecology 71:2060–2068

Williams ES, Barker IK (2001) Infectious diseases of wild mammals. Iowa State University Press, Ames, IA

Williams BK, Brown ED (eds) (2012) Adaptive management: The U.S. Department of the interior applications guide. Adaptive Management Working Group, Washington, DC

Williams BK, Nichols JD, Conroy MJ (2002) Analysis and management of animal populations. Academic, San Diego, CA

Witmer GW (2007) The ecology of vertebrate pests and integrated pest management (IPM). In: Kogan M, Jepson P (eds) Perspectives in ecological theory and integrated pest management. Cambridge University Press, Cambridge, pp 393–410

Wyckoff AC, Henke SE, Campbell TA et al (2012) Movement and habitat use of feral swine near domestic swine facilities. Wildl Soc Bull 36:130–138