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

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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.

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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?

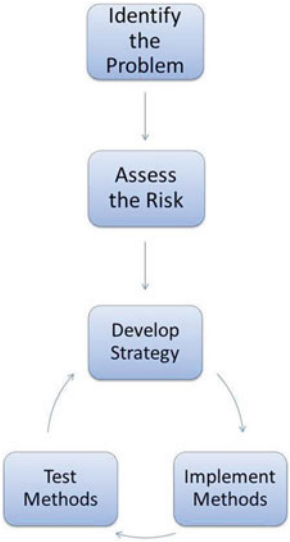

Fig. 8.1 General flowchart for developing and applying methods to mitigate contamination of agricultural operations by food-borne pathogens carried by wildlife

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).

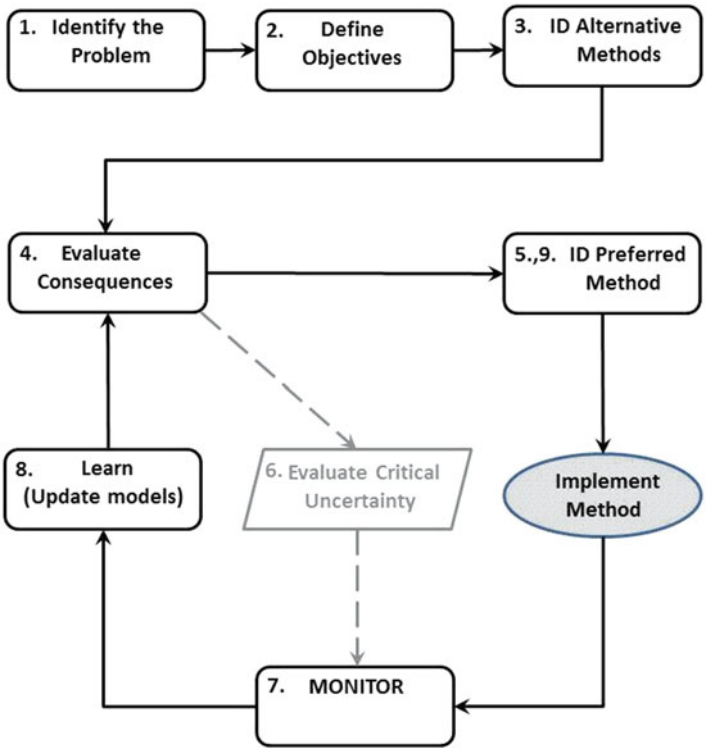

Fig. 8.2 Conceptual framework of adaptive management for managing wildlife contamination of agricultural operations (modified from Runge 2011)

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.

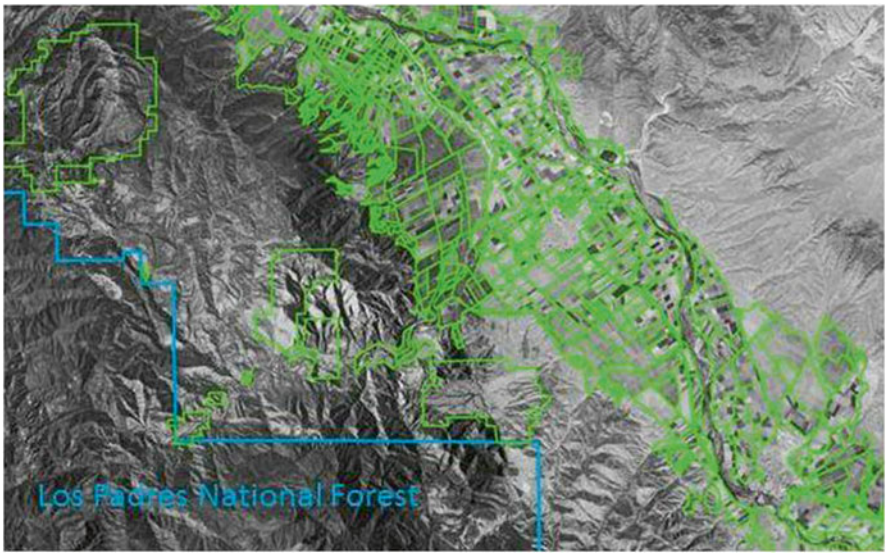

Fig. 8.3 Portion of the Salinas Valley, California, showing different farm and ranch ownerships (*green boundaries*) in proximity to large expanses of public lands (*blue boundaries*)

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.

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