Chapter 12
Containment and Eradication of Invasive Pathogens

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Abstract A plant disease outbreak resulting from an invasive pathogen can threaten a country's agricultural enterprise, economy and trade, and pose a threat to human food and animal feed. Therefore, following the detection of a new disease, the preferred response objective is elimination of invading pathogen(s). Invasive pathogen eradication requires a well prepared infrastructure and a coordinated process of early and rapid detection, identification of the pathogen, and the adoption and careful execution of an appropriate strategy. Since selection of the best approach in a given situation depends upon a realistic assessment of the effectiveness of various available approaches, and the feasibility for their use and success, a quantitative assessment of all the factors influencing the eradication process is recommended.

Keywords Emerging infectious disease • Emerging infectious pests • Quarantine • Management • Pest control

12.1 Introduction

Introduction of an invasive pathogen is a threat to a country's agriculture, economy and trade (Anderson et al. 2004). Furthermore, certain pathogens can threaten the safety of human food and animal feed. Therefore, response objectives following a disease outbreak due to an invasive pathogen are targeted to pathogen containment and eradication from the invaded area, emphasizing the goal of zero inoculum and disease left in the invaded area. These goals differ from those used in managing an endemic pathogen, which, driven mainly by economic considerations, emphasize

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reduction of pathogen development and limitation of disease impact below an economical threshold. Eradication of invasive pathogens should begin with risk assessment of short and long-term consequences from the establishment of a new pathogen and implementation of procedures to effectively eliminate the pathway for such establishment. It involves a number of interrelated or repeated management measures combined with surveys and inspections to validate the efficacy of the process. Moreover, successful pest eradication requires coordinated action among regulatory authorities, plant pathologists, extension personnel and, ultimately, the farmers. Individual tasks of an eradication program may have little impact unless all tasks relate, logically and temporally, to each other (ISPM 9).

Eradication of an invasive pest begins with the assessment of various approaches and measures for the elimination of a particular pathogen and their effectiveness in interrupting the disease cycle and dynamics. Validated means for quantitative assessment of the effects of the control measures, singly and in combination, should be implemented. All of these actions are essential for an integrated and practical strategy to eliminate the pathogen, and in some cases the relevant host, from the outbreak area. The choice of inappropriate measures, their inefficient application, or omission of key factors from consideration may lead to failure of eradication (Gottwald and Irey 2007).

Pathogen eradication may not always be practical or achievable. In certain cases it may be evident early on that eradication is a far-reaching goal. Nevertheless, if the possible consequences of an unmanaged plant disease epidemic are highly significant, an eradication strategy may be justifiable as the first line of action.

Criteria for characterizing the impact of an invasive pathogen were numerically rated in the "Effective Pathogen Index – EPI" by Schaad et al. (1999)). These ratings reflect parameters of the pathogen, i.e. survival, establishment and spread, which can increase its potential damage when introduced to a new area.

Approaches to prevent the establishment of an introduced invasive begin with preventing the invasion, and then, following detection of an outbreak, eradication. Plant biosecurity principles are designed to achieve rapid mitigation, and eventual eradication or management of invasive pathogens. Eradication, the preferred goal in any invasion of a new pest, depends upon preparedness and rapid response.

The following terminology further explains the various approaches and mitigation concepts.

- ***Prevention*** – The first set of precautionary measures is intended to prevent the introduction of pathogens in any form. Prevention strategies begins with priority setting; i.e. conducting regular surveillance of high-threat exotic plant pathogens, assessing the probability that one of those pathogens could move into the nation or region of concern and the possible impact of such movement, and taking precautionary measures to prevent its entry. Most countries have developed prioritized lists of quarantine pests, those agents considered to be of greatest threat to that nation's biological resources. Quarantine pest lists form the basis for border inspections and controls to stop the entry of any items (propagation material, plant parts, food) infested with listed agents. The prevention

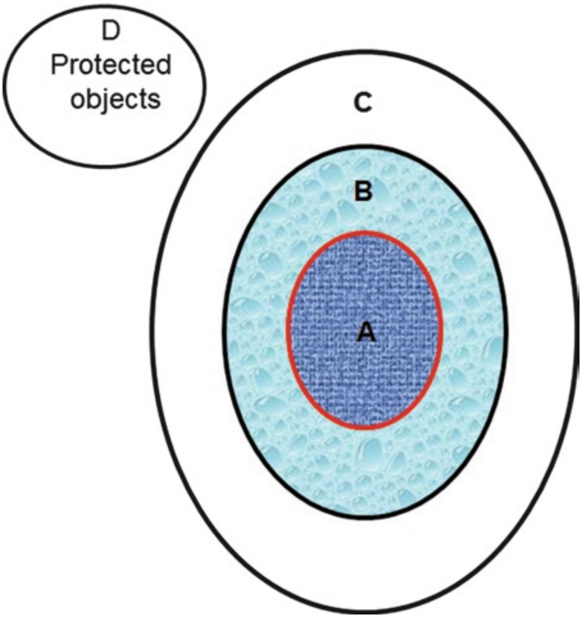

Fig. 12.1 Spatial delineation of the area of an outbreak for the deployment of containment and eradication procedures. *A* – outbreak area; *B* – buffer zone; *A* + *B* – quarantine area; *C* – area outside quarantine zone; *D* – protected object or area (e.g. nurseries)

strategy also should include contingency plans, including emergency regulations and special unit training, to mitigate a possible outbreak should it occur. Appropriate, dedicated administrative and physical infrastructures are essential to achieve the goals of prevention.

- ***Outbreak and quarantine setup*** – After an outbreak is detected and its causal pathogen identified, response begins with delineation of the outbreak area as a quarantine zone, which is under rigorous control to prevent any means by which the invasive pathogen could be moved into or out of the quarantine area (Fig. 12.1). Restricted items often include plants (plant parts and fruits), machinery, equipment, and packing materials.
- ***Containment*** – In the attempt to prevent the movement of an invasive pathogen from the outbreak area to new loci, measures are taken to suppress the initial inoculum and to prevent new infection and spread beyond the detected outbreak (quarantine) zone.
- ***Eradication*** – Executed following, and in parallel to, the containment process, eradication is the application of available and effective phytosanitary measures to eliminate all existing and potential inoculum, including infected host plants, possible vectors and alternate hosts, from a contained area (ISPM 5).
- ***Management*** – Following successful execution of the containment and eradication process, or in cases in which eradication strategies are deemed unlikely to be effective, management actions are applied. Strategies include prevention of new infections, introduction of resistant plant cultivars, application of pesticides and more. Management should continue for an extended period to ensure the continued success of the eradication process. Ref?

12.2 Aspects of Pathogen and Disease with Relevance to Containment and Eradication

12.2.1 Pathogen Traits

Successful eradication of invasive pathogens requires a concerted complex of detection, risk assessment, adoption of appropriate strategies, and careful execution of management procedures. Early disease detection in a confined outbreak area is followed by adoption of appropriate strategies to terminate the outbreak. The latter depends on realistic assessment of the effectiveness of available approaches, and the feasibility for their success. Quantitative assessment of all the factors that influence the eradication process can assist in the selection of the most effective eradication approach and eventually to pathogen elimination. The following factors are important for evaluating the threat and assessing its relevance to the selection of appropriate response measures.

- ***Type of threat and its possible impact***. Threats posed by an invasive pathogen include food poisoning, trade interruption, economic damage (loss of crop yield or quality), and loss of biodiversity in natural habitats. The potential impact of each threat in terms of time and severity dictates the urgency and the priorities for response. For example, a threat of food toxicity should draw the highest attention and response, since human and animal health are at the top of the priority ladder.
- ***The pathogen***. The systematic classification of pathogens (*i.e.* viruses, bacteria, fungi, and their taxonomic ranks) indicates types of potential disease and can therefore help investigators to assess the magnitude of the threat (Gamliel 2008). Moreover, it also suggests what types of response may be effective. For example, strategies to eradicate myctoxin-producing fungi target both the fungus and the contaminated products. For viral diseases, in contrast, most measures are directed towards eradication of insect vectors and destruction of the infected crop.
- ***Pathogen biology and disease epidemiology***. The ultimate objective of containment is to suppress new infectious inoculum. To apply appropriate countermeasures and accomplish this goal requires knowledge of the pathogen and host biology, life cycle and disease progress (Jeger 2004). For example, soilborne fungi, which have a relatively slow, spatial distribution pattern, can be contained if the inoculum is suppressed. In contrast, it is much more difficult to contain foliar fungal diseases, such as Karnal bunt of wheat (*Tilletia indica*), in which large masses of spores are produced.
- ***Vectors***. The involvement of vectors, usually (but not always) insects, in a disease cycle introduces complexity in several ways. Some plant pathogens move from plant to plant only through the actions of vectors, while for others insects may disseminate propagules to greater distances and more quickly than they would move on their own. Vector transmission also introduces new elements of host and geographical specificity that are characteristic of the vector rather than

of the plant or pathogen. Therefore, it is critical to prevent vector entry to the outbreak area, or to eradicate vectors already present. For example, *Xyllela fastidiosa*, the bacterium that causes Pierce's disease of grapevine, has recently detected in Italy, but not in other EU countries (EPPO 2016). Since, numerous species of *Cicadellidae* and *Cercopidae* known to be vectors of *X. fastidiosa* (Hopkins and Purcell 2002) reside in these areas, vector management should play an important role in any preparedness and eradication program if and when this pathogen invades that territory.

- ***Other hosts***. Many pathogens can infect, survive on and spread to hosts other than an economically important crop (primary host). The range of pathogen hosts can include cultured or wild plants that are taxonomically close (or not) to the primary host, and a wide spectrum of weeds. Failure to identify and eradicate all host species from the invaded area can result in failure of the overall eradication process. For example, because *Phytophthora ramorum*, the causal agent of sudden oak death, colonizes at least 97 host species (USDA-APHIS 2006), containment and eradication must include all the possible hosts.
- ***Size and location of the outbreak area***. The success of containment and eradication measures is inversely correlated with the size of the outbreak area. In a small and confined area, a rapid response could be successful. However, if the disease is present over a wide area, or in multiple sites, pathogen distribution may have occurred beyond the detected location. In such cases the chances for successful containment and eradication are lower. introduction of a tree pathogen into an urban area or forest could be much more difficult to handle than one in an open agricultural field setting, since other factors may dominate the response approach. For example, the fact that the Florida citrus canker outbreak was initially localized within an urban area with many back yard citrus trees, prompting vigorous opposition to the tree eradication strategy that had been adopted,was one of the main reasons for eradication failure during 1995–2001 (Gottwald et al. 2001, 2002; Graham et al. 2004).
- ***Extreme climatic events***. Unusual climatic conditions can induce, spread or suppress epidemics. For example, hurricanes were a significant factor in the spread of citrus canker in Florida in 2005 (Gottwald and Irey 2007), and in the introduction of soybean rust to the southern U.S. in 2004 (Rupe and Sconyers 2008).
- ***The lag time from infection to detection***. Early detection and accurate diagnosis are crucial to prevent the establishment and dispersal of introduced pests and pathogens and to minimize subsequent impact. Once an invading pathogen species becomes established in an area it can be difficult or impossible to eradicate. A good example of effective and quick detection is the case of pathogens in propagation material that are detected before their introduction into the soil. In contrast, symptoms of citrus greening (caused by *Liberobacter* sp.) were expressed in a period of 2.5–3.5 months after leaves emerged from buds on diseased trees (Su and Huang 1990). Furthermore, detection of citrus greening pathogens in asymptomatic tissue is inconsistent by any known method Molecular detection assays may be complicated, and results are not always reliable. The incubation period (i.e. the time from infection to disease), and the latent period

(the time from infection to production of an infectious propagule) further extends the time from invasion to detection, possibly beyond the threshold timing for effective containment and eradication.

- ***Available measures and time of response***. Two critical steps in emerging infectious diseases (EIDs) are pathogen establishment in a new area and spread to other loci. Because preventing these events is time dependent, the success or failure will depend on the rapidity of the response as well as to the specific measures taken.

12.2.2 Clustering Pathogens by Recommended Eradication Strategies

Quarantine pathogens and pests can be grouped into categories to facilitate appropriate selection of "containment and eradication" approaches. In this chapter we describe five such pathogen clusters (Table 12.1). The containment-eradication approach for each aims at addressing both general and specific traits of the cluster's members. A list of representative or example pathogens for each cluster, which are relevant for EU countries, is also shown in Table 12.1.

Table 12.1 Pathogen clusters for selection of containment-eradication protocols

	Pathogen group	Representative pathogens of concern to EU nations	Pathogen type
1.	Pathogens that contaminate edible plant parts with toxins/byproducts harmful to human consumers	*Tilletia indica*	Fungus
		Fusarium proliferatum	Fungus
2.	Viral pathogens	*Andean potato latent virus*	Virus
		Beet leaf curl virus	Virus
		Pepino mosaic potexvirus (PeMV),	Virus
		Plum pox potyvirus	Virus
		Potato spindle tuber viroid (PSTV)	Virus
3.	Foliar pathogens	*Xanthomonas axonopodis* pv. *citri*	Bacteria
		Xyllela fastidiosa	Bacteria
		Magnaporthe grisea/Pyricularia oryzae	Fungus
		Phakopsora pachyrhizi	
4.	Soilborne pathogens	*Aphanomyces euteiches*	Fungus
		Fusarium oxysporum f.sp. *albedinis*	Fungus
		Ralstonia solanacearum race 3 biovar 2	Bacteria
		Synchytrium endobioticum	Fungus
5.	Forest tree pathogens	*Ceratocystis fagacearum*	Fungus
		Mycosphaerella poplorum	Fungus
		Microcyclus ulei	Fungus

12.3 Containment and Eradication Procedures

Successful eradication of invasive pathogens can be accomplished through rapid response and the use of the appropriate strategy, including an accurate delineation of the outbreak area and a well-structured and interdisciplinary coordinated set of activities for containment and eradication. Adoption of the appropriate strategies and their effective application are the key to outbreak termination. The temporal chain of procedures and activities in the containment and eradication process are discussed in this section.

12.3.1 Delineation of the Quarantine Zone

Once an outbreak is reported, responders conduct a spatial delineation of the area to establish the quarantine zone and areas to which the appropriate containment and eradication procedures will be applied (Fig. 12.1). The following definitions describe the zones involved in the process:

- **Outbreak area** – The area in which the pathogen was detected originally
- **Buffer zone** – An area surrounding or adjacent to the outbreak area, officially delimited for phytosanitary purposes in order to minimize the probability of spread of the target pest into or out of the delimited area, and subject to phytosanitary or other control measures, as appropriate
- **Quarantine area** – An area within which a quarantine pest is present and is being officially controlled
- **Protected objects** – areas such as nurseries, seed production fields, etc., which are remote and outside the quarantine but areof significant importance for potential spread of the pest

The zone delineation can follow man-made boundaries (e.g. roads, large buildings, walls), or natural boundaries (e.g. rivers, valleys) to support management within the relevant zone.

The initial focus in setting a quarantine zone is to block every possible pathway of pathogen escape from the contained area, and restrict any entry and exit of machinery, equipment, farm materials and products that may contain the pathogen. An outstanding example is the spread of *Synchytrium endobioticum*, the causal agent of potato wart, from infected fields to other fields by contaminated automobile wheels (Jennings et al. 1997). *Erwinia amylovora*, the causal agent of fire blight of pome fruits, is spread by the movement of infected fruits that are ready for market (Roberts et al. 1998). Furthermore, it is essential to clean and disinfect vehicles, machinery, commodities and any products that can potentially carry contaminants within the quarantine area. These measures are important to apply, especially with regard to accidental transfer of pathogens such as those causing potato wart and fire blight of pears and apples. These two examples demonstrate that care should be taken to address any possible pathogen exit pathway. Measures which are applied in the quarantine area to assure the success of quarantine process include:

12.3.2 Containment

Containment procedures in the outbreak area should cover the agricultural, rural and the urban sectors. Specific procedures include:

- **Sanitation** . The main goal of sanitation is to reduce and suppress the spread of the pathogen within and beyond the quarantine zone. It includes disinfection of large and small equipment, machinery and tools. On large scale farms this procedure applies to heavy machinery, which can transfer inoculum by moving soil particles, infected grains and more. Examples of pathogens that can be transmitted by tools include a wide spectrum of viruses, bacteria and fungi.
- **Physical barriers** . Barriers can be positioned to contain the inoculum within the outbreak area. Such practice is especially important with soilborne pathogens, which can spread by root to root contact. For example, trenching to disrupt grafted root systems is an effective control strategy for oak trees infected by the fungus *Ceratocystis fagacearum*, the causal agent of oak wilt (Wilson and Lester 2002).
- **Vector control**. Intensive insect control and monitoring is directed at eliminating any vector that transmits the pathogen, and preventing further infection within and outside the outbreak area. Vector elimination is important especially with certain insect transmitted viruses, phytoplasmas and spiroplasmas, and fastidious walled bacteria, but a few plant pathogenic fungi and other bacteria are insect-transmitted as well.
- **Intensive chemical treatment of the plants before or as a part of removal of infected plants**. This strategy is used to suppress the epidemic, prevent further infection and possible pathogen spread outside the outbreak area, and suppress generation of new inoculum. It also prevents the spread of inoculum during the process of removal and destruction of infected plants or plant parts. An appropriate pesticide should be applied to infected plants to reduce the pathogen and vector populations and to prevent inoculum spread during the consecutive activities of plant removal and destruction. For example, USDA-APHIS guidelines for the eradication of citrus greening disease, caused by *Candidatus* Liberibacter sp., indicate that the psyllid vectors *Trioza erytreae* and *Diaphorina citri* should be controlled prior to tree removal to minimize pathogen spread (USDA-APHIS 2016).
- **Destruction and removal of infected plants** . Infected plants or plant parts can harbor infectious inoculum internally, but the removal and destruction (by burning, composting, etc.) of the entire plant or plant part can eliminate the majority of the inoculum. Whether a whole plant, or only the infected part, is uprooted or destroyed depends on the type of infection (systemic or localized), the area and the size of infection, the crop type and many other considerations. Because of the time lag between infection and symptom development, the procedure should cover all the cultivated plants regarded as potential hosts in the outlined area, not just those that are visibly infected. Root diseases and soilborne pathogens can be controlled by destruction of host root systems by soil fumigation and herbicide

applications. These procedures can suppress both existing and new pathogen inoculum and are especially important with annual crops, as they also will minimize any viable inoculum left in soil after uprooting the infected plants.

- **Intensive foliar treatment program (perennial crops)**. When it is impractical or impossible to remove whole plants efforts are made to suppress the internal inoculum, arrest further development of the epidemic, and prevent further infection and spread. Such approaches may be successful when an infected area is small and spread is limited. However, this approach may be a weak link in the eradication chain; Hopkins and Purcell (2002) noted that the decision to not remove Pierce's disease affected grapevines may have led to the failure to control that disease despite intensive management of vineyards in California to control the vectors of *Xyllela fastidiosa*, the causal agent.
- **Volunteer cultivated hosts and wild weeds** . Elimination and eradication of other plant species that can serve as volunteer hosts may be very helpful in assuring containment success. For example, because *X. fastidiosa* has a wide host plant range in California vineyards (Wistrom and Purcell 2005), eradication of all the possible host species from the outbreak area will be crucial for containment.
- **Water reservoir management** . Treatment in and around water reservoirs to prevent pathogen contamination can be followed by suppressing possible movement of inoculum into and through water. Eradication of volunteer hosts and pathogen vectors around water areas is recommended. However, this procedure may not be feasible in cases where the pathogen has already invaded large water reservoirs or in areas where access for treatment is limited (forests and rangelands).

12.3.3 Eradication

Although eradication is the main pillar in the chain of steps toward ultimate pathogen elimination, it is interlinked with containment and can be successful only if containment procedures are also fulfilled. In fact, measures relevant to and part of the containment strategy serve also as initial steps for eradication. Eradication procedures are performed both within the affected area and in the outlying buffer zone. Additional measures of eradication are:

- **Removal of infected parts**. It is generally preferable to remove and destroy entire plants, often by burning (Schubert et al. 2001), although composting can be effective also (Termorshuizen et al. 2003). It is important to delineate an area larger than that containing visibly infected plants, and to remove all the plants within it, because symptomless plants may be infected but in a latent period during which the pathogen population is increasing. The appropriate dimensions of the eradication perimeter must be determined through epidemiological study and risk assessment (Gottwald et al. 2001). In practice, to suppress any inoculum remaining after the containment treatments and to prevent new infections, the area should be surveyed several times over the following days and weeks to identify new infections and remove additional plants.

- **Intensive foliar treatment program (perennial crops)**. Efforts are made to apply the relevant pesticides in perennial crops and susceptible plants that were not removed in order to suppress any existing internal inoculum, and prevent further infection.
- **Soil disinfestation** . Soil borne pathogens can survive in soil in many forms, including dormant and chemical-resistant resting structures. Eradication of such pathogens from the soil requires, therefore, a robust treatment such as soil disinfestation using highly toxic soil fumigants having non-selective activity. Effective disinfestation depends upon establishing proper application conditions (e.g. appropriate soil cultivation, moisture levels, etc.). So as to be effective at deep soil levels, disinfestation should be repeated to assure removal of pathogens that may survive the first application. Until 2005, methyl bromide was an effective and recommended soil disinfestation fumigant. However, due to its ozone depletion potential, this chemical is no longer available. Other fumigants (MBTOC 2007) are available; however, their performance is currently inferior to that of methyl bromide.
- **Destruction of new emerging plants from a treated area**. The use of soil fumigants or herbicides to kill new emerging plants or offshoots from destroyed perennial plants prevents reestablishment of inoculum left in soil after the containment treatment and soil disinfestation.

12.3.4 Management

Management follows successful execution of containment and eradication actions in the outbreak area. One objective is to assure the elimination of any new emerging inoculum and to prevent conditions suitable for the beginning of a new epidemic. Alternatively, management strategies may be employed when an eradication strategy failed or is regarded as not feasible. An effective management program should include all the above mentioned procedures for quarantine and containment practices. Additionally, measures performed during the eradication process (e.g. removal of infected plants, pesticide applications against the pathogens and/or their possible vectors, and destruction of weeds and wild hosts) should continue. Intensive pesticide applications are most important in tree crops, if trees were not removed during eradication. Additional specific practices relevant to the management stage include:

- **Cultural practices** . The cropping system may be modified to create conditions that hamper reemergence of the pathogen. For example, to suppress new infections of *Erwinia amylovora* (the causal agent of fire blight of pome fruit trees), recommendations include reducing fertilization to slow the growth rate of the trees, withholding irrigation water and nitrogen fertilizer, and cultivation (Brunner 1994). Similarly, practices that reduce tree wounding and bacterial movement can reduce the risk of infection. Other cultural procedures may include changes in planting dates and the establishment of windbreak rows of trees as mechanical barriers to pathogen movement.

- **Resistant cultivars**. Planting of crop varieties bred for resistance to specific pathogens, thereby eliminating susceptible hosts for a period beyond the survival of the pathogen, can reduce the likelihood or rate of new infection.
- **Pathogen-free propagation material** . The use of certified planting material, and disinfection of seed and other propagation material by means of chemicals, thermal treatment or combination of approaches, may be recommended.

12.4 Selection and Adoption of the Appropriate Strategy Against Invasive Pathogens

Although eradication is generally the preferred goal following the introduction of a new pathogen, it may not always be feasible. Eradication steps are often very expensive and there is no guarantee of success. Therefore, in addition to having knowledge of all the factors described above, it is helpful to understand the impact level of each specific tactic on each disease element (e.g. the initial inoculum, the infection rate or the vector, etc.), and the implications of the strategy on the possible outcome. Failure to adopt a quantitative approach can lead in many cases to establishment and spread of the pathogen over a wide area. In many cases eradication is sought to protect trade, particularly if a pathogen is new (exotic) to a country or region (Gamliel et al. 2008). After the invasion, a rapid assessment of the potential for pathogen spread and disease epidemiology should be made. If key elements of the disease are not known, eradication plans may be ineffective and the pathogen may become established and distributed in spite of efforts to prevent it. If eradication is not a reachable goal, its pursuit will only waste resources. Therefore the following factors should serve as guidelines when selecting the strategy to mitigate an invasive pathogen:

- The impact of the pathogen and its potential to disrupt the economy and the stability of the society should be assessed in order to gauge an appropriate level of response. Various aspects of plant disease impacts were discussed in previous sections.
- The extent of the affected area plays an important role in the decision. Eradication is more likely to be effective if the outbreak area is relatively small and/or located in a remote and isolated place. It contrast, eradication of a pathogen from an outbreak that spans several locations or covers a huge area, is much less likely to be successful.
- Specific characteristics of the causal pathogens (type of organism, vector, epidemiology, etc.) that influence pathogen spread and establishment, regardless of the initial size and location of the introduction, will impact the likelihood of successful eradication.

- An appropriate regulatory framework for delineating the quarantine zone and for supporting decisions related to crop destruction are crucial for rapid response. The lack of regulation will result in delay of containment and eradication procedures, hampering the success of these activities. Such considerations are particularly relevant in urban areas in which plant removal and destruction should be made in backyards and home gardens.
- Response measures should be available and able to be applied by appropriate responders. Relevant issues include the previous registration of the relevant pesticide, and the availability of the appropriate technology as well as personnel trained to apply them.
- The cost of the eradication process is also a factor to consider.

After considering these aspects, the selection of a strategy must meet the capabilities and resources of the responders. Since the weights of these factors vary among pathogens, and location types, it is useful to make a quantitative assessment of the probability of successful eradication in a given situation. Previously, we suggested the value of a "successful eradication probability" (SEP), calculated from various elements of the pathogen's characteristics and the specific disease situation (Gamliel and Fletcher 2008). SEP is a cumulative value based on a hierarchy of criteria specific to the relevant event. It can give a weighted assessment for the probability of eradication success, and indirectly suggest an appropriate strategy. Important to any of SEP assessment is knowledge of previous documented eradication efforts for the relevant pathogen in other locations and situations.

SEP is not a mathematical model, but rather a practical tool for simple and quick assessment of the probability of eradication success, and indirect suggestion of appropriate strategies. In a simple arithmetic calculation of all assessed factors, the weight of each variable in overall SEP scoring is identical (although in practice their influence on disease eruption and spread may differ).

A practical plant disease eradication "manual" should be available as part of each country's preparedness for crop biosecurity, in order to facilitate the identification and execution of an appropriate management approach (USDA-APHIS 2016). Such a document should include analyses of all factors relevant to the biology and epidemiology of pathogens of high priority in that country, as well as recommended response plans.

12.5 Conclusions

Although eradication of an invasive pathogen involves many uncertainties, it is usually the strategy of top priority. Therefore, to successfully eliminate an introduced pathogen a concerted series of simultaneous as well as sequential procedures should be planned and executed. Clearly, developing a successful strategy against invasive pathogens requires knowledge of the factors described above, as well as estimates of the level of the impact of each specific tactic on each factor (e.g. on the initial inoculum or, the infection rate, the vector, etc.), and understanding of the implications of strategy choice on possible results. If eradication fails, the pathogen is likely to become established and to spread further, and the input made in the eradication program will have been wasted. Hence, preparedness and cooperation within the agricultural community are critical for successful eradication. A robust preparedness plan depends upon having an organized and effective agricultural management infrastructure, and reliable and sensitive detection and diagnosis tools. Effective eradication requires the availability of the appropriate measures and a cadre of well-trained plant health specialists to implement them. Finally, because a high percentage of invasive pathogen incursions occur across national boundaries, international cooperation and collaborations are also crucial to the establishment of optimal practices.

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