Biosecurity

A Systems Perspective

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Chapter 7

Prepare, Respond, and Recover

Selecting Immediate and Long-Term Strategies to Manage Invasions

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7 Prepare, Respond, and Recover

Selecting Immediate and Long-Term Strategies to Manage Invasions

Susan M. Hester and Lucie M. Bland

ABSTRACT

When an invasion of a pest or disease is first discovered, the immediate response is typically to determine the extent of the incursion as quickly as possible and to control detected outbreaks. Ideally, this initial response preserves all longer-term management options, whether they be eradication, containment, impact reduction, or mitigation. Although eradication may be an appealing strategy for decision makers (as there is an expected end-date to expenditure and threat impacts), eradication is not always the most appropriate or cost-efficient strategy. The socio-political, technical, and economic feasibility of different management strategies must be carefully assessed prior to making any long-term decisions. Understanding how to efficiently allocate limited funding to manage outbreaks of biosecurity threats is a huge challenge for biosecurity agencies. In this chapter, we discuss the feasibility of longer-term management strategies and provide a decision-making framework to show how a biosecurity agency might select a cost-efficient strategy to respond to a pest incursion.

GLOSSARY

Eradication The elimination of every single individual or propagule (e.g. seed) of a species from an area in which recolonisation from new invasions is unlikely (Myers, Savoie, and van Randen 1998).

Containment Aims to restrict the spread of a threat by containing it to a defined area. Containment can be full (i.e. all spread beyond the containment area is prevented) or partial (i.e. spread beyond the containment area is slowed).

Impact reduction (also known as maintenance control) Aims to suppress the population level of a threat to below an acceptable threshold. The acceptable threshold relates to the level of impact on the ecosystem or area invaded, which can be expressed in terms of a threat's distribution or density, or a combination of both (Wittenberg and Cock 2001). Impact reduction is typically selected when eradication and containment are no longer feasible.

Mitigation (also known as asset protection) Involves finding the best way to live with the introduced species by managing impacted assets (e.g. native species or ecosystems), rather than managing the introduced species directly. Within an agricultural context, mitigation is often referred to as adaptation.

Detectability The conspicuousness of the invasive species within the invaded landscape (Panetta 2009), which influences the feasibility of management (Cacho et al. 2006).

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Delimitation The process of establishing the boundaries and extent of an incursion. Delimitation maps (i.e. probabilistic maps of detection or absence derived from surveillance data) can be created to assist with this process.

Control methods The management methods used to reduce the abundance and/or distribution of a pest, disease, or weed. Control methods may be manual (e.g. use of hands or hand-held tools), mechanical (e.g. machinery or powered tools), chemical (e.g. herbicides, pesticides, or fungicides), or biological (i.e. ongoing control by another species; Panetta et al. 2011).

Search and control The key activities involved in managing invasive species and integral to the calculation of feasibility of eradication and containment (Cacho et al. 2006). Search and control are often undertaken together (i.e. the threat is controlled as it is found).

Surveillance Searching activities that are undertaken to detect threats. Active, general, and passive surveillance are types of surveillance that differ in terms of the level of coordinated and deliberate searching involved (see Chapter 6. Detect).

Feasibility The degree of ease anticipated in attempts to manage an invasive species. The feasibility of management strategies is influenced by socio-political, technical, and economic factors (Wilson, Panetta, and Lindgren 2016).

INTRODUCTION

Although preventing the entry of pests and diseases is the most cost-effective and environmentally sustainable option for dealing with invasive species (Finnoff et al. 2007; Leung et al. 2002), some pests and diseases will still slip through prevention and screening mechanisms and establish. This occurs even in biosecurity systems that are considered highly effective and comprehensive (Scott et al. 2017).

When a biosecurity threat (i.e. exotic pest or disease) is detected, a rapid and well-coordinated emergency eradication response can reduce adverse impacts and limit the need for post-incident recovery and adaptation. If the emergency response fails to eradicate the biosecurity threat, managers are faced with four long-term management alternatives: (1) continue to pursue eradication, or switch strategies to (2) containment, (3) impact reduction, or (4) mitigation. Containment aims to prevent or reduce the likelihood of establishment and reproduction beyond a predefined geographical range (Wittenberg and Cock 2001), whereas impact reduction attempts to reduce a threat's impacts without necessarily restricting its range (e.g. by suppressing population levels; Grice 2009). Impact reduction methods (e.g. biological control) are usually the only economically feasible, long-term management option for widespread pests and diseases (Cacho and Hester 2022). A fourth course of action, mitigation, does nothing to stop the further spread and establishment of the threat, but rather focuses on mitigating the impacts of the threat on affected assets (e.g. native species; Blackburn et al. 2011; Wittenberg and Cock 2001).

Unfortunately, there are many examples of failed management responses, particularly failed eradication programmes (Pluess et al. 2012; Wittenberg and Cock 2001). Many response programmes start as eradication programmes and change by default to containment, impact reduction, or mitigation when the threat proves too difficult to control (Fletcher et al. 2015; Grice 2009). For example, efforts to manage the spread of the emerald ash borer (EAB) in North America changed from eradication to containment due to the extent of its spread, and then to the control of satellite populations when the pest was detected beyond the containment zone (Liebhold and Kean 2019), and finally to impact reduction via biological control (APHIS 2020; Duan et al. 2022). The continued spread of EAB has cost municipalities, property owners, nursery operators, and forest products industries hundreds of millions of dollars per year (Aukema et al. 2011); the predicted impact of the pest in the eastern United States over a 10-year period (2009–2019) was in the order of billions of dollars (Kovacs et al. 2010).

When faced with an incursion, biosecurity agencies must carefully decide which management strategy is most suitable, as embarking on programmes that are unlikely to be successful will waste the agencies' resources and taxpayer money. This chapter discusses available strategies for managing incursions of pests, diseases, and weeds when funding is drawn from the public purse. First, we describe responses that occur immediately following the detection of an incursion, also known as "emergency" responses. If eradication is not achieved at this stage, decision makers are faced with selecting a long-term management option (namely eradication, containment, impact reduction, or mitigation) based on its feasibility. The feasibility of a management strategy is determined by the interplay of multiple socio-political, technical, and economic factors (Bomford and O'Brien 1995; Hulme 2020; Moon, Blackman, and Brewer 2015). Finally, we discuss practical considerations for selecting and implementing post-border management strategies.

EMERGENCY RESPONSE STRATEGIES

The first detection(s) of a pest, disease, or weed may occur as part of a surveillance programme or via passive or general surveillance (see Chapter 6. Detect). Once a detection is made, biosecurity agencies are tasked with limiting the spread of the threat and preserving eradication as a viable option, while more information is gathered to inform the long-term management of the threat. Generally, eradication or containment are appropriate initial responses to an incursion, put in place until the extent of the incursion and the costs and benefits of long-term management are better understood (Hester, Hauser, and Kean 2017). Biosecurity incident management teams often follow a sequence of activities prescribed in pre-agreed response plans, which can include:

- Incident definition and initial investigation.
- Emergency response activities.
- Providing proof of freedom (where eradication is feasible), particularly where market access is important.
- Options for transitioning to long-term management (where eradication is not feasible).

The emergency response phase often relies on well-developed plans of activities that are enacted immediately when a particular pest or disease is detected (e.g. APHIS 2019; MPI 2018). Eradication of notable pests and diseases is an automatic, pre-determined decision in many countries where loss of market access or unacceptable environmental impacts would occur if the pest or disease were to establish—for example, for foot-and-mouth disease in Australia (Animal Health Australia 2014) and New Zealand (MPI 2022), khapra beetle in the United States (APHIS 2022), and avian influenza in Canada (Government of Canada 2022). When pre-agreed emergency response plans are not available, agencies still need to act quickly in response to the detection of unwanted organisms if they are to preserve all long-term management options, particularly eradication.

The effort (and hence investment) involved in an emergency response comprises the surveillance effort required to delimit an invasion (i.e. determine the extent of its spread) plus the search-and-control effort required to remove the threat from the entire infested area and prevent further reproduction (Figure 7.1). A short-term research budget is also necessary to fund initial investigations and to create a map to direct search-and-control efforts (see Chapter 14. Map).

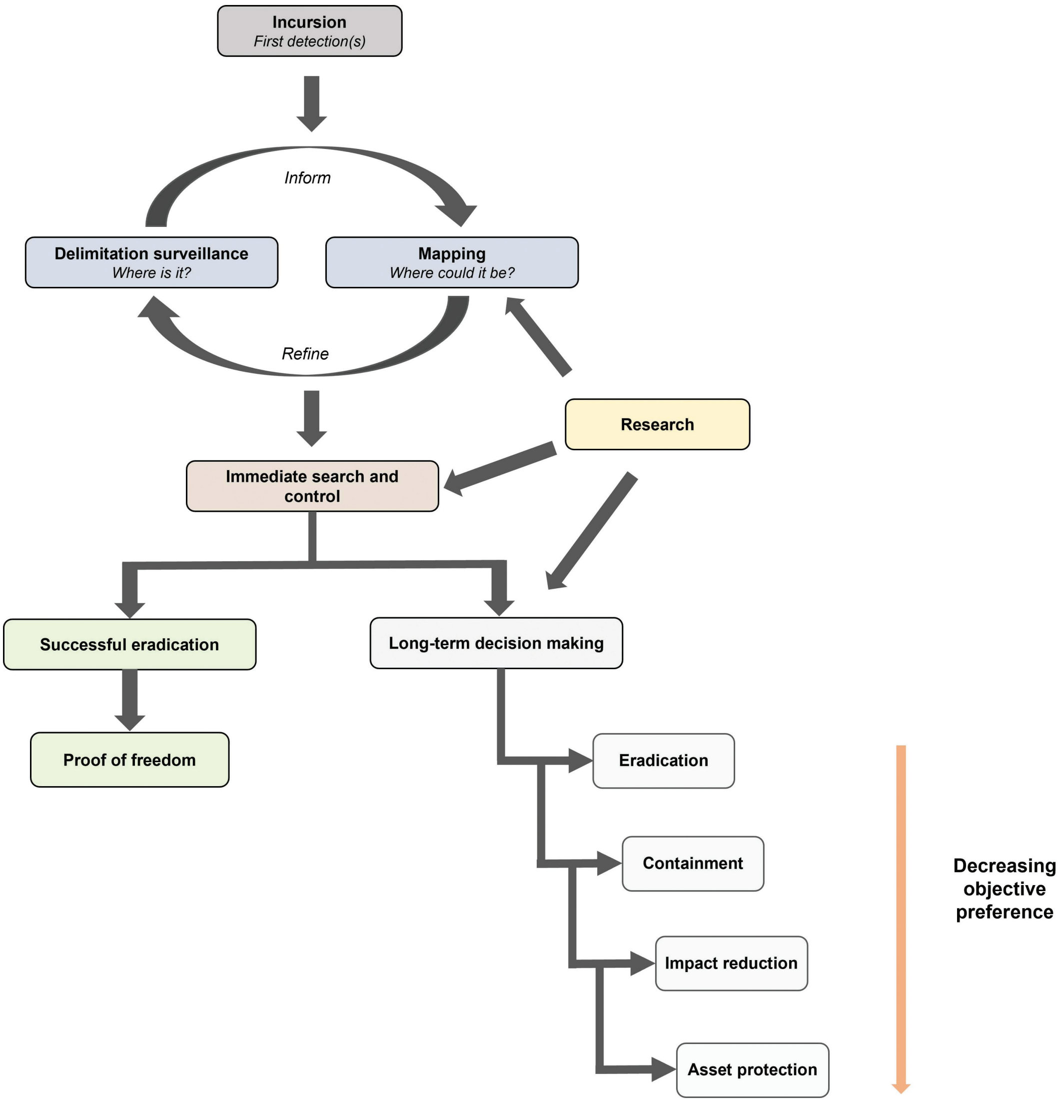

FIGURE 7.1 Short and long-term decision-making processes in response to the detection of a new biosecurity threat.

Delimitation Surveillance and Threat Mapping

As a matter of priority, agencies need to understand the current extent of an incursion. Delimitation should occur as quickly as possible to limit further spread and to limit the effort and cost required to manage the incursion (Panetta and Lawes 2005). Initial delimitation is difficult because (1) the pest or disease may only have been observed in a few locations, (2) the pathway of entry may be unknown, (3) the first detection(s) may not be where the species first arrived or in the epicentre of the outbreak, and (4) the potential dispersal of the species in the new environment may be unknown (Leung, Cacho, and Spring 2010).

Trace-back and trace-forward techniques, combined with pathways analysis, can be used to gather information on threat introduction and spread (see Chapter 6. Detect). Trace-back activities are used to locate the likely site of introduction, and if this is successful, trace-forward activities are used to locate areas, infrastructure, or organisms that may be infested and need to be surveyed

(Hester et al. 2015). Tracing can more easily be implemented for some threats (e.g. livestock diseases), but it is much more difficult for other threats (e.g. hitchhikers, plant pests). National databases of animal location and movement are useful for tracing. For example, Australia's National Livestock Information System (NLIS) and New Zealand's National Animal Identification and Tracing (NAIT) programme collect data that can be used to delimit incursions (Integrity Systems Company 2022; MPI 2018).

When pest and disease incursions are likely to impact market access, survey designs for delimitation are often guided by international regulations (see Chapter 6. Detect). When delimiting incursions for which there is little or no trade imperative, there are no clear rules about where to search, how much search effort should be applied, or the point at which searching should stop. Rather, these decisions can be conceptualised as a trade-off between the possibility of the invasive species escaping the delimited area versus wasted effort if the search area, time, or intensity are too high (Leung et al. 2010). The speed at which delimitation occurs is also important because as the species continues to spread and increase its population size, the likelihoods of escape and reproduction outside the search area increase, in turn increasing management costs. Delayed delimitation was thought to be responsible for a significant increase in the cost of managing red imported fire ant in Australia (Spring and Kompas 2015), a campaign that has been underway for more than 20 years.

The emergency management response phase will be guided by a delimitation map, which informs the likelihood of a species being present, or a habitat suitability map of abiotic and/or biotic conditions suitable for establishment. More sophisticated maps approximate the establishment potential of the species by accounting for the likely propagule pressure caused by different pathways of entry and spread (see Chapter 14. Map). At this early stage, maps are used to inform where to undertake preliminary delimitation surveys. The surveys undertaken are then used in combination with statistical models to infer likelihoods of absence, which in turn, allow delimitation and refining of the spatial extent of the incursion (see Chapter 6. Detect). If time permits, surveillance data can be complemented with additional research on the biology, ecology, and management feasibility of the threat (Cacho et al. 2018; Epanchin-Niell et al. 2014; Hester et al. 2010; Jentsch et al. 2020).

Search and Control

Search and control activities carried out in the emergency response phase are integral to the development of delimitation maps and to determine whether eradication in this phase is possible (Hauser et al. 2016). For example, emergency biosecurity measures were implemented on French poultry farms in response to outbreaks of highly pathogenic avian influenza between 2015 and 2017 (Delpont et al. 2021) and in the United Kingdom foot-and-mouth disease outbreaks of 2001 (NAO 2002) and 2007 (DEFRA 2008). The 2007 outbreak of equine influenza in Australia was eradicated in the emergency response phase using a range of outbreak control measures, including movement restrictions, vaccination, quarantining of properties, and issuing of biosecurity guidelines (Schemann et al. 2012). Emergency measures with a view to eradication were put in place following the detection of the red imported fire ant (a pest with significant environmental, social, and domestic economic impacts) in Queensland, Australia, in 2001. Eradication did not occur in the emergency response phase, however, due to the rapid spread of the pest and difficulties delimiting the incursion, but several outbreaks were subsequently eradicated.

If pre-agreed emergency response plans are in place in a jurisdiction, then search-and-control methods will be clearly defined. In general, eradication attempts during the initial response phase are more likely to be successful for pests and diseases that have pre-agreed emergency response plans compared to those who have not, as there is an imperative for a jurisdiction to regain trade access as quickly as possible for high-priority threats. To regain market access, surveillance evidence is used in combination with statistical models to infer the likelihood of species absence (also known as proof of freedom; see Chapter 6. Detect). If this likelihood is above a predefined level of confidence, the threat is deemed eradicated and management activities end here.

For weeds, eradication requires the elimination of every viable seed, which may mean that longer-term management is required for most weed emergency responses. The minimum duration for an eradication programme for weeds will be determined by seed persistence, which may range from several weeks to several decades (Panetta 2015). This contrasts with animal diseases, where eradication can occur quickly when control involves culling animals (Animal Health Australia 2021).

LONG-TERM RESPONSE STRATEGIES

If the emergency response phase determines that immediate eradication of a threat is not feasible or if immediate search and control is not successful, management will transition to a long-term response. At this stage, biosecurity agencies need to decide which long-term management strategy (namely, eradication, containment, mitigation, or asset protection) is most suitable (Figure 7.1). A key challenge for biosecurity agencies is understanding which management strategy (and combination of activities within a chosen strategy) will achieve the best long-term outcomes for society.

Assessing and comparing the benefits and costs of different actions requires a clear definition of the proposed actions, based on information collected during delimitation and search and control. Such data may include:

- Whether the species is known to be invasive elsewhere, and its establishment potential in the local environment (see Chapter 14. Map).
- The likely consequences of establishment.
- Control methods and their costs.
- The likelihood that the species will invade again in future.
- Information on political will and community sentiment with regards to management.

Managers must also anticipate how a given strategy might unfold if selected. This requires determining the activities that will form part of the strategy, the scale at which these activities will be applied (e.g. intensity, area of control, and duration), and predicting the effects of control over time (e.g. through population or distribution modelling). Many of these factors are uncertain at the time of decision making.

Feasibility of Response Strategies

Feasibility should guide the choice of long-term strategy (Panetta 2009). Feasibility is determined by the interplay of multiple factors, which can be broadly classified as socio-political, technical, or economic:

- *Socio-political feasibility*: Relevant socio-political considerations include the land tenures over which control will be required, whether the species is regarded by the public as native or non-native (e.g. dingoes in Australia; Ballard and Wilson 2019), societal values around the species being managed (e.g. feral horses in Australia; Nimmo and Miller 2007) and control methods (e.g., live trapping and euthanasia of grey squirrels in Italy; Bertolino and Genovesi 2003), and crucially, whether long-term financial and institutional commitment to a strategy is possible (Panetta and Timmins 2004). Although socio-political support is crucial to implementing an effective management strategy, social values are often overlooked in decision making or assumed to be in favour of proposed government responses. This in turn can lead to failed management programmes or de facto implementation of mitigation (“living with the threat”) when proposed strategies are rejected by communities

(Baker et al. 2022). Value elicitation methods can help develop an understanding of social values to integrate into management (see Chapter 12. Elicit).

- *Technical feasibility*: Once socio-political considerations are deemed suitable for management, selecting a strategy becomes a question of technical feasibility. Technical feasibility refers to multiple factors that together determine management success, such as the biology of the invasive species, its detectability, control effectiveness, and logistical considerations around the number, spatial distribution, and accessibility of incursions (Panetta and Timmins 2004). Treatment methods under different strategies may include mechanical, chemical, and biological control, separately or in combination. Surveillance will inform where treatment should occur and may involve trained experts in surveillance, members of the public, dogs, satellites, drones, or other aircraft. At this stage, it may be possible to rule out some strategies as they are unlikely to be technically feasible given available technology, resources, and/or the extent of the incursion.
- *Economic feasibility*: While a proposed strategy may be technically feasible, it may be economically inefficient compared to other strategies. Understanding economic feasibility requires calculating the costs of a management strategy over time and the benefits generated for society (Cacho et al. 2006). Understanding technical feasibility (i.e. the technical factors that influence implementation) is a prerequisite for assessing economic feasibility. Ideally, the decision maker would select the strategy that maximises "value for money" when generating benefits for society (i.e. the most economically efficient strategy; see Chapter 9. Resource Allocation).

Below, we discuss how each of these factors influences the feasibility of eradication, containment, impact reduction, and mitigation.

Eradication

Eradication involves the complete removal of the target pest or disease from an infested area. Eradication can be appealing compared to containment or control, which require an ongoing investment of resources unless the threat can be brought under effective biological control (i.e. ongoing control by another species; Panetta et al. 2011).

Successful eradications have been conducted for most taxonomic groups (Hester et al. 2004; Mack et al. 2000; Rejmánek and Pitcairn 2002). Eradication is more likely to be successful for land vertebrates on islands regardless of size, compared to non-island eradications, with 85% of 1,200 mammal eradications on islands having been successful worldwide (Holmes et al. 2019). Compared with animal eradications, weed eradication programmes are less often successful. When persistent seedbanks occur, eradication requires the elimination of every viable seed, which may take years or even decades beyond the elimination of adult plants (Panetta 2015; Wilson et al. 2016). Further reproduction must be prevented, otherwise the seedbank will be replenished, and the duration of the eradication programme will be extended, or eradication may no longer be the most appropriate course of action. Weed eradication programmes also face challenges in terms of detection. Although invasive animals are typically attracted by lures and baits and in some cases are amenable to control via aircraft, invasive plants must be detected in situ, with regular search and control for as long as it takes to deplete the seedbank (Panetta 2009). For example, seeds of miconia (*Miconia calvescens*), often dispersed over long distances by birds, can persist for 15 years (Hester et al. 2010), while seeds from Scotch broom may persist for 20–25 years in introduced habitats (Hosking, Smith, and Sheppard 1996).

The feasibility of eradication will generally be determined by:

- *Infestation area*: Eradication is generally only possible during the earliest part of the expansion of a threat because species abundance and density are usually relatively low in this stage of invasion (Cacho 2004; Mack and Foster 2009; McNeely et al. 2001) or for isolated populations (Grice 2009). The level of effort required throughout an eradication programme (to search, control, monitor, and apply follow-up control) means that the economic feasibility of eradication declines rapidly with increasing area. A review of 136 eradication programmes across 75 species of invasive alien invertebrates, plants, and plant pathogens (Pluess et al. 2012) analysed the impact of: reaction time; size of the infested area; biological knowledge and preparedness to react; and insularity (whether the campaign was on an island or continent). The study revealed that only the spatial extent of the infestation was significantly related to the eradication outcome: a smaller infestation area was more likely to lead to successful eradication (Pluess et al. 2012). In most cases, well-established populations and large infestation areas are unsuitable for eradication (Harris and Timmins 2009; Rejmánek and Pitcairn 2002; Wittenberg and Cock 2001).

- *Invasive species characteristics*: Pests and diseases with traits that facilitate rapid expansion, or species that are cryptic or harder to detect, may be more difficult to eradicate (Grice 2009). For example, the EAB colonises the upper portions of the canopy of large trees before the main trunk, making early infestations difficult to detect (Herms and McCullough 2014).
- *Environmental characteristics*: Inaccessible landscapes can reduce threat detectability and increase the cost of control actions (or prohibit the use of some controls altogether). For example, orange hawkweed can be difficult for human searchers to distinguish visually from the surrounding vegetation in forested and sensitive alpine areas, particularly when not in flower. Detector dogs and drones can be used to assist with detection, with drones being particularly useful over large areas (Cacho et al. 2018; NSW Department of Planning and Environment 2020).
- *Land management*: Eradication tends to be easier in landscapes that are intensively managed (e.g. agricultural areas where the imperative to eradicate is high). Heavily populated landscapes may pose social challenges to eradication, for example when the aerial application of biological control agents or chemicals is unpopular with urban residents (Brockerhoff et al. 2010).

Containment

When eradication fails or is not feasible, containing or delaying the spread of a pest or disease may still prevent substantial ecological damage (Mack and Foster 2009; Simberloff 2003). A containment strategy aims to prevent or slow the establishment and reproduction of a threat beyond a predefined geographical range (Grice et al. 2020; Wittenberg and Cock 2001). In contrast to eradication, containment requires control activities to be applied indefinitely. A containment strategy involves putting most surveillance and control efforts at the invasion front, or "barrier zone", to halt expansion (Grice 2009). One notable containment programme has been the management of the flighted spongy moth complex (*Lymantria* spp.) in the United States, where traps were placed close to the expanding population front to slow the expansion of the pest (Sharov and Liebhold 1998).

The feasibility of containment should be assessed once eradication has been rejected as a goal (i.e. when eradication is deemed infeasible), rather than as the default result of an unsuccessful eradication (Grice 2009). Deciding whether to embark on a containment strategy should be based on clearly defined goals, such as preventing the invasive from spreading beyond a nominated perimeter. Different management activities that can take place within barrier zones should be considered and evaluated in terms of their costs and benefits. Many jurisdictions also establish domestic biosecurity or quarantine zones to restrict the movement of high-risk material between zones. In Australia, phylloxera management zones have been established to limit pest movement within the state of Victoria (DJPR 2022).

Factors that affect the feasibility of eradication also affect the feasibility of containment (specifically, infestation area, species characteristics, environmental conditions, and local land tenure). Although containment can be applied at any management scale (e.g. country, region, or landscape), the effort required to contain the edge of an invasion front increases with invasion size. This is particularly true for threats that are capable of long-distance dispersal (Fletcher et al. 2015; Panetta and Cacho 2014), making containment more likely to be feasible during the early stages of invasion when the boundary of the incursion is relatively small (Grice 2009). Permanent physical barriers may be erected as part of containment programmes, with exclusion fences for rabbits in Australia extending many thousands of kilometres (Crawford 1969). However, most containment programmes relying on physical barriers have not been successful (Grice 2009; McKnight 1969).

Impact Reduction

Impact reduction aims for a long-term reduction in density or abundance to below a threshold where impacts caused to the environment, community, or economy are considered acceptable (Wittenberg and Cock 2001). Impact reduction typically occurs when the use of traditional control techniques over large areas has become economically inefficient, and thus eradication and containment are no longer considered feasible. In contrast to containment, impact reduction attempts to reduce the impact of an invasive species without necessarily restricting its range, and it is most often applied in areas where the impact of the threat is the greatest (Grice 2009). Like containment, impact reduction requires activity indefinitely. In Australia, national strategies and frameworks guide biosecurity participants in their efforts to continually manage invasive plants, animals, and pests and diseases of national significance (e.g. IPAC 2016a, 2016b). Participants that fail to control noxious weeds on their property can be directed to do so by state and territory legislation.

Establishing biological control agents to permanently control the pest is usually the only economically feasible, long-term impact reduction option. There are many successful examples of biological control programmes, including the control of the prickly pear cactus in Australia by the *Cactoblastis* moth from Argentina (Dodd 1940), control of European rabbits in Australia using various pathogens (Cooke et al. 2013), control of the South American alligator weed in Florida by a flea beetle, and control of the South American cassava mealybug in Africa by a South American parasitic wasp (Mack et al. 2000).

Whether a biological control programme is worthwhile pursuing depends on the potential benefits generated from a reduction in pest abundance and the costs of research, testing, breeding, release, and monitoring of the biocontrol agent (Hester et al. forthcoming). The efficacy of the proposed agent in supressing the pest (i.e. technical feasibility) is fundamental, and information about agent efficacy, costs, and benefits should be understood prior to spending significant time in screening and testing (Hajek et al. 2016). For example, Cacho, Hester, and Tait (2023) and Cacho and Hester (2022, 2023) developed a bioeconomic model to understand whether the European wasp (*Vespula germanica*) could be a candidate for a management programme in south-eastern Australia given the availability of a biocontrol agent (*Sphecophaga vesparum vesparum*), following successful screening and testing of an agent several decades earlier. The authors found that although the economics of controlling European wasp using biological control appear promising due to the benefits of control, proceeding with the chosen agent was not recommended based on current knowledge about its performance.

Mitigation

When eradication, containment, or impact reduction have failed or are not feasible, a final course of action is to do nothing to directly influence the abundance of the threat, but rather to focus on mitigating impacts on affected biodiversity and ecosystem assets (Blackburn et al. 2011; Wittenberg and Cock 2001). For example, when extensive rat control measures failed to alleviate extinction pressures on the Critically Endangered Seychelles black parrot (*Coracopsis nigra*), a trial program of building and installing rat-proof nesting boxes on the Seychelles islands was successful in improving breeding outcomes (Wittenberg and Cock 2001). Mitigation also involves threat monitoring so that managers can detect and respond to changes in the abundance and/or range of the threat. Managers must also account for new technologies that may render new or previously discarded management strategies feasible, including the development of new vaccines, camera sensors, or the introduction of biological control agents (Wittenberg and Cock 2001).

PRACTICAL CONSIDERATIONS FOR POST-BORDER RESPONSES

A huge challenge for biosecurity agencies is deciding how to efficiently allocate limited resources to activities that will generate the best outcomes for the economy, society, and/or the environment (Bomford and O'Brien 1995; Epanchin-Niell 2017; Fletcher et al. 2015; Hulme 2020; McNeely et al. 2001; Panetta and Timmins 2004). Responding quickly and cost-efficiently to incursions requires planning to assess the feasibility of response strategies and to select the best strategy from a well-defined set of options (Box 7.1).

A cost-efficient approach to selecting long-term biosecurity response strategies starts with clearly defining the response strategies (and different activity combinations within each strategy, where relevant) under consideration (Box 7.1). Based on information collected during initial delimitation and search-and-control activities, managers must outline the specific activities that will form part of each strategy, including: the scale and timing of these activities; associated monetary, human, or other costs; and expected benefits in controlling the threat.

Within the long-term decision-making process, eradication should be assessed first as the preferred option (Box 7.1). The details of one or more eradication scenarios should be assessed, including details of the area to be managed, timeframes to achieve management goals, and the conditions under which the management decision will be revisited (Wilson et al. 2016). Although eradication may be politically appealing because resources are applied for a finite amount of time, it should only be attempted and persisted with if it remains feasible (e.g. during the emergency response or as a carefully selected and monitored strategy; Mack et al. 2000). Psychological frailties such as the "sunk cost fallacy" (i.e. where a decision maker is reluctant to abandon a strategy because they

BOX 7.1. A COST-EFFICIENT APPROACH TO SELECTING LONG-TERM BIOSECURITY RESPONSE STRATEGIES

Here, we describe how a biosecurity manager can select a cost-efficient biosecurity response strategy for a hypothetical pest based on socio-political, technical, and economic feasibility (Figure 7.2). For the hypothetical pest, a suite of long-term response strategies may encompass:

- Full eradication of the incursion (strategy A).
- Containment involving only measures at the barrier zone (strategy B).
- Containment involving measures at the barrier zone and the establishment of a quarantine zone (strategy C).
- Impact reduction using a biological control agent (strategy D).
- Impact reduction using manual control (strategy E).
- Mitigation focusing on affected native species (strategy F).

Within a cost-efficient approach, socio-political feasibility is assessed first. In this hypothetical example, asset protection is deemed politically unpalatable as an initial strategy given the potentially large adverse impacts of the pest. As a second step, technical feasibility is assessed using detailed information on activities to be implemented. At this stage, eradication is deemed technically infeasible given the low detectability of the pest using current approaches. Using an economic analysis, the remaining potential strategies (strategies B, C, D, and E) are compared to each other using information on their relative costs and benefits (i.e. their return on investment; see Chapter 9. Resource Allocation). In our example, strategy C (containment with a barrier zone and quarantine zone) is found to provide the highest value for money and is selected as the initial long-term strategy to manage the threat.

This decision is revisited at regular intervals by managers based on new information concerning the spread of the threat, its impacts, and the feasibility of different management strategies (Figure 7.2).

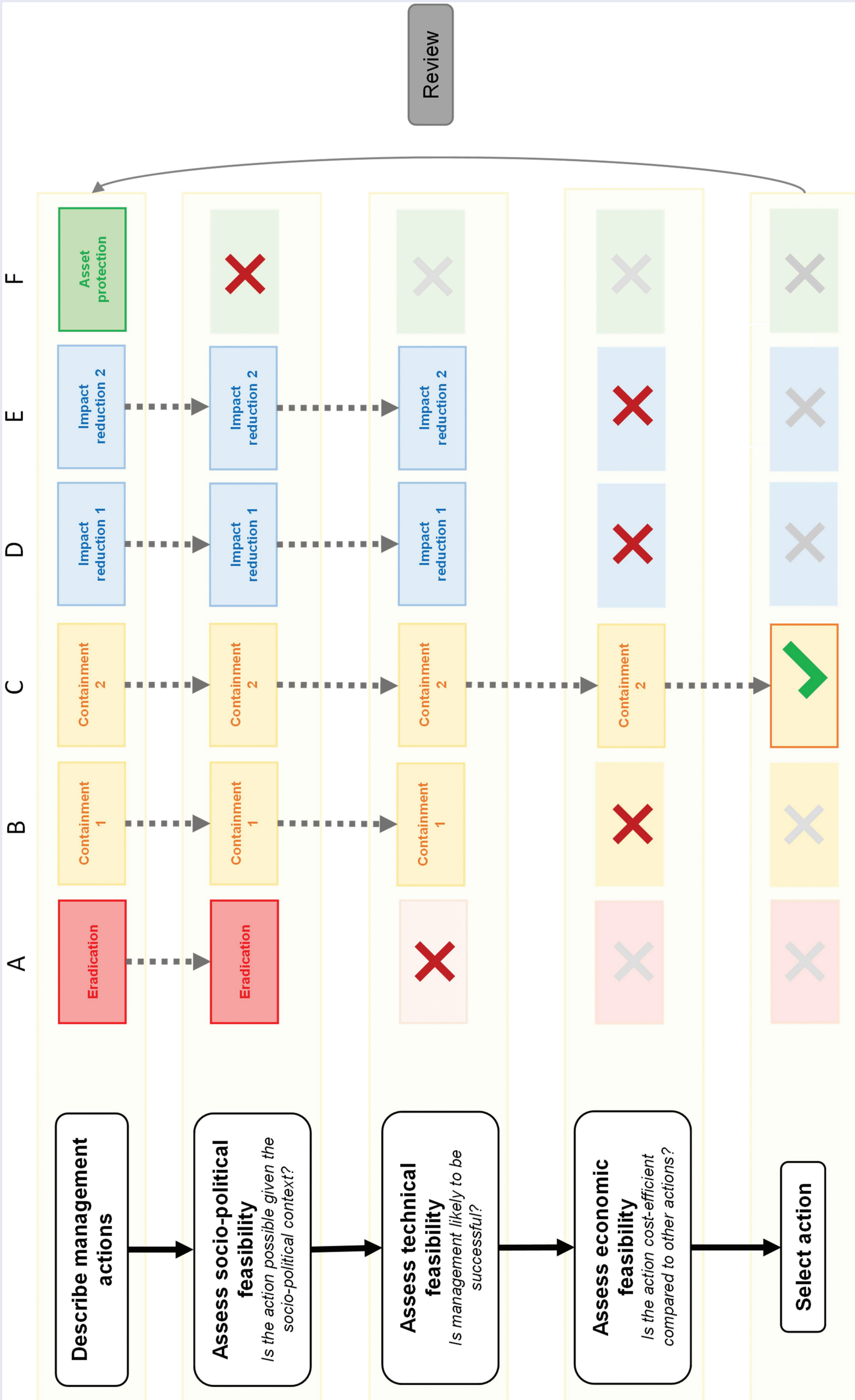

FIGURE 7.2 Decision-making framework to select a long-term cost-efficient strategy to respond to a threat incursion.

have invested heavily in it; Arkes and Blumer 1985) may result in delaying the decision to give up on eradication even when it is clear that abandonment is the preferred option. Understanding if and when to cease eradication (or any other strategy) relies on objectively monitoring and evaluating the outcomes of management over time (see Chapter 10. Monitoring, Evaluation, and Reporting).

There are many examples of eradication programmes that have failed because feasibility was not assessed appropriately, for example when the initial extent of the incursion was not well understood, management costs were underestimated, and when views about the likely success of the programme were overly optimistic (Wilson et al. 2016). Understanding public sentiment is not always straightforward, and many proposed eradication programmes have been strongly opposed by members of the community (e.g. feral horses in Australia and grey squirrels in Italy; Wittenberg and Cock 2001). Apart from wasting resources, failed or mis-communicated eradication programmes can erode public trust in biosecurity agencies, which does not bode well for future incursion responses that are likely to require assistance and collaboration from the community (Wittenberg and Cock 2001).

As such, the selection of strategies should not be a case of "set and forget", and switching strategies may be required due to events that render the existing strategy infeasible or because new technology now renders new or previously discarded strategies possible (Liebhold and Kean 2019). Eradication or containment may be an appropriate initial response to an incursion, put in place until the extent of the incursion, and costs and benefits of management are understood, allowing a longer-term management decision to be made (Hester et al. 2017). Although eradication, containment, and impact reduction are typically discussed as if they are mutually exclusive, this is not necessarily the case (Hulme 2006). For example, containment could occur at the edges of an incursion at the "barrier zone", while eradication of small, isolated populations could occur within the barrier zone. It may also be possible to shift the barrier zone backwards to eventually eradicate the entire population (Sharov and Liebhold 1998). To assist with these complex decisions, multiple decision-support tools have been developed to help practitioners select and switch response strategies based on the characteristics of incursions and proposed management actions (Box 7.2).

BOX 7.2. DECISION-SUPPORT TOOLS TO SELECT BIOSECURITY RESPONSE STRATEGIES

In recent years, various decision-support tools have emerged to assist biosecurity agencies in determining when to use and when to switch strategies based on economic feasibility. For example, the Switching Point Tool helps determine when the eradication of a weed is no longer the optimal course of action and when containment or impact reduction should be attempted (Cacho 2010; Cacho and Hester 2013). The tool is based on identifying two switching points: the invasion size at which it is no longer optimal to attempt eradication but where containment may be an option; and the invasion size at which it becomes optimal to apply just enough control to maintain the invasion at a steady state (containment point) within which impact reduction is feasible. The model calculates the maximum area that should be targeted for eradication based on minimising the combined costs of controlling the invasion plus the damages caused by the invasion.

To understand weed eradication feasibility, the WeedSearch spreadsheet tool was developed by combining population dynamics and search theory (Cacho and Pheloung 2007). WeedSearch allows users to calculate the probability that a weed invasion will be eradicated based on the amount of time spent searching for it (search effort; Cacho and Pheloung 2007). Spatial models of detection and treatment have been developed for specific weeds, such as for the orange hawkweed in Victoria, Australia, to help determine effort allocation across a landscape by comparing the costs and benefits of earlier detection (Hauser 2009). The Eradograph tool can also be used to assess progress towards eradication of weeds (Burgman et al. 2013; Panetta and Lawes 2007).

In practice, it may be difficult for biosecurity agencies to obtain the data required to compute and select the most economically efficient set of activities across threats. Yet, adopting principles of economic efficiency is essential if biosecurity agencies are to achieve maximum value for money from the use of limited taxpayer funds. This means understanding the value of risk-reduction across a range of potential management targets and using available funds where value is highest (see Chapter 9. Resource Allocation). In addition, the question of "how much funding is required to efficiently address a nation's biosecurity risks" has not been studied, preventing biosecurity agencies from requesting budgets that can adequately meet risk-reduction requirements.

Addressing biosecurity threats is one of many calls on society's resources, and the division of resources among sectors (e.g. cybersecurity, public health, counterterrorism, and disaster risk management; World Economic Forum 2022) has largely been a political decision, rather than an evidence-based decision underpinned by value for money. Responding quickly and efficiently to a biosecurity threat requires a financially sustainable biosecurity budget—a budget that is large enough to cope with the growing number of likely incursions as the volume of travellers and cargo increases across the globe (CSIRO 2020). Biosecurity response activities are typically funded by taxpayers and the domestic industry stakeholders who stand to be most impacted by particular incursions. Those who inadvertently introduce pests, diseases, or weeds (e.g. travellers, importers, or vessel owners) typically have no role in bearing the cost of responding to incursions. Relying on taxpayer money or impacted parties to respond to incursions is not economically efficient or financially sustainable, and this approach neither penalises nor incentivises those who are causing the damage to domestic economies, environments, and communities.

New thinking around an economically efficient and financially sustainable approach to funding domestic biosecurity responses has recently emerged. Stoneham et al. (2021) outlined a biosecurity risk insurance mechanism whereby risk creators (importers and vessel owners) would be required to purchase insurance. Premiums would be calculated by actuaries and based on the level of biosecurity risk associated with the type and origin of the good imported (or the vessel's risk of biofouling). Funds collected through premiums would be pooled by a government insurance agency and used to fund biosecurity system costs and the cost of controlling outbreaks of pests and diseases if and as they occur (Stoneham et al. 2021). Importantly, incursions are likely to be reduced in number and/or severity because the scheme has powerful incentive properties: importers of goods assessed as low-risk will incur lower premiums compared to high-risk importers, creating an incentive for importers to seek out low-risk sources of goods.

A biosecurity risk insurance mechanism could also be applied to domestic biosecurity policies. For example, it could be applied to the industry levies paid by producers to fund responses to incursions and could be calibrated with the level of biosecurity risk mitigation measures implemented on farms. Farmers whose biosecurity risk-mitigation measures are substantial and verifiable would be levied at lower rates than those who do not apply measures. The latter group would have an incentive to implement biosecurity risk-mitigation measures, thus reducing biosecurity risks to the industry. Biosecurity risk insurance could also be more broadly applied to human health responses, such as in response to pandemics. Domestic health responses (which can amount to many millions of dollars; Richards et al. 2022) could be funded from a levy on travellers from high-risk countries. This group would have an incentive to reduce their "riskiness" by seeking out vaccinations and other risk-mitigation measures prior to arrival.

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- Because management of invasive species involves spending taxpayer's funds, it is imperative that biosecurity agencies consider the best way to use available funds (or indeed the amount of funds required to achieve the management goal that provides the best outcome for society).
- Eradication, while very appealing, may not always be the most appropriate management strategy, and should not be embarked upon unless it is feasible and offers the best outcome for society.

- Response plans need to be evaluated in terms of the technical and socioeconomic feasibility, not off-the-top-of-one's-head, subjective judgement.
- Switching strategies may be required due to events that render the existing strategy infeasible or because new technology now renders new or previously discarded strategies possible. Ongoing monitoring and evaluation of strategies is therefore critical.

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