

Chapter 9

Risk Assessment and Contingency Planning for Exotic Disease Introductions

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9.1 Introduction

Globalisation has greatly enhanced opportunities for the spread of infectious diseases throughout the world, giving rise to serious threats to human and animal health. This is illustrated by the recent introduction and subsequent spread of West Nile virus in the USA, and outbreaks of Severe Acute Respiratory Syndrome (SARS) in South-East Asia. It is therefore becoming increasingly important that national (and potentially regional) governments should not only have robust systems in place to reduce the risk of disease introductions, but that they need to also consider how to identify and deal with outbreaks of pathogens in wild and domestic animals. In this chapter we will discuss the roles of risk assessment and contingency planning in the management of exotic disease risks involving wild mammals.

The principal purpose of contingency planning is to ensure that a state of preparedness exists in the event of a disease introduction. This requires that the most likely risks of pathogen introduction are identified, that there are adequate means of detecting the pathogen's presence, and that a set of instructions exists describing the best available methods for its rapid and cost-effective containment and control. Contingency planning will involve some of the approaches to disease surveillance (Chapter 10) and management (Chapters 6–8) discussed in other chapters, and so will entail many of the associated challenges, costs and benefits. However, as the aim of a contingency plan is likely to be the rapid containment and subsequent elimination of a pathogen (that is either exotic or endemic but emergent) within a restricted area, the methods of management should reflect this urgency. This may mean that it is appropriate to deploy more severe or costly measures over a short period than would be considered for the sustained control of an endemic pathogen.

It would be impractical to attempt to develop contingency plans for every pathogen of wildlife that could theoretically be introduced. Instead, risk assessment approaches should be used to identify those pathogens where the risks of importation and subsequent establishment are high, and the potential effects, usually in terms of human

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health or economic impact, are sufficiently serious. Some diseases of wildlife, such as rabies, are of such public health concern that almost all disease-free countries have some form of contingency plan to deal with them. A cursory internet search will reveal a number of local and national rabies contingency plans for the UK, USA and Canada. Similar national contingency plans exist for several serious diseases of livestock. In the UK, there are plans covering a range of diseases in livestock, including foot and mouth disease (FMD), avian influenza, Newcastle disease, classical swine fever, African swine fever, swine vesicular disease, rabies and bluetongue. Many of the most important global pathogens of wild mammals are listed by the World Organisation for Animal Health (OIE, Office International des Epizooties). However, the risk from other diseases may also be worth assessing, owing to their geographical proximity, the probability of entry through trade routes or changes in their global status. Some pathogens such as rinderpest, are close to being eradicated (2010 is the target date set by the Global Rinderpest Eradication Programme), while others such as West Nile and Nipah virus are considered to be emerging diseases, and some such as FMD appear in a variety of strains, each of which may need to be considered separately. For those diseases where the risk and potential impact of an outbreak is deemed to be sufficiently great, it would seem prudent to plan an appropriate response.

An exotic disease could be imported in infected domestic animals, wildlife or animal products, or through natural movements of infected hosts or disease vectors. The first line of defence against introduced pathogens is prevention through systems such as quarantine, screening, animal movement tracing and import controls. Risk assessments can inform the development of measures to prevent disease introduction, and contingency planning will provide a level of preparedness should this fail.

Clearly, historical surveillance data on wildlife diseases could provide a background against which to identify novel or emerging pathogens. However, surveillance systems for diseases in wildlife are almost certainly likely to be more poorly developed than systems for monitoring disease in livestock. Surveillance of disease in wild hosts is unlikely to produce strong evidence that a particular pathogen was previously absent (see Chapter 10 for more details). In practice therefore, records of novel pathogens in domestic animals may provide the most reliable predictors of exotic disease introductions that require intervention.

Contingency plans should have a clear overall objective. The choice of acceptable outcomes might include elimination of the disease, or containment within defined limits in terms of geography, prevalence or economic impact. The chosen outcome will determine the scale and characteristics of the response. The level of resources required to achieve this outcome (both equipment and trained personnel) must be available. The response should be described in a series of instructions that should also indicate which organisations are responsible for the implementation of each part of the plan. As the precise conditions of the outbreak cannot be accurately predicted beforehand, the plan should describe the action required under a variety of circumstances. For example the appropriate response may differ depending on whether the disease was initially detected in domestic animals or wildlife, or in relation to the extent of its geographic spread. Indeed, the overall aim of the intervention may be influenced by the conditions (e.g. extent of disease spread, time of year) at the time when the problem is initially

identified. It is important that the plan describes how the outcome of intervention is monitored, and ultimately the conditions required for action to be terminated (e.g. no disease detected for x weeks or months). It is clear from this brief overview that any effective contingency plan needs to consist of instructions that are adaptable to a range of circumstances, which may change in the course of a disease outbreak.

Mathematical modelling (see Chapter 4) can be a valuable tool for the development of contingency plans and to guide intervention during their implementation. Models provide a means of simulating a range of disease outbreak scenarios and of estimating the level of effort and resources required to eliminate or contain infection. The incorporation of an economic dimension in the modelling will provide information on the relative cost-effectiveness of different approaches (see Chapter 5).

Contingency planning for the control of some diseases of domestic animals is likely to require careful consideration of the potential role of wild hosts. The development of effective contingency plans to control disease in both wild and domesticated species will have many features in common. However, management of disease in wildlife raises particular additional challenges related to determining their abundance, distribution and disease status, the practicalities of capture and handling, and the potential for complex behavioural and ecological responses to intervention (see Chapter 2). Inevitably, disease contingency plans involving wildlife are substantially more challenging than those designed for domesticated animals alone, and require dealing with higher levels of uncertainty in terms of both available data and the predictability of outcomes.

There has been a recent trend in modern government in some parts of the world towards cost sharing for animal disease control in livestock. The increasing freedom of information and an inclination towards greater government transparency has led to many contingency plans being publicly available, and even subjected to consultation while in draft form. Both these trends have tended to foster ever-greater stakeholder participation, which is now generally welcomed and encouraged by many governments. This allows all organisations with any interest in the disease outbreak or the methods of control to be involved at an early stage of contingency plan development, and should in theory achieve maximum 'buy-in' from organisations prior to the implementation of any plan.

9.2 Risk Assessment

Since it is impractical to produce a contingency plan for all potential exotic pathogens of wildlife, we need to prioritise by identifying those that present the greatest risk. There are two broad approaches to assessing such risk. A qualitative risk assessment uses subjective categories (e.g. low, medium, high) whereas quantitative assessments use numerical data to quantify parameters (and their uncertainty). The use of real data is clearly preferable but may be difficult to obtain for some parameters. Risk assessments that are an amalgamation of the two approaches are sometimes referred to as semi-quantitative.

Qualitative approaches are useful for rapid assessments of disease risks and in particular for those pathogens and hosts for which little or no quantitative data exists. A qualitative risk assessment often takes the form of a series of questions, each of which may be assigned a rank or score, or alternatively all questions may be considered equally important. One or more experts may then be asked to answer each question with a categorical response. Wherever possible, the uncertainty in their response, and their level of expertise in each area should be estimated. This allows the depth of knowledge of different assessors to be taken into account and areas of uncertainty and data shortfall to be identified. The UK government has published a generic qualitative risk assessment scheme for non-native organisms (Baker et al. 2008), which considers the introduction of exotic animals, plants and pathogens. The advantage in using a generic risk assessment is that the risks posed by a range of organisms that may be important in the epidemiology of a disease (including both hosts and vectors) can be assessed and compared. This provides a framework for the rapid assessment of the relative risks of different pathogens. The scheme can be used to assess the potential for entry, establishment and impact of an exotic pathogen in the UK. The magnitude of the potential consequence of pathogen introduction was included in the risk assessment as a weighting. Scores relating to the likelihood of entry and establishment, and the magnitude of impact, were then given a numerical value as an aid to interpretation. Such an approach allows direct comparisons to be made between risk scores associated with different pathogens and hosts.

A quantitative risk assessment uses numerical data (probabilities, rates, etc.) and is thus regarded as more objective. This approach is useful for determining the risk of disease importation, particularly through trade, where importation rates, and routes are quantifiable. While quantitative risk assessments could be regarded as more accurate, they are not necessarily more useful. Generic risk assessments are much more difficult to produce, as all the necessary quantitative data may not be available; hence comparative quantitative risk assessments are difficult to accomplish. Comparative assessment of the likelihood of importation of different diseases through trade routes may be a relatively straightforward exercise, but it may be problematic to attempt to compare these with risks of disease introduction by other means (e.g. via migrating birds or wind-blown invertebrate vectors). A quantitative risk assessment requires that all routes of disease introduction are quantified, which can be very difficult where illegal importation occurs (e.g. bushmeat). A UK government report on the potential introduction of terrestrial rabies used a quantitative risk assessment approach, and determined that the likelihood of introduction into the country was approximately once in every 36 years (range 21–87 years) under a regime of six months quarantine for all imported domestic cats (*Felis catus*) and dogs (*Canis lupus familiaris*) (Kennedy et al. 1998). This report was used as the basis for the introduction of a pet travel scheme involving vaccination, identification and blood testing of companion animals as a replacement for quarantine, since this led to only an estimated 2% increase in risk: much less than the uncertainty of the assessment for quarantine. Subsequently, as the movement of pets increases and the scheme is expanded to a wider selection of countries,

so the changing risk can be reassessed. Such re-assessments cannot be performed well using a qualitative approach as the final measure of risk is only described in relation to categorical levels (e.g. low, intermediate, high). Quantitative risk assessments are therefore far superior when the aim is to assess changes in risk following the adoption of new policies or procedures.

Risk assessments can be extended spatially, to provide measures of local risks across a broad geographical area. One such approach involved assessing regions at risk of West Nile virus by matching local temperatures to the competency of arthropod vectors to incubate the virus effectively (Zou et al. 2007). A comparative risk assessment of the relative roles of Eurasian badgers (*Meles meles*) and wild deer as sources of *Mycobacterium bovis* infection for cattle, also included a spatial dimension (Ward et al. submitted). The density of badgers and deer across England and Wales were estimated in 10 × 10km squares. Information on host body weight and the mean prevalence of *M. bovis* infection (from surveillance studies) was then used to estimate the potential relative levels of environmental contamination with bacilli from each host species. When data on cattle stocking density in each 10km square was overlaid this created a spatial map of potential TB risks to livestock. Thus risk assessments can be performed to predict the effects of policy changes, or when linked to GIS, to determine the geographical risks in different areas with the potential to inform local decisions on disease management for exotic or endemic diseases.

The risk of disease establishment, and the rate of spread, will depend on the availability of suitable host species, and their combined density and behavioural characteristics (e.g. dispersal rates and distances). This is difficult to determine because of the uncertainty in the suitability of many wild mammals to be competent hosts, and the lack of information on their local density and dispersal behaviour.

9.3 Detection/Surveillance

The challenges and approaches to disease surveillance in wild mammals are discussed in detail in Chapter 10. Here we describe how the detection of disease relates to the implementation of contingency plans, and the value of ongoing surveillance during the course of dealing with an outbreak.

There are a variety of approaches to the diagnosis of infection in the host, including serological tests, identification of gross or histo-pathology and isolation of the pathogen itself. All such tests have their limitations, which are usually expressed in terms of sensitivity and specificity. For many diseases, the appropriate tests will not have been validated in wild hosts, as it is frequently the case that they were initially developed for use in livestock or humans (see Chapter 10). Also, by the time infection has been identified in a given individual, there will almost certainly be further cases present. Hence contingency plans need to take account of the probability of case detection and the likely rate of disease spread prior to detection. Some system

of surveillance should be initiated (or any existing system should be intensified) as soon as possible once the first case has been detected. The initial aim of this surveillance will be to determine the spatial spread of disease and to gain some information on the likely time since its introduction. When such disease outbreaks are detected in livestock the first response is often to stop movements and perform contact tracing. However, this course of action is rarely possible for wildlife, although restrictions on the movement of captive wildlife and susceptible livestock or domestic animals may help contain the spread of disease.

Within the European Union (EU), the standard alert system for confirmation of disease status after a suspect report relies on referral to the relevant EU reference laboratory (EU 2008). For diseases with high mortality or morbidity the submission of suspect individuals is the most efficient method of detecting disease. The detection of a novel disease will usually increase the submission rate of suspect animals, thus increasing the absolute number of infected cases detected. As a result, this sample is not sufficiently representative to provide an estimate of disease prevalence, and should rather be used to indicate the detection rate during a disease outbreak.

Determining disease prevalence is best performed by active stratified sampling so as to minimise detection bias. Where relevant, hunting bags may be a secondary choice, although the processes of capture and submission of carcasses by hunters can be prone to inherent bias. It is important that such bias is minimised (or at least quantified or constant) in samples obtained for disease surveillance during control measures, or this data will be inadequate for monitoring progress during implementation. During the latter stages of disease elimination, unbiased sampling can estimate the likely maximum level of undetected disease. For example, if we assume we apply a sufficiently sensitive test to an effectively infinite population, then a sample consisting of 300 negative cases would demonstrate (with 95% confidence) that the disease, if present, was at a prevalence of less than 1%. Consequently, it would require a sample of 3,000 negative cases to demonstrate a maximum prevalence of less than 0.1%. This demonstrates how sampling effort becomes increasingly critical for diseases that occur at low prevalence, and importantly, for detecting initial cases of an introduced disease. Hence, the results of disease surveillance can be particularly influenced by sample size and sources of bias during the closing phase of any contingency plan, when they should inform the exit strategy (e.g. the time which must elapse after the last case, before "freedom from disease" can be established).

Diseases which are deemed to be important, but which do not cause mass morbidity or mortality, can only be reliably detected by continuous surveillance. The effort (or sample size) required should be determined by the cost of sample collection, the ability to respond to the disease if detected, and the cost of an outbreak. There is little point collecting data for the presence of a disease, if it is not very costly and cannot be managed or eliminated once detected. Economic analysis could be used in these situations, but it should be borne in mind that once a disease detection strategy is in place, it is likely to cost relatively less to investigate each additional pathogen.

9.4 Contingency Plans

9.4.1 Design

Wherever possible the principal aim of any contingency plan for an exotic pathogen should be elimination. However, this may be unachievable in a practical sense, or the available approaches may be too costly to implement, or have undesirable consequences. Where infection cannot be eliminated from the wild host, then the aim may be to reduce it to such levels that spillover into domestic animals or people is acceptably infrequent. This could be achieved by reducing disease prevalence below some level, and containing the disease within specified geographic boundaries.

It is critical that any contingency plan clearly identifies those hosts that will be the subject of management action. Definitive lists of pathogens are rarely available, and are non-existent for most wild mammals, so the susceptibility of different species often has to be inferred from knowledge of the disease in other hosts. Another area where data is frequently limited relates to the distribution and population density of wild mammals. This data is unlikely to be available at a suitable resolution to provide information relevant to local disease outbreaks. In contrast, relatively good quality information is often available on the abundance and distribution of people and domestic livestock. Developing contingency plans for the containment of disease in wild mammal populations is therefore likely to be far more challenging than planning for livestock disease management. Improved abundance and distribution estimates for wild hosts, and information on their behaviour and ecology, will greatly enhance our ability to predict the likely spread of disease and hence the timing and area over which control should be applied. In addition, the ongoing monitoring of disease outbreaks and the impact of interventions will be greatly improved by the application of practical methods to rapidly assess wildlife presence and abundance in targeted areas. The future development of such methods should be considered as a priority amongst those organisations with responsibility for the control of disease in wildlife.

As not all hosts will necessarily be important in the maintenance and spread of an infectious disease, it follows that control measures do not need to focus on all affected species. However, the identification and targeting of true reservoir hosts (see Chapter 1) will be instrumental to effective disease management. Both reservoir and spillover hosts may be involved in perpetuating disease in wildlife or livestock, but effective action targeted at maintenance hosts will also reduce infection in spillover hosts. In some circumstances host status may vary in space and time, such that a particular species only constitutes a reservoir of infection when population density is sufficiently high, for example. This is the case for *M. bovis* infection in feral ferrets (*Mustela furo*) in New Zealand; where in places they occur at densities above 2.9 km⁻², and can be considered as maintenance hosts (Caley and Hone 2005). Conversely, some species may not only be reservoir hosts but may also be carriers. Such hosts do not exhibit clinical signs of disease, but are able to

transmit the pathogen. Furthermore, where infection is indirectly transmitted (by an arthropod vector for example) then control of vector species may also be required. This will require information on the biology and distribution of vector species, which in practice, however may be incomplete or simply unavailable.

In its simplest form a contingency plan will comprise of three steps: (1) a trigger for implementation (e.g. detection of disease), (2) a set of procedures to adopt (e.g. wildlife vaccination) and (3) exit strategies to decide when to cease action. However, the last of these three steps is missing from many contingency plans. A hypothetical contingency plan for a disease outbreak in wildlife is given in Fig. 9.1. The plan is triggered

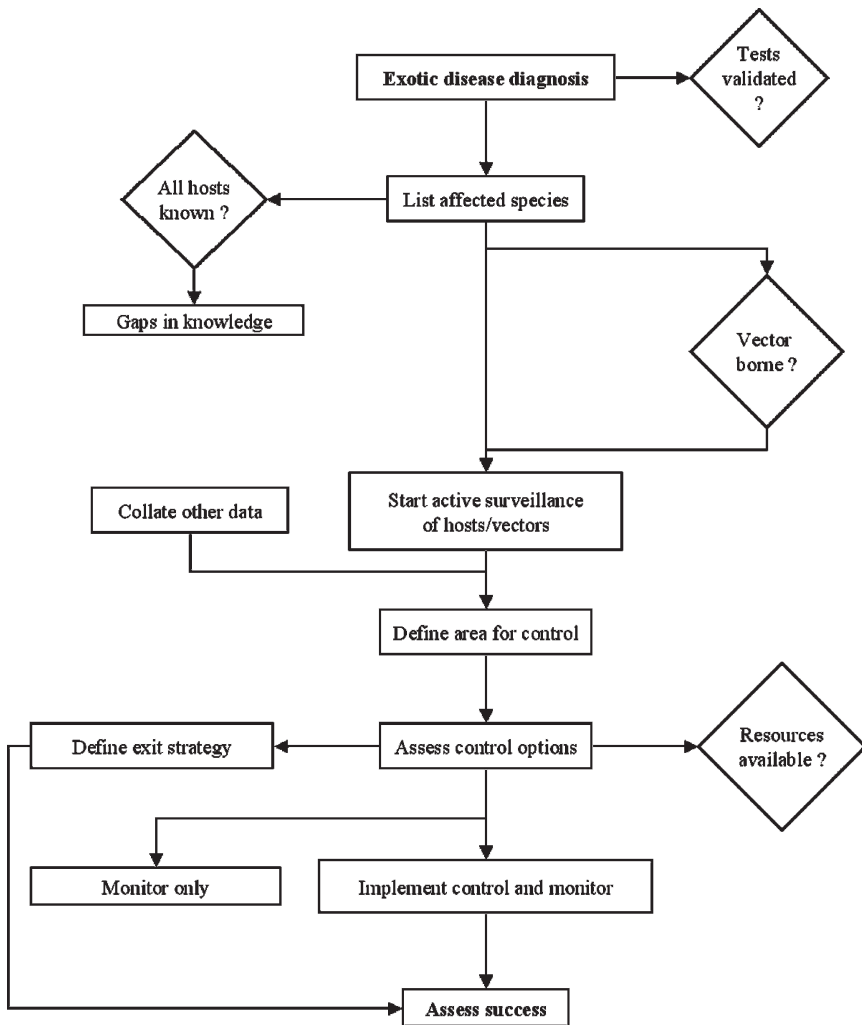


Fig. 9.1 A generic contingency plan for the implementation of control measures to deal with an exotic disease outbreak in wildlife

by the detection of a disease or pathogen, although the validity of the tests in the species of concern will be instrumental in determining the probability of a false positive result. It is important that a list of species that can be affected and are regarded as competent hosts is formulated, as this will identify where there are important gaps in our epidemiological knowledge. Another early consideration is whether the disease is vector borne, and if so, the relevant species and their distribution should be determined. Once this information has been gathered then an active surveillance strategy can be designed and implemented to determine the area currently affected. This should include data from all sources and feed into risk assessments for livestock and humans, so that suitable containment and prevention strategies can be adopted as required. Knowing the current area of spread, we can then assess the options for disease control. If management or elimination appears to be achievable, then the control plan is implemented, and monitored until a pre-determined point at which the exit strategy is triggered. This point may be reached once the disease has been eliminated, whereupon control activities will cease (although heightened surveillance may continue for some time). Alternatively, failure to contain and control the disease may require a switch from the current plan to adoption of measures for the management of endemic disease (i.e. having to live with it). In practice, disease control will be implemented before the geographical area of spread can be determined for two reasons: (1) successful disease control is more likely if control starts as early as possible and (2) it is politically difficult to do nothing while further data are obtained.

The principal options for disease control and management in wild mammals have been discussed in detail in previous chapters, and many of the same considerations apply when these approaches are employed in contingency plans. Hence, the optimal approach may be to combine methods, perhaps applying diverse approaches in different zones or periods of time. However, as contingency plans are often concerned with the rapid containment or eradication of an exotic pathogen in a limited area, the appropriate responses will frequently differ markedly from those required for the sustainable management of an endemic infection. Hence it may be appropriate to employ more severe measures over a restricted area or time frame. For example, culling of wildlife is considered more acceptable when used to control an epidemic outbreak than to manage endemic disease. This approach has been successful in halting rabies incursions over an isthmus (Westergaard 1982) and along alpine valleys (Irsara et al. 1982).

The UK Rabies Contingency Plan (see Box 9.1) includes the possibility of focal population reduction by culling, surrounded by vaccination (often referred to as ring vaccination). The objective is to vaccinate those individual animals that would disperse into the culled area during and after culling, and to reduce the number of susceptibles in the area into which infected foxes may disperse. Modelling studies suggest that this is the optimal strategy for control of a focal outbreak of rabies in a high-density area of foxes (Smith 1995). The effectiveness of this approach for rabies control in racoons has been demonstrated in the field (Rosatte et al. 2001). The clear aim of such a plan is to rapidly contain and eradicate this exotic zoonotic pathogen. In contrast, where rabies is endemic in wild mammal populations, the deployment of vaccine in baits has been demonstrated to be the most effective

Box 9.1 The UK rabies contingency plan

In Great Britain, domestic dog (*Canis lupus familiaris*) (urban) rabies has been recorded historically from the 11th to the 19th century. This includes two recorded human fatalities resulting from being bitten by pet foxes, and two outbreaks in park deer (King et al. 2004). There are no definitive descriptions of rabies spread in wildlife, so we must assume that these historical records are of dog rabies. By 1902, dog rabies had been eliminated following legislation enforcing quarantine, muzzling and the rounding up of strays. This approach has also been successful in eliminating dog rabies in many other countries. Terrestrial rabies was subsequently absent from Britain until a brief period (1918–1922) after the First World War when returning servicemen brought infected dogs back with them. Following two cases of dog rabies outside of quarantine in 1969 and 1970, a contingency plan was established with statutory powers set out in the Rabies Control Order 1974. These included powers to leash and muzzle domestic animals, seize strays and prohibit gatherings of animals and hunting. The Order also permitted the establishment of an infected area, within which wild mammals could be destroyed and the deliberate feeding of wildlife, and their access to waste food, could be controlled. Since then the UK Rabies Contingency Plan has gradually evolved in line with our improved understanding of the range and biology of hosts, and the differentiation of species-specific viral strains. The current plan describes the basic approach for dealing with a rabies outbreak, including implementation, zoning and the logistics of control. In essence, following a confirmed positive case, a decision is made (based on the viral strain and the case history) as to the likely risk to wildlife. ‘Minimal risk’ would result from a case in domestic animals or livestock where the infected individual has had no opportunity for contact with wildlife, and so no wildlife response would be deemed necessary. The risk would be considered ‘possible’ if an infected animal had been in an environment where some contact with wildlife might have occurred, but where the rabies strain was unlikely to spread in British wild mammals (e.g. a dog strain of rabies). The appropriate action in this case would be monitoring of wildlife (i.e. enhanced passive and potentially some active surveillance, depending on the case history) for a period of time not exceeding two years. Risk would be considered ‘likely’ where contact between wildlife and a compatible rabies strain were considered probable. In this instance the control of infection in wildlife would be initiated. This would also be the course of action where the first confirmed case of infection was identified in a wild species. The area and species targeted for control are determined from data on case history, host ecology and the outcome of simulation modelling. In the UK, mathematical models are used to estimate the rate of spatial spread of disease, and to determine the optimal control method (vaccine or culling), area and cost-effectiveness (see Box 4.3 and Box 5.1).

The default control strategy for wildlife rabies in the UK is vaccination following the EU protocol of twice-yearly bait distribution up to a radius of

between 20–50 km from the outbreak (European Commission 2002). However, at high fox densities, or where other host species such as the Eurasian badger (*Meles meles*) may be involved, the optimal control strategy may include the focal deployment of poison baits and ring vaccination (Smith and Wilkinson 2003; Smith 2006). An additional reason for the adoption of focal culling is the apparent lack of immunity in the badger following vaccine bait distribution (Smith 2002). It is likely that in some areas of the UK, the badger may be at a sufficiently high density to be a reservoir host, and so should be included in the contingency plan. Recent work has focused on predicting the costs of different control strategies, and the expected time to achieve rabies elimination, so that their relative cost-effectiveness can be determined (see Box 5.1).

approach to its control (see Chapter 6). In practice however, vaccination of wild hosts may seldom be an option, as vaccines are only available for a limited number of diseases of wild mammals, and even these may not work in all host species. Nevertheless, appropriate vaccines may be available for those livestock, domestic animals and humans that are most at risk during an outbreak of disease in wildlife.

One means of reducing the risks of spillover from infected wildlife is to manage the opportunities for contact with people or domestic animals (see Chapter 8). In effect, this amounts to improving systems of biosecurity (see below), but has no effect on the circulation of disease in the wildlife host species. In the event that the disease cannot be eliminated, then this may remain the only option.

For some diseases of wild mammals, control measures may need to be targeted at vector species in addition to hosts (see Box 9.2). However, this may be logistically difficult, particularly when highly mobile arthropod vectors are involved. If a pathogen is only transmissible via a vector, or an intermediate host is necessary for the completion of its life cycle, then control of the vector or intermediate host is often more effective than controlling the definitive host species. However, in many instances vector control is extremely difficult, if not practically impossible, in which case minimising infection of the host species may be the best policy. Bluetongue virus is transmitted by midge vectors and a recent outbreak in the UK (serotype BTV8) is thought to have occurred due to infected midges being blown from Northern Europe, following its introduction there from sub-Saharan Africa. The virus is consequently now likely to be circulating in midge species that were not previously exposed to the virus. This demonstrates how it may be necessary to consider the potential for involvement of novel vector species in the spread of an exotic pathogen, following its initial introduction. Control of bluetongue in the UK through vaccination of domestic ruminants is considered a more achievable strategy than attempting to control midge populations. Wild ruminants are also known to be susceptible to bluetongue but their role, if any, in the UK outbreak is unknown. Targeting all vectors may also be impractical when there are many species or where the full array of potential vectors is unknown. Control is often most challenging when winged arthropods are involved in the epidemiology of

Box 9.2 Management of plague in wild hosts and vectors

Plague is caused by the bacterium *Yersinia pestis*. The disease is relatively stable in enzootic cycles in maintenance hosts but can cause mass die-offs in amplification hosts when epizootic cycles arise. Both maintenance and amplification hosts are usually rodent species, although the bacterium is able to cause disease in a wide range of mammals. Although a susceptible animal may acquire infection by inhalation or ingestion, inoculation via bites from infected fleas is regarded as playing the most important role in disease transmission between individuals, with some flea species acting as more competent vectors than others. Control of spillover into wild or domestic mammal populations should focus on pulicide (an insecticide that kills fleas) treatment either simultaneously or prior to rodent control, to prevent infected fleas leaving dead hosts and disseminating disease (Perry and Fetherston 1997). Care must be taken in selecting appropriate insecticides and rodenticides as resistance has been observed in some flea and rodent populations. Pulicides are formulated for application either in the environment or on individual animals (although the latter is impractical for controlling disease in wildlife hosts). Both environmental and individual animal treatment must be practised for the control of fleas on pets and it is important to carry out prophylactic treatment of households and pets in enzootic areas or where an outbreak occurs. This is both to prevent disease in pets and to minimise transmission to humans, which is particularly associated with inhalation of aerosol during close facial contact with domestic cats (*Felis catus*).

Plague has proven difficult to eliminate from some parts of the world. In such enzootic areas control methods are usually employed in an attempt to quell or prevent an epidemic rather than to achieve local elimination. For example, since the introduction of the disease to areas of the western USA, foci of infection have persisted in ground dwelling rodents such as the black-tailed prairie dog (*Cynomys ludovicianus*) and the California ground squirrel (*Spermophilus beecheyi*). Attempts to eliminate the disease have proven unsuccessful. However, a programme of public education and the existence of state emergency plans, with rapid reporting of cases and efficient risk communication, have ensured that the number of human cases per year in the USA has remained relatively low (approximately 3.7 cases per million people in the period 1992–1999) (Change et al. 2003).

Still more information is required on the epidemiology of plague, in particular its ability to persist in wild mammal populations despite control efforts. It has been postulated that the bacterium may survive for long periods in burrows outside the mammal host, possibly in dormant fleas. Certainly the bacillus does not appear to have long-term environmental stability and is thought to die quickly outside the vector or mammalian hosts, particularly in dry conditions with high temperatures and on exposure to sunlight. However, viable bacilli have been recovered under natural conditions after at least 24 days

in soil contaminated with infected blood. The reason for this extended survival time is unknown but may be attributed to the blood serving as an enrichment medium (Eisen et al. 2008).

The epidemiology of plague is complex and epizootics appear to arise in relation to sudden increases in populations of mammal hosts and competent flea vectors. Flea populations are dependent on host availability, which is influenced by environmental conditions. In addition, flea species differ in their competence as vectors and in the extent to which they are host specific. Hence the occurrence of an epizootic, or the maintenance of the disease as an enzootic, is the result of a complex interplay between hosts, vectors and environmental conditions. The development of transmission models using existing knowledge will further our understanding of the factors that may influence the persistence of plague in host and vector populations, and so help to identify the most appropriate control strategies.

the disease, as there is the potential for transmission of infection over long distances, particularly in windy conditions. Mass application of insecticides can reduce the likelihood of exposure to arthropod vectors but potential benefits will need to be weighed against the risks of environmental contamination and adverse impacts on human health and non-target species. Following the introduction of West Nile virus to New York City in 1999 attempts at controlling human exposure to the mosquito vector included the widespread distribution of insect repellent and both terrestrial and aerial deployment of insecticide. Although such measures may reduce exposure to arthropod vectors, changes in weather conditions can ultimately play the most decisive role in determining their abundance.

Control of livestock in the event of a disease outbreak is made easier by the availability of areas on farms where animals can be concentrated and if necessary isolated for treatment or dispatch. Wild mammals, however, are considerably less tractable and if disturbed may disperse over a wide area. The likely behavioural responses of wild mammals to interventions, and their potential to exacerbate disease spread (see Chapter 2), are crucial considerations when devising contingency plans. Sufficient understanding and assessment of these possibilities will require input from experienced wildlife managers.

9.4.2 Modelling of Control Options

The utility of mathematical models for improving our understanding of disease transmission, and the likely impact of control options, is generally accepted. Models permit a low-cost assessment of the potential outcome of various management interventions, which can be compared with a non-intervention scenario. However, for the risk of success (or failure) to be determined, model outputs must

be stochastic so that they can demonstrate the range of potential responses to intervention. A full discussion of how models should be used is given in Chapter 4. In relation to contingency plans, modelling can be performed in advance of any outbreak to help determine policy (e.g. quarantine, importation restrictions), or to help devise a control strategy. Models incorporating spatial aspects of disease control and heterogeneity in host density (Smith and Harris 1991 and Chapter 4) were used to inform the design of the UK rabies contingency plan (see Box 4.3). Modelling can also be used to simulate conditions during an outbreak, and so assess the likely outcome of interventions as the epidemiological situation changes. This can provide valuable guidance to operations on the ground during the course of the outbreak, particularly when integrated with Geographical Information Systems (GIS). In recent years there has been an increasing reliance on GIS to provide ‘real-time’ monitoring of the spatial distribution of cases to aid rapid interpretation of the changing situation during disease outbreaks (Kroschewski et al. 2006).

In 2001, three different models were used to predict disease dynamics and inform control options during a foot and mouth disease (FMD) outbreak in UK livestock. A critical appraisal of these models indicated that each had its strengths (Kao 2002), but we should be mindful that all models need to be adaptable to changing conditions during an outbreak. Of overriding importance is that such models are transparent, can be easily communicated to non-specialists, and the methods and levels of control are achievable in real life. During interpretation of model outputs, care should be taken to consider the underlying assumptions and limitations and the ‘real world’ practicalities of management. Model predictions should therefore be used to guide policy decisions, rather than to make them.

9.4.3 Economic Analysis of Control

A contingency plan can only be considered as a realistic proposition if the proposed actions are cost-effective. Hence, the development of a potentially effective contingency plan will require careful consideration of the economic implications of intervention, and indeed the costs of non-intervention. We can determine whether any intervention is economically worthwhile by means of a cost–benefit analysis (see Chapter 5). Assuming that the economic case is made for intervention, then an assessment of the cost-effectiveness of different management options will be necessary. For example, either culling or vaccination may be the most effective means of controlling disease under certain circumstances, but the most effective approach may also be the most costly. If either vaccination or culling were performed through the distribution of baits, then the costs may be similar. However, poison baiting may be much more expensive if the baits need to be recovered. As a general rule, culling is usually more expensive than vaccination (if the costs of vaccine development are not included), since the major component of wildlife control is personnel time.

Just like any other components of a contingency plan, costs are likely to change over time as the epidemiological situation develops and methods are adapted.

This will alter the cost:benefit ratio, making it necessary to periodically review the economics of control. This is likely to become particularly critical during the later stages of disease control when the detection of cases becomes infrequent and the cost of control can appear to be increasingly disproportionate. At this point there is likely to be pressure for the early curtailment of control measures on financial grounds, but the risks of disease resurgence are unknown if control ceases before the time specified by the exit strategy.

9.4.4 Implementation

It may be simple enough to design a hypothetical plan of action to eliminate, contain or manage a disease in wild mammals based on our understanding of disease dynamics and host ecology. However, a wide range of practical considerations will determine whether such a plan can be implemented. Even a relatively simple exercise such as a spatially restricted cull of a wild host population during a focal outbreak of exotic disease, might require the availability of a range of resources such as adequately trained staff (including both veterinary and wildlife management expertise), vehicles, specialist equipment, stocks of consumables (such as poison baits, protective clothing and disinfectants), transport, laboratory and carcass disposal facilities, GIS skills for mapping, administration and the establishment of local offices. Hence, systems need to be in place to allow many of these essential resources to be swiftly released from storage, purchased or seconded in the event that the contingency plan is invoked. But resources are no use whatsoever unless they can be deployed effectively, and this will require the existence of an appropriate organisational structure with clearly defined roles, responsibilities and lines of communication. There may be one or more areas where resources are strictly limited: for example, laboratory diagnosis, specialist equipment or suitable numbers of highly trained staff. Such limitations need to be considered when producing the overall plan. The availability and time required to access these resources will become important if it is necessary to expand the contingency plan from the scale of a local outbreak to that of regional control.

Following an outbreak of FMD in UK livestock in 2001 the government carried out extensive re-evaluation of its animal disease contingency plans, in the light of the experience gained. Although this was primarily concerned with the containment and elimination of infectious diseases in livestock and poultry, the basic principles are also relevant to any civil contingency response. They suggested a four-stage alert system to define the status of a disease outbreak: (1) disease not present; (2) disease risk higher than normal (because it is present in a nearby country for example); (3) suspicion of disease on clinical grounds, and (4) disease presence confirmed. During the last two stages, suspect animals may be slaughtered as a preventative measure, and samples taken for diagnosis. When the final stage is reached the Chief Veterinary Officer is obliged to set out the objectives for disease control and must establish a National Disease Control Centre (NDCC) and Local Disease Control

Centres (LDCC). The NDCC is responsible for policy and operations at a national level and advises Government Ministers. The LDCCs on the other hand, are responsible for the local co-ordination of disease control, including tasks such as the implementation of biosecurity, cleansing and disinfection of farm premises, disposal of carcasses, handling samples, GIS mapping, licensing animal movements, record keeping, surveillance, contact tracing, and health and safety. This complementary approach allows policy and strategic decisions to be made nationally, and tactical implementation to be performed locally. During an outbreak all relevant data is collected and checked locally, and communicated daily to the national centre. Both bodies can have a prescribed daily timetable that will include communications meetings, media briefings, daily report compilation and 'birdtable' meetings (where defined participants contribute in the same order at each meeting to communicate between all operational partners, provide situation reports, identify emerging issues and a structure for dealing with action points).

The roles and responsibilities of all those involved in the implementation of a contingency plan should be clearly defined. The range of expertise required to co-ordinate action should not only include those with veterinary and wildlife management experience, but also those versed in statistics, modelling, GIS, economics, management and finance.

In the case of diseases of wildlife that affect livestock, additional biosecurity measures may be required. These may include the restriction of livestock movements to stop further spread, and reducing opportunities for contact with wildlife and vector species. The latter may require that steps be taken to control wild mammal incursions onto farm premises. In areas where livestock are culled, stringent measures may be needed to ensure that wild mammals (carnivores and rodents in particular) cannot gain access to infected carcasses.

In order to reveal the full extent of logistic considerations it may be advisable to carry out trial exercises to simulate real-time outbreaks. This will have the added benefit of familiarising key staff with the necessary procedures.

9.5 Conclusions

Contingency plans should play a vital role in disease management, but their value depends on the accuracy and level of information underpinning the decision processes. As has been seen in previous chapters, there are examples where intervention has not always been successful in terms of disease reduction, and may have even exacerbated the problem. However, a detailed contingency plan based on risk assessments can provide practical advice for rapid implementation once disease in wildlife is suspected.

In summary, horizon scanning should identify which diseases may be imported by natural or anthropogenic means and risk assessments should be performed to identify those diseases which merit intervention. Expert opinion and the availability of vaccines will inform on the design of control strategies that can then be modelled

and economically evaluated to produce an overall contingency plan. This plan will also depend upon the availability of resources and suitably trained personnel, and should be publicly discussed with all appropriate stakeholders in order to maximise consensus on the control strategies.

It is likely that there will be shortfalls in the data required for qualitative and quantitative risk assessments, although it is important that some attempt is made to formulate initial contingency plans for those diseases of most concern. These should not only include description of the most appropriate methods of control, but should also indicate the personnel, organisational framework and resources that will be necessary. In particular, the plan should define the exit strategy, to determine when control should cease (i.e. how long after the last recorded case) or change. Contingency plans should also be subject to regular review as risks change, new data becomes available and novel management techniques are developed.