Wildlife Health
Australia

National Guidelines for Management of Disease in Free-ranging Australian Wildlife

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From Australia's Chief Environmental Biosecurity Officer

The science of wildlife disease management is relatively new. Attempts to manage disease in wildlife populations post-date attempts to manage disease in humans and domestic animals. Triggers for wildlife disease management traditionally included significant disease events spilling into humans or domestic animals. The situation is, however, changing with the realisation that disease can also impact upon biodiversity, in some cases leading also to extinction. There is therefore a need for an accessible, practical document that outlines the science of wildlife disease management and outlines what options might be of use to those needing to manage wildlife diseases in an Australian context. The need will only become greater as the risks to Australia posed by these diseases become greater with changing land use and climate change and as societal attitudes bring wildlife, livestock and people into closer contact.

I congratulate Wildlife Health Australia for their production of this document. The Guidelines complement the National Wildlife Biosecurity Guidelines and together they make a significant contribution to improving our environmental biosecurity and our ability to manage wildlife health in Australia.

Ian Thompson
Australian Chief Biosecurity Officer
Department of Agriculture, Water and the Environment

Wildlife Health Australia acknowledges the Traditional Owners of Country throughout Australia and their continuing connection to land, sea and community. We pay our respects to them and their cultures and to their elders both past and present.

Contents

Executive summary

Disease is a natural part of ecosystems and control of disease in wildlife may not always be necessary. In the modern world, there are few environments that have not been changed by humans and, in many cases, foreign diseases have been introduced into wildlife populations. In these instances, wildlife disease management may need to be considered.

In general, wildlife disease should be managed from an ecological perspective, with an understanding of the role that disease plays in ecosystems. Concerns about welfare impacts on individual animals may, however, drive a need to manage wildlife disease, even when wider ecological impact is considered unlikely.

The overall objective of disease management is to decrease the impact of the disease. Wildlife disease management follows basic principles but has challenges, which in some instances may result in a lack of effective options for management of disease.

Wildlife disease management is most often applied in situations if there is:

- significant risk to threatened or vulnerable wildlife populations or species, or those that are iconic or of Indigenous significance
- significant risk to human health, food safety or food security
- significant risk to the health of domestic animals, in particular production animals
- significant concern around animal welfare, especially when wildlife disease is a consequence of human-mediated actions
- significant community concern
- a good chance of success
- an option which is cost-effective and, optimally, will cost less that the projected impact of the disease
- an option available under existing legislation and regulation and supported by political will.

The four fundamental approaches to disease management are: prevention, control, eradication and "watch and see". The options for disease management include targeting the host, targeting the agent of disease, targeting the environment, targeting human behaviour or a combination of these.

The suitability of the approach will depend on the particular circumstances and there will be different considerations for managing an endemic disease or an exotic disease incursion. An understanding of the causation and ecology of the disease in question and the population biology of the host and agent of disease (and vector) will significantly improve decision making. Prior to any intervention, consideration should be given to any potential unintended consequences.

These guidelines highlight the following key messages:

- wildlife disease management should be undertaken as a multidisciplinary, collaborative effort, with input from (including but not limited to) ecologists, wildlife disease experts, responsible governmental agencies (including public health where relevant) and the community, including Indigenous people
- decisions and agreed approaches should be based on risk assessment, underpinned by scientific expertise

- clearly defined objectives need to be identified and the impact of management methods needs to be measured
- possible impediments to success, costs of inaction, and unintended consequences of actions should be identified
- clear and consistent communication is necessary to build awareness, understanding and support from stakeholders, including the wider public, for any actions undertaken
- endpoints and an exit strategy need to be agreed before measures are put in place, and an objective review of the nominated approach undertaken prior to any intervention.

Preface

These *Guidelines for Management of Disease in Free-ranging Australian Wildlife* provide information and advice to guide management of disease in wildlife in terrestrial environments. The Guidelines are intended to be a generic, overarching summary document outlining the options available for managing disease in Australian wildlife.

Wildlife are defined as unmanaged populations of Australian native wild animals (mammals, birds, reptiles and amphibians). The management of disease in native fish and invertebrates is outside the scope of the Guidelines. The information in this document can be applied to marine and aquatic environments, although they are not a specific focus of this document. Although these Guidelines focus on free-ranging native wildlife, the principles discussed are applicable to all wildlife in Australia under the broader definition, which includes feral animals and exotic fauna (see Glossary).

The focus of these Guidelines is on management options for disease in populations of native wildlife at a population level. The Guidelines discuss the information required and the factors that shape the decision making process. They do not discuss the management of a specific wildlife disease event, incident or emergency situation i.e. they do not discuss management of a "wildlife disease response". Arrangements for a response to disease outbreaks or incursions in Australian native wildlife are presented in the *Guidelines for Management of an Emergency Wildlife Disease Response* (Wildlife Health Australia 2018), *Australian Veterinary Emergency Plan* (AUSVETPLAN) and specific disease strategy manuals[1]. The information in these Guidelines may nonetheless be useful when assessing management options during an outbreak or incursion.

The Guidelines are intended for use by those involved in management of a disease in Australian wildlife and are ***not*** intended as a substitute for training or qualifications.

These Guidelines focus on principles, with the understanding that the reader can modify the options to suit different contexts. Information relating to the technical management of specific diseases should be determined at the time of need, on a case-by-case basis, with the potential to draw on currently available documents (e.g. Australia's *White-nose syndrome response guidelines*[2], Threat Abatement Plans for Beak and Feather Disease and Chytridiomycosis[3], AUSVETPLAN disease documents etc.)

These Guidelines collate currently available knowledge in an effort to help those faced with the challenge of managing a disease in a wildlife population. There are five main sections to these Guidelines:

- Section 1: Introduction, including important background information
- Section 2: Key questions when considering management of wildlife disease
- Section 3: Approaches to disease management in wildlife, which discusses commonly used approaches including prevention, control, eradication and "watch and see" options, and;
- Section 4: Options for control of disease in wildlife
- Appendixes include Global and Australian standards and processes for wildlife health management, Examples of wildlife disease management programs globally, References and recommended reading and Glossary.

1 www.animalhealthaustralia.com.au/our-publications/ausvetplan-manuals-and-documents (Animal Health Australia 2011, 2018)

2 www.wildlifehealthaustralia.com.au/Portals/0/Documents/ProgramProjects/WNS_response_guidelines_1.1_Jul_2019.pdf (Wildlife Health Australia 2019)

3 www.environment.gov.au/system/files/resources/5764cda0-5e94-48c7-8841-49b09ff7398c/files/beak-feather-tap.pdf (DEH 2005) and www.environment.gov.au/system/files/resources/d7506904-8528-411e-a3f4-19d4379935f9/files/tap-chytrid-fungus-2016.pdf (DEH 2006)

Section 1

Introduction

1.1 Key terms

For the purpose of this document, **disease** refers to any disturbance in the health or function of an animal or human, which may be infectious or non-infectious. **Wildlife disease**, in the context of these guidelines, is disease that impacts free-living individuals or populations of non-domestic, native species of mammals, birds, reptiles and amphibians. **Wildlife disease management** means to restrict or curb the occurrence and impacts, or risk of disease, within a wildlife population or ecosystem.

Biosecurity, in the national context, is defined as "the management of risks to the economy, the environment, and the community, of pests[4] and diseases entering, emerging, establishing or spreading". Biosecurity can also be explained as the set of precautions taken to minimise the risk of introducing a pest or infectious disease into an animal (or human) population.

Wildlife biosecurity means managing risks, primarily associated with infectious diseases transmitted from wildlife to humans (and vice versa), from wildlife to domestic animals (and vice versa), and between groups of wildlife. It focuses on minimising and managing the risk of infectious disease spreading from one individual or population to another and looks at practices which may play a role in decreasing the risk of infectious disease.

Other definitions are found at the end of this document. Some key definitions are also included in the main body of the document.

1.2 Wildlife health, biosecurity and management

The health and biosecurity of wildlife are important global issues. The risk of disease to, and arising from, wildlife is of significant concern to environment, agriculture and human health agencies. Disease in wildlife can contribute to the decline and extinction of vulnerable, threatened and endangered species and diseases originating from wildlife are the major source of emerging zoonotic diseases. Wildlife diseases can affect domestic species, including production animals, with impact on trade and food security and resulting socio-economic consequences. In some cases, a disease may affect both wildlife and domestic species. In other cases, wildlife may not be affected but disease spillover to domestic animals can be very serious (Woods and Grillo 2019).

Effective biosecurity is extremely important in reducing the risk of introduction or spread of disease. Australia's "National Wildlife Biosecurity Guidelines"[5] provide detailed information on effective biosecurity when working with Australian wildlife. Everyone in the community needs to do their bit to protect the economy, environment and community from biosecurity threats[6]. Ongoing disease surveillance is essential for early detection of diseases (new, emerging or spreading) in wildlife[7].

4 A pest is any species, strain or biotype of the Kingdoms Animalia (excluding human beings), Plantae, Fungi, Monera or Protista that has had an impact (i.e. significant negative consequences), or poses a likely threat of having an impact (Intergovernmental Agreement on Biosecurity).

5 www.wildlifehealthaustralia.com.au/Portals/0/Documents/ProgramProjects/National_Wildlife_Biosecurity_Guidelines.PDF

6 General biosecurity obligations (GBO) means that everyone is responsible for managing biosecurity risks that are under their control and that they know about, or should reasonably be expected to know about. They must take all reasonable steps to ensure they do not spread a pest, disease or contaminant. (Qld Dept. AF; https://ablis.business.gov.au/service/qld/general-biosecurity-obligation/39040)

7 WHA administers the national electronic Wildlife Health Information System (eWHIS) database, a web-enabled, secure database capturing information relating to wildlife health surveillance and disease investigation in Australia. For more information visit www.wildlifehealthaustralia.com.au

Management of wildlife disease is likely to draw in people with different wildlife and animal health backgrounds and experiences, from a number of different agencies and organisations, including state and territory governments, the Australian Commonwealth Government, universities, zoos, wildlife carer and welfare groups, and others.

Wildlife health may be managed at international, national or state levels depending on the scale of the issue and the sectors affected. In Australia, animal and wildlife health issues are managed at both state/territory and national levels. Further information on international standards for wildlife health, and Australia's government processes that support wildlife health can be found in Appendix B.

1.3 Risk analysis in wildlife disease management

Risk analysis looks at both the probability of an event occurring and the likely impact of the event if it does occur. Risk analysis can be used to decide if you need to do something, to decide what you need to do, how likely this is to succeed and therefore whether you should go ahead with the proposed management plan.

A risk analysis framework can help decision makers by encouraging them to adopt an accepted, standardised and formal approach to decision making. It helps to identify gaps, record necessary assumptions, evaluate different options, quantify assessments and critically evaluate decisions. Risk analysis is also a useful tool for brainstorming ideas.

Disease risk analysis is a framework to assess the risk of disease in populations and individuals and is increasingly used in wildlife, in particular prior to conservation translocations. See the IUCN/OIE "Manual of Procedures for Wildlife Disease Risk Analysis" (Jakob-Hoff et al. 2014) for detailed information.

Risk assessment can also be used during strategic planning for disease management, to help assess various approaches and options. The strategic risk assessment will need to address the full range of risks associated with the management plan. These include political, economic, environmental, social, technical, operational, legal, and media and communication related risks.

1.4 Wildlife disease at a population level

Disease is a part of normal ecosystems and in many wild populations, disease management will not be necessary. Disease can play an important role in regulating wildlife populations but the presence of disease always comes at some cost to the individual host. The overall impact of a disease upon a population is often very difficult to determine.

Controlling wildlife disease unnecessarily is costly and can have negative impacts on ecosystems (e.g. wildlife overpopulation). In some ecosystems, a "steady state" is achieved between the host and the disease. However, in the modern world, no wild animal lives in an environment that has not been modified to some extent by humans and many wildlife populations have been exposed to foreign diseases. These and other associated changes influence the ecology of disease, often for the worse. Consideration may need to be given to managing disease in all natural systems, and in particular when there is evidence that disease is significantly affecting the population.

In Australia, most wildlife diseases of concern are considered to be a result (either directly or indirectly) of human-related change. There may be cumulative impacts to the wildlife from habitat loss and degradation, climate change, feral animals, predation, competition and pollution, as well as disease. Disease management may need to be part of a wider integrated management process for species or ecosystems that are impacted by (human-related) change. Disease management may need to be prioritised if there are multiple negative factors influencing a vulnerable wildlife population, with limited options to control some of them (i.e. habitat may have degraded and climate is changing, but little can be done to mitigate these factors, so disease management may need to be prioritised to reduce pressure on the population).

1.5 Disease transmission and persistence in populations

Disease persistence and transmission are important considerations when considering disease management (Wobeser 2006, 2007).

Different types of parasites are transmitted through different mechanisms or pathways (e.g. inhaled, close contact, biting, faecal-oral). In general, the more efficiently a disease is transmitted, then the more difficult it will be to manage.

Factors including host population size and density and the “infectiveness” or “basic reproductive rate” of the disease will influence transmission. Relatively speaking, disease may impact less on large populations than on small or fragmented populations. The length of time an agent of disease persists in the host, along with the presence of reservoirs, vectors and carriers influence the ability to control disease.

Key points:

- understanding how a disease is transmitted and why the disease has occurred is the key to identifying management options
- disease often occurs in wild populations because something has changed in the animal’s environment, leading to disease emergence
- by understanding the disease cycle, how the disease is transmitted and the factors responsible for the disease occurring, control points or a “weakest link” can be identified and targeted to help control or manage the disease.

1.6 Challenges in disease management in wildlife

Disease management in free-ranging wildlife brings with it considerable challenges (Stallknecht 2007; OIE 2010). The techniques of disease management that are used in humans and domestic species can be used for wildlife, but there may be additional limitations, including:

Detection of disease issues:

- disease is more difficult to detect (less surveillance, less reporting, less diagnostic abilities, less understanding of disease and poorer baseline health information compared with domestics; tests may not be available or may not be considered accurate for the host species)
- elusiveness of wild animals (also an issue for management).

Management of disease issues:

- techniques used to deliver treatment in domestic animals may be ineffective in wildlife because of differences in behaviour or avoidance of strange foods and smells etc.
- interventions acceptable in domestic species may cause unacceptable stress, injuries and mortalities in wildlife
- difficulties in capturing or accessing sufficient proportion of the wildlife population.

Managing sick or dying animals and making decisions about the survival of individual animals can be mentally and emotionally taxing for the people involved. People working with wildlife need to make sure they look after their own well-being which might include taking regular breaks, finding supportive people to discuss concerns with, and other aids for mental, physical and emotional well-being. Wildlife disease managers should take these factors into consideration when planning disease management programs.

1.7 Unintended consequences of disease management actions

All free-living species are embedded in complex ecosystems. Managing the impact of disease on a particular host species can have repercussions on whole of community structure. For example, removal of Tasmanian devils due to Tasmanian devil facial tumour disease control may have consequences for both lower-order predators and prey species, and may indirectly impact the whole ecosystem. Vaccinating lions in the Serengeti against canine distemper virus may indirectly result in negative impacts on cheetah populations, as lion numbers increase (Chauvenet et al. 2011). The full range of unintended consequences needs to be carefully considered prior to any disease management actions being applied. Scenario planning and the use of modelling and strategic risk assessment can assist in this process.

Section 2

Key questions when considering management of wildlife disease

The questions that need to be answered before developing a plan to manage a wildlife disease are outlined below. For all steps during the assessment process, the need for a multidisciplinary approach to wildlife disease management is strongly encouraged.

1. **Is management *required* or *desirable* and why? What are the *consequences* if there is no intervention?** A decision on whether disease management is required and desirable will be underpinned by a knowledge of the presence of disease (and change over time), information that the disease is impacting (or will soon impact) the population and information on the severity of disease impacts on the population and ecosystem.

   Answering the question "*Why* do we want to manage this disease?" allows the focus of management to be directed to the purpose. For example, if the purpose of managing a disease is to improve welfare rather than for conservation purposes, approaches may be aimed at ensuring the well-being of the individual animal, rather than at a population level.

   The consequences of non-action (or a "watch and see" approach) also need to be considered. Disease may spread or impacts may magnify if no action is taken. Managing public expectation and concern is an important consideration in wild animal disease management.

2. **Is the disease *present* in the population and to what extent?** Presence or absence of the disease strongly impacts approach to management. For example, if the disease is not previously known to be present in the population of interest it might be a new or previously unreported disease. There may be greater interest in managing a newly arrived "exotic" disease than for a scenario where the disease is already widespread. An already widespread disease may be much harder to manage. Efforts to prevent entry of a disease into a population will be different to efforts taken to control or eradicate a disease already present.

   Information on disease presence is obtained through surveillance, baseline data gathering on disease or infection status and historical reports and records. There may be a lack of baseline information on disease in wildlife populations, and it may be challenging to determine presence or absence of disease, due to the nature of wild populations.

3. **What is the *impact* of the disease on the population?** It is important to know if the disease is having population-level effects and how severe these are. If the disease has little impact at a population level there may be less interest in applying disease management. Additionally, knowing the level of population impact, allows for measurement of the effectiveness of any intervention. Knowledge of the previous impact of the disease (or a similar one) on a similar population can also be useful as there may be a strong argument to undertake disease management if the disease has had a significant impact on another population.

   It can be very challenging to determine the true impact of disease (or other negative factors) on wildlife populations. It generally requires long-term study of population dynamics, linked with disease prevalence studies, and studies of disease impact on individuals (e.g. blood testing, pathology).

4. **Can this particular disease be *detected, diagnosed and measured* in the population and what techniques are available for this?** In order to effectively manage disease, we need to be able to assess the change occurring as a result of a disease management action. In the first instance we need to know if the disease is present, and at what level, which requires the ability to identify the disease. An accurate test is not necessarily required before intervention, but agreement on what constitutes a case of the disease (a "case definition") is required. Eradication of a disease is assisted by an accurate test, preferably one with known sensitivity and specificity. In general, the more accurately that disease presence can be determined, the more efficient and effective any intervention will be.

   There are a wide variety of options for detecting disease, confirming a particular diagnosis and measuring the rate of disease in a population. The input of wildlife disease professionals (clinicians, pathologists, microbiologists and epidemiologists) will be critical in determining the best ways to detect, diagnose and measure the disease in question.

5. ***How* will management be undertaken?** Options available for disease management are discussed in Section 3. Approaches should be considered for their efficiency, effectiveness and feasibility. A strategic risk assessment and analysis of the available options may help to guide the decision on how management will be undertaken.

6. **Is management *feasible*?** The nature of free-ranging wildlife means that feasible disease management options may be limited, or unavailable. For example, there may be challenges in effectively delivering a newly developed vaccine to a sufficiently high proportion of a free-ranging wildlife population so that transmission is decreased and disease is eradicated.

   A collaborative multidisciplinary approach is needed to determine if feasible management options are available. Global consultation with others who have undertaken similar disease management programs will help to refine options and highlight areas of vulnerability in the program.

7. **Is there the necessary understanding of the *ecology* of the disease and ecosystem?** The more knowledge there is of the disease pathway and the factors that affect each stage in that pathway, the more targeted the disease management option can be. Firstly, there needs to be an understanding of how the disease in question acts within an ecosystem. Usually, there are a number of necessary factors that lead to the disease having a significant impact. For example, a population of parrots widely distributed across the landscape may have a very low prevalence of psittacine beak and feather disease. If, however, the habitat for these birds is contracting due to land clearing, then the birds may be forced into smaller areas of sub-optimal habitat, bringing them into closer contact, forcing more aggressive competition for food and increasing the overall stress and disease susceptibility of the population. The solutions for managing the disease in these animals may include a focus on habitat restoration rather than specific disease intervention.

   Knowledge of the disease ecology allows disease management options to target weak points, or "control points" along the infection pathway. Disease ecologists and ecosystem ecologists will be essential in helping to answer these questions.

8. Are all the other *components* that are necessary for an effective intervention available e.g. multidisciplinary team, resources, commitment, capacity etc? Disease in wild populations of animals is complex. Multidisciplinary teams are required to generate the broad thinking and knowledge-base to maximise success. Likewise, appropriate resourcing and commitment is required.

Successful wildlife disease management is possible when scientists (e.g. ecologists, biologists, modellers, pathologists, virologists, and toxicologists) and practitioners (e.g. public and private land managers, veterinarians) participate together in formulating and implementing management plans with clearly stated goals and objectives. For example, ecologists can provide information on the ecology of the species of concern and the options for targeting risk factors as part of management. Veterinarians have knowledge of specific treatments that could be applied. The two together will have a much better chance of developing potential options for control or management. For endangered species, recovery teams offer a strong operating environment for control options to be developed. The participation of other local stakeholders, including wildlife care groups, Indigenous interest groups and other community groups is strongly encouraged for all disease management programs.

Some disease management programs may require long-term and ongoing intervention to create sustainable change.

In general, a successful wildlife disease management program requires:

- sufficient resources
- cross-disciplinary expertise
- a collaborative approach
- baseline and ecological information
- measurements before, during and after
- monitoring and evaluation of the program
- a unified approach with clear, agreed goal, aims and objectives
- leadership, coordination, a clear idea of control and command.

9. What are the *objectives* of the wildlife disease management program? Objectives need to be clearly articulated and agreed upon, including quantification of outcomes. For example, an objective of “Decreasing the incidence of paspalum staggers in wild eastern grey kangaroo populations in the district of Malvern in south east Victoria to one episode each five years involving no more than 20 adult animals each time” is a clearer and more effective objective to work towards than “To try and do something about the sick kangaroos”. There may be more than one objective, and they may not relate to disease prevalence, incidence or other measures used to assess the amount of disease or impact on a population. For example, a secondary objective may be to: “Ensure that there is no public outcry associated with paspalum staggers in wild eastern grey kangaroo populations in the district of Malvern in south east Victoria”. Despite meeting the disease management objective, this objective may not be met, and a reassessment of one or both of the objectives and the definition of success (next point) may be necessary.

10. **What is the *definition of success* for the program?** A clear definition of success is required; this unites and provides focus. It provides a benchmark against which progress can be determined, monitored and assessed. This also allows for "cut-offs" and "triggers" to be set and endpoints and an exit strategy to be determined. The ability to transition from one form of management to another or increase management effort is facilitated by a clear definition of success. A definition of success is usually based on the objectives of the program, however "success" may not mean that all objectives have been reached. Clearly articulated "trigger points" may also prompt the need to review and possibly modify the management plan and its objectives (see "Monitoring and evaluation" below).

11. **What is the *likelihood* of success?** It is important to have a realistic estimate of the likelihood of success if the program is instituted. If the likelihood of success is very high, then there will be more enthusiasm for intervention. A low likelihood of success does not necessarily mean that no action should be taken, but rather that the objectives need to be adjusted to better reflect the reality of the situation, or that more resources may need to be made available to increase the activities of the program and hence improve the likelihood of success. A strategic risk assessment should include an evaluation of the likelihood of certain outcomes, or overall success.

12. **Are there clear steps for *monitoring and evaluation* of the program, and for an ongoing iterative process?** It is vitally important to have processes in place to monitor change over time, so it can be seen how the program is progressing and whether objectives and targets are being met. The program needs to be regularly evaluated. This may include third party or external audits or reviews. An iterative approach (reappraising the methods of the program as new information or results become available) is essential for best outcomes. Aims and objectives of the program should be SMART: specific, measurable, achievable, realistic and timely.

13. **Is there a clear communication strategy?** Communication is key to successful disease management programs. This includes communication within the disease management group and most importantly, communication to external stakeholders such as land-owners, wildlife rehabilitation groups, animal rights advocates, politicians, the media and the general public. A failure to appropriately communicate with stakeholders, or an inability to acknowledge their concerns, can lead to failure of a wildlife disease management project. Social scientists and professional communicators are generally required to assist in development of communication strategies, as they will have a far better understanding of what people need to hear, and how best to communicate it, than those with a traditional scientific background.

14. **What is the *endpoint* of the program, who decides this and how?** Identification of an endpoint allows for completion of the program. Resources are always limited and activity cannot occur indefinitely. It is important to understand who holds the responsibility for setting the endpoint of the program, and how this is to be determined. Common scenarios driving completion of a management intervention include when objectives have been met; when funds run out; when it is realised that costs outweigh benefits, or community support or political will is lost.

15. **Is there an *exit strategy* and what is the trigger for initiating it?** It is essential that an exit strategy be identified at the beginning of any disease management program. An exit strategy allows the program to be wound down in a controlled and planned way. An iterative approach can be used to finesse the exit strategy as the management intervention progresses.

    An exit strategy may be triggered when success is reached for the program, or when a decision is made that the objectives (initial or modified) cannot be met.

16. **Who are the *beneficiaries*, who is *responsible*, and who will pay?** Finding secure ongoing funding and resources for wildlife interventions can be very challenging. Determining who are the beneficiaries and who is responsible will help to determine possible funding sources and will also assist in effective stakeholder engagement, planning and sustainability. In many wildlife cases it is ultimately the public who are likely to benefit (albeit indirectly) from wildlife disease management.

17. **Has the proposed approach been objectively reviewed and has the plan been well considered from all angles?** A feasibility check helps to focus on what, exactly, is the problem that is being managed and what realistically can be done to improve the situation. For many wildlife disease management programs this can be best addressed by answering the question "What is the minimum we need to achieve and can we support this in the medium to long term?"

In all cases, the people responsible for wildlife disease management are encouraged to consult with professional wildlife disease managers and others with expertise and experience in this area when developing a management plan. Strategic risk assessment and analysis of available options will help decision-making.

Section 3

Approaches to disease management in wildlife

Disease management should be considered first and foremost from an ecological perspective, with an understanding of the role that disease plays in ecosystems. It is important to have an understanding of:

- the **causation and ecology of the disease** in question
- the **course of the disease** in the individual
- the **population biology of the host and disease agent (and vector)**.

Triggers for considering wildlife disease management include:

- a disease with the potential to negatively impact a wildlife colony, population or species
- risks to the ecosystem or biodiversity
- zoonotic disease risk
- disease risk to domestic animals
- disease risk to wildlife species or populations which are considered beneficial to humans
- animal welfare concerns
- societal expectations and political decisions.

Sometimes there will be a need to manage disease due to concerns for the welfare impact on individual animals, regardless of whether a wider ecological (or other) impact from disease is considered likely.

Decisions around wildlife disease management should be made through a collaborative process drawing on the expertise and opinions of a range of people, including:

- **scientists** (e.g. ecologists [ecosystem and disease], biologists, disease and population modellers, pathologists, virologists, epidemiologists and toxicologists)
- **practitioners** (e.g. managers, agriculturalists, veterinarians, social scientists, public health professionals, communicators)
- **community** and other **stakeholders**.

A management intervention should only occur under the direction of the responsible authority. Ideally, all participants should have their roles identified and agreed. Inclusion of a diversity of groups when formulating and implementing management plans can significantly improve the effectiveness of an intervention. A strategic risk assessment will help decide on the best disease management option to be deployed (see also Section 1).

Communication is key to successful disease management programs. This includes communication within the disease management group and communication to external stakeholders (see Section 2).

The four commonly used approaches to disease management are prevention, eradication, control and “watch and see” (sometimes called “do nothing” or “laissez faire”). The overall objective of disease management is to decrease the impact of the disease. It is important to recognise that in wildlife management, there may be a lack of effective options, tools or tactics to enable effective control and eradication of disease.

Key points:

- the suitability of the approach will vary depending on the particular circumstances
- there will be different considerations for managing endemic disease or an exotic disease incursion.

  For example:
  - prevention may be preferred to protect a population which is free of a particular disease
  - eradication may be the preferred option for the first occurrence of an exotic, emergency disease
  - control may be selected for an endemic disease for which effective management options are available
  - for a common, low prevalence disease, with few impacts, or a disease which might be expected to "burn out" based on its epidemiology, or persist with low impact, a "watch and see" option may be selected
- the most cost-effective approach is prevention
- communication (both within the program and to external stakeholders) is a key component of any disease management undertaking
- ideally a decision should be made on the approach/strategy **before** management measures are put in place. However, in many instances (e.g. an emergence of a novel disease, or arrival of a foreign disease), interim management measures (e.g. risk reduction measures such as movement controls) may be put in place while a more considered management strategy is developed.

Prior to any intervention, consideration should also be given to any unintended consequences (see Section 1).

3.1 Prevention (proactive)

Definition: "All those measures designed to exclude or prevent the introduction of disease into unaffected individual animals within a population or into an unaffected population" (Wobeser 2002).

Options include:

- stopping the infection or disease from entering into an area (options include quarantine, zoning and or movement controls)
- stopping infection or disease from occurring at an individual animal level (options include vaccination and any techniques that decrease infection and transmission between individuals, including biosecurity practices such as hygiene and disinfection).

Advantages:

- stopping the infection or disease from occurring in a new individual or entering into a new area is considered to be the most important, easiest and most cost-effective method of disease management
- **general** biosecurity[8] or disease prevention practices can be followed, as a precautionary measure, even when there is no specific information on disease presence.

8 See National Wildlife Biosecurity Guidelines, section 5.1 "Basic biosecurity practices".

Disadvantages/challenges:

- relies on a baseline knowledge of the absence or presence of disease, which in turn requires an investment in surveillance and research activities
- most useful if the disease is not already present (but can be used to minimise further spread or impacts)
- general disease prevention principles will only go so far; in most cases you will need to apply risk management measures that are **specific** to the disease in question
- a desire to stop introduction of disease can result in a very low risk-appetite for any action, which may in turn have consequences (e.g. a decision not to undertake conservation translocations could affect species survival)
- Proving that prevention was, and continues to be, necessary is difficult, with a possible loss of motivation and funding over time. Willingness to spend money on preventative measures wanes over time, especially and paradoxically, if no new disease arrives or spreads.

Key messages:

- "Think before you act": Prevention is the most cost effective and easiest method of disease management
- communicating the importance and objective of a preventative program to all involved is key to a successful outcome
- the more detailed the knowledge, the more effective the prevention
- "The most important method of management of disease of wild animals is by restricting translocation of wild animals to prevent the movement of disease" (Wobeser 2002)
- general biosecurity practices (hygiene and disinfection) should **always** be followed when humans interact with wildlife (either directly – e.g. animal handling or indirectly – e.g. offering food to birds in the garden)
- do not translocate wildlife without first performing a disease risk assessment (see Section 1). If wildlife is to be translocated, appropriate risk management strategies need to be put in place **and** the health of the populations monitored afterwards.

3.2 Control (reactive)

Definition: "Activities designed to reduce the frequency of occurrence or the effects of an existing disease within an individual animal or a population to an acceptable or tolerable level, or to contain the spatial spread of infection" (Wobeser 2002).

Options include:

- manipulation of one or more of **four** factors contributing to the presence or persistence of disease in a population (discussed in detail in the next section):
  - **disease agent** (e.g. removing the agent from the environment; altering the disease agent)
  - **hosts**, recognising that disease may involve multiple different hosts, including reservoirs, spillover and dead-end hosts (e.g. medical treatment, vaccination or genetic manipulation of the host; culling)
  - **environment** or **habitat**
  - **human activities** (e.g. addressing factors that may facilitate disease presence or transmission and spread).

Advantages:

- the most flexible approach, with the most options available
- can be applied (in some form) to almost all existing wildlife disease situations
- is generally sufficient to achieve the desired outcomes, for most diseases, when compared to eradication
- in many cases, control will be the most publicly acceptable option (with the exception of culling).

Disadvantages/challenges:

- some level of disease will persist in the population (which may be appropriate)
- information may be lacking on the effectiveness of control options
- control measures (e.g. treatment, vaccination) may be difficult to apply to free-ranging animals
- often requires long-term commitment as repeated interventions and control measures (including monitoring disease) will have to be continued in perpetuity, in most cases
- may be the most expensive option, when costs are measured over the long term
- if culling is a potential action, public opinion may limit the viability of this option.

Key messages:

- control is generally the most acceptable option, but requires ongoing commitment and may be the most expensive option
- communication is key to maintaining ongoing commitment from all parties
- measurable targets and ongoing monitoring of progress are vital.

3.3 Eradication (reactive)

Definition: Eradication technically means getting rid of the infectious agent completely, as in global eradication (e.g. smallpox, rinderpest) (Wobeser 2002). However, most people understand it to mean “eradication from a population or a geographic area”. The techniques available will generally be the same as those used for control but extended to ensure the total elimination of the disease from the population or area of interest.

Options include:

- all the options for control of disease in wildlife.

Advantages:

- it is generally a **permanent** solution to the problem, if done correctly and post-eradication prevention is maintained; after this, the effort of control is no longer needed
- if the decision to eradicate is made early in the course of a “new” disease, it can be more cost-effective than the option of control.

Disadvantages/challenges:

- a large, long-term investment of time and resources is often required
- it is generally much more costly than control
- in many cases, eradication is neither necessary nor cost effective
- disease management is generally more complex in eradication than in control; there may be a need to focus on different “links in the disease ecology chain” to those targeted during a control program

- generally, only suitable for exotic diseases or diseases with a significant public health or social impact
- may require management practices (e.g. depopulation) that are socially or legally unacceptable
- generally requires intensive long-term surveillance post-eradication to ensure eradication has been complete
- there may be no effective means by which to achieve eradication in wildlife, even when desirable.

Key messages:

- eradication should always be considered as an option
- effective communication is necessary to build stakeholder understanding and support for programs that involve culling or other potentially unpopular methods
- eradication of disease is difficult to achieve in practice, may not be necessary and control is often the preferred approach.

3.4 "Watch and see" (non-reactive)

Definition: "Not attempting active management" (Wobeser 2002). It is sometimes termed a "do nothing" or "laissez faire" approach. In order for a "watch and see" option to be acceptable, it should always include aspects of ongoing monitoring to ensure that any changes in disease ecology or expression, which might necessitate more active intervention, are detected in a timely fashion. Triggers for intervention should be established as part of the decision to adopt a "watch and see" approach.

Options include:

- no active management of disease, but ideally will include ongoing monitoring of the disease situation.

Advantages:

- "Watch and see" is a suitable option for many situations, especially if it has been identified that disease occurs naturally, with low level impacts, or there is little confidence that intervention will produce the desired effect.

Disadvantages/challenges:

- an effective communication strategy will be required to explain why this approach is being adopted as there may be significant public pressure, with a public expectation that "something must be done"
- it may be the only possible option, even if management is desirable, because of a lack of effective options for control (see Section 2: Is management feasible?)
- long-term monitoring of disease and populations will be required.

Key messages:

- "wait and see" is a suitable option for many situations, including those where disease is naturally occurring or has little impact, or where attempts to manage disease may bring unexpected consequences such as increased transmission of disease through disruption of social networks
- a communication plan is necessary to ensure all understand and accept the approach
- ideally this option should be linked to ongoing disease monitoring and a pre-agreed plan of when and how intervention might be required if the circumstances change and over the longer term, if research reveals new understandings of disease ecology and epidemiology
- a "wait and see" approach can have consequences for spread of disease through a population, biomagnification and bioaccumulation of environmental contaminants, and movement of disease into new areas and new hosts.

Section 4

Options for management of disease in wildlife

"What can actually be done?"

- different types of disease will require the use of different disease management options
- a combination of management options may be used (concurrently or sequentially) in a disease management program and may achieve greater success than the use of a single option.

Most wildlife disease management frameworks focus on targeting the:

- disease (or causative agent) or its vector (4.1)
- host or hosts (4.2)
- environment or habitat (4.3)
- human activities (4.4).

4.1 Targeting the causative agent (or its vector)

The overall aim is to reduce transmission of the infection or to reduce the presence of non-infectious disease in order to limit, decrease or prevent exposure.

Options include **targeting the causative agent of disease** either:

- within the affected host or hosts (4.1.1)
- free in the environment or (4.1.2)
- within a vector, reservoir or carrier animal (4.1.3).

A combination of these options may be used.

Targeting the causative agent of *infectious* diseases

The more potential sources there are for an infectious agent, the harder it is to control or eradicate.

When would you use the method of targeting the causative agent (in general)?

- if there is only one known vertebrate host (e.g. *Chlamydia* in koalas)
- if transmission is limited to some identifiable part of the external environment (e.g. a harmful algal bloom)
- when you have a tool that can specifically target the causative agent (i.e. an effective antimicrobial agent)
- if the disease is non-infectious e.g. due to a biological or chemical toxin or an environmental contaminant; removing carcasses of birds affected by botulism to remove the causative agent (botulinum toxin) from the environment.

Challenges and disadvantages of targeting the causative agent (in general)

- less likely to be an effective strategy if there is more than one potential source of the causative agent (e.g. ongoing spillover of an infectious disease from feral species into a native wildlife species [sarcoptic mange])
- less likely to be effective if the disease is widespread.

Non-infectious agents (e.g. toxins) can sometimes be more easily controlled than infectious agents. They generally do not replicate or increase in the environment and there is a finite amount of time that a non-infectious agent can persist (although some may persist for a very long time). For most non-infectious agents, if you remove the source, or exposure to it, the disease should die out.

4.1.1 Targeting the causative agent within the host ("medicating wildlife")

This option involves treatment of the host with a product that will kill or inactivate the agent of disease. The aim is to reduce the duration and/or intensity of the infectious period and reduce the number of infectious individuals present at a particular time, or diminish the welfare impacts on the individual animal.

This option focuses on medicating wildlife and includes:

- use of an antiparasitic (to kill parasites in or on the host)
- use of an antibiotic (to kill or inactivate bacteria in the host)
- use of a medication to reduce the effects of a toxin or contaminant.

Examples from the Australian context:

- use of a topical antiparasitic effective against mites to target sarcoptic mange in free-living wombats
- use of antifungal medication to treat hand-raised macropods with fungal skin disease (ringworm)
- use of an antiparasitic to treat free-living juvenile Australian sealions for hookworm infection
- use of a binding agent to reduce the effects of heavy metal intoxication in birds.

Advantages of using this method:

- non-lethal to host (except for rare and unintentional instances)
- less impact on host than some other non-lethal options
- if targeted to individual (e.g. directly medicate individual), then less chance of impact on non-target species
- in most cases, no need to isolate host for an extended period
- more ethically acceptable (for both the practitioner and general public) than many other alternatives
- generally, improves individual animal welfare (although if handling is required for treatment this may result in physiological stress)
- if animal captured and restrained for this process, it is an opportunity to check general health, collect samples and data, mark the animal and check or test for other issues of concern in the individual.

Main problems/challenges:

- practical application; effective delivery of drug to sufficient numbers of wild animals (to achieve an effective outcome) is difficult
- costs are generally high
- use of drugs (antiparasitics and antibiotics) are generally limited to small numbers or localised situations, due to logistics
- there are limited means of drug delivery for wildlife and each one (e.g. oral, topical, parenteral) has challenges
- treatment may need to be indiscriminate, or applied to all, as specific treatment of affected individuals may not be possible for logistical reasons
- generally, requires use of regulated drugs. Official permission may be required to use these medications in the species and situation at hand. Most drugs are not registered for use in wildlife however off-label use by veterinarians is considered permissible (with conditions) in Australia. Use of Schedule 4 drugs by non-veterinarians must occur under authority of a registered veterinarian
- potential of side effects of drugs on the individual animal
- residues of drugs in the ecosystem, including on predators (see below)
- potential development of antimicrobial resistance or other drug resistance
- potential toxicity from drug in both target and non-target recipients. It is more difficult in wild animals than in livestock to manage delivery of drug treatments and manage which individuals receive a treatment, how much and how often. There is lower risk in situation where a wild animal is temporarily brought into care for treatment
- the effectiveness of treatment can be difficult to predict – firstly because there may not be detailed data on how the drugs work, and effective doses for most wildlife species may not be known and secondly because it is not possible to accurately predict all the effects and consequences in a complex uncontrolled ecosystem
- there are biosecurity risks in bringing wild animals into care for treatment (they may acquire or spread infections to other animals or humans, and there is a chance that new infections could be released back into wild populations) and in attempting treatment in the wild (i.e. equipment used to delivery medication in the field may act as a pathway to transmit infection between wild animals[9])
- the disease may have already damaged the host and the impact may continue even if the agent of disease is removed (e.g. skeletal and dental disease in macropods after chronic exposure to fluoride in the environment[10])
- in general, the ecological consequences of wildlife medication remain poorly understood and there have been few attempts at mass treatment of wildlife.

9 See National Wildlife Biosecurity Guidelines (www.wildlifehealthaustralia.com.au/Portals/0/Documents/ProgramProjects/National_Wildlife_Biosecurity_Guidelines.PDF)

10 See WHA Fact Sheet "Fluorosis in Australian Wildlife"

When and why would you use this method of disease management?

The option of targeting the causative agent of disease is most likely to be useful for small populations of threatened or vulnerable wildlife species, when there are no other practical options available. It may be the management option of choice if there is a zoonotic disease risk. This technique may be used during wildlife rehabilitation, temporary care or as a part of disease risk management during conservation translocations.

There needs to be an effective method of treatment. It is also desirable to have situations where:

- "one-off" treatment is going to be effective
- risk of toxicity or non-target dosing is low
- the host develops some natural resistance to reinfection or chances of reinfection are low.

4.1.2 Targeting the causative agent in the environment (outside the host)

This option involves removing, inactivating or killing the causative agent of disease **in the environment,** to prevent infection of the host. This option can be used for both infectious agents and non-infectious agents, as long as they can be accessed within the environment.

This option includes:

- **removal** of a non-infectious disease agent e.g. remove a toxin (e.g. lead) from the environment
- **removal of carcasses** that contain a disease agent (e.g. botulinum toxin, secondary rodenticide toxicity)
- **disinfection or removal of substrates** and items, e.g.
  - disinfect soil to kill parasite eggs or pathogen
  - sterilise or disinfect water sources or other items such as nest boxes or feeding areas with chemical disinfectants to kill a virus or bacteria
- **directly manipulating a free-living agent of disease** within the environment
  - sterile insect release (e.g. for screw-worm fly control).

Examples from the Australian context:

- removing carcasses of wild birds that have died from botulism from a waterbody, to decrease the available substrate for proliferation of the Clostridial bacteria and the botulinum toxin
- long-term plan to remove free lead from the environment by introducing lead-free petrol
- cleaning and chemical disinfection of feed tables and nest boxes in the orange-bellied parrot management program, to kill beak and feather disease virus and other infectious agents.

Advantages of using this method:

- removes the source of the problem
- no direct impact on the host
- may be able to use chemicals or methods on the environment that would be toxic if used on a living entity
- may be relevant for both infectious and non-infectious agents
- may have general biosecurity benefits beyond the specific agent of disease in question (keeping things clean).

Main problems/challenges:

- only effective if the infectious agent or toxin is present in the environment in appreciable amounts
- **disinfection and use of pesticides** in the environment are practically limited to localised situations and small areas
- use of chemical disinfectants and other treatments can have serious environmental effects and may result in acquired drug resistance
- **physically removing** carcasses or toxins is logistically difficult and resource intensive (e.g. intensive human labour required) and it may be difficult to locate and remove carcasses or sources of toxin. Additionally, it may be difficult to safely and effectively dispose of carcass/toxin and there may be human health and safety issues with exposure to disease agents (including toxins).

When and why would you use this method of disease management?

- when there is a clear link between presence of carcass/toxin and disease
- when there are large numbers of carcasses, easily retrievable and disposable
- when close to human facilities, so that remote access is not a problem
- when motivated by concern from the community
- in situations where wild animals are concentrated at higher densities.

Most likely to be useful for:

- small areas
- as one part of a wider disease management plan
- during the acute phase of a disease outbreak
- situations where the ecology of the disease indicates this will be appropriate.

4.1.3 Attacking the infectious agent in a third party (vector, reservoir or other carrier)

Vector: a living organism (generally arthropods) that transmit an infectious agent from one vertebrate host to another.

Vectors (often insects) can play an important role in the spread of a disease, both temporally and spatially (e.g. overwintering and moving into new geographic zones). It is important to have knowledge of key aspects (e.g. if vector disease transmission is mechanical or biological; if the vector is a facultative or obligatory part of transmission) before assessing vector control as part of a disease management plan.

Reservoir host: a species which can harbour a pathogen indefinitely with no ill effects.

Carrier: a human or animal which harbours a pathogen in its body without manifesting signs of disease, thus acting as a potential source or distributor of infection.

Manipulation of a third party aims to reduce the exposure of the host to the vector, reservoir or carrier and hence to the disease agent. The population of the vector or reservoir may be reduced or eradicated or the infectious agent may be eliminated from within the vector or reservoir.

There are few examples of attempts to control vectors in wildlife disease management. Global examples in zoonotic disease management include manipulation of mosquitoes to control malaria (vector), manipulation of rodents to control bubonic plague and vaccination of foxes to control terrestrial rabies.

This option includes:

- managing a vector through activities such as:
  - clearing vegetation so that flies can't survive and multiply (tsetse fly)
  - removing standing water or treating water bodies so that mosquitoes can't breed
  - prescribed burning of vegetation to reduce tick populations
  - treating a host with an antiparasitic so a tick or mosquito or other vector doesn't bite them
  - emerging biocontrol approaches such as introduction of a predator of the vector; sterile or genetically manipulated vectors
- managing another infected host (carrier or reservoir, non-target host etc.).

Specific examples from Australian context:

- release of sterile/*Wolbachia*-infected mosquitoes in Qld to reduce risk of dengue-fever (a mosquito-borne disease).

Advantages of using this method:

- non-damaging to the host of concern
- often much less social concern around destruction of insects or feral or pest species.

Main problems/challenges:

- chemical control of insect vectors may have wide-ranging negative effects on environment
- acquired resistance of vector to chemical control can occur rapidly.

When and why would you use this method of disease management?

- chemicals to control vectors are likely only to be used in localised areas in a very specific manner
- chemicals are best used in combination with other methods of vector control such as environmental manipulation and biological controls
- may also be applied to control of vertebrate carriers and reservoirs.

Most likely to be useful for:

- diseases where vectors and or reservoirs/carriers play an important and vital role in disease transmission or persistence
- situations where the role of vectors or reservoirs is well understood
- situations where it is more cost effective/feasible/acceptable to attack a vector or other host than the main host of interest
- situations where multiple actions are undertaken either concurrently or in series, to control the disease.

4.2 Targeting the hosts

Targeting the host is the most **commonly used** method to manage disease in wildlife.

This option includes:

- vaccination of the host(s) (4.2.1)
- altering host distribution or density (4.2.2)
- extirpating the host(s) (4.2.3)
- genetic, physiological or immunological manipulation of the host(s) (other than vaccination) (4.2.4)

4.2.1 Vaccination or immunisation

Immunisation or vaccination makes the individual resistant to the infectious agent by stimulating a specific host immune response to the disease agent, prior to infection. In theory, vaccination should be a useful method for infectious disease management in wildlife. In reality, effective vaccination of wildlife is difficult, either because there are no effective vaccines for the disease and host in question or because there are no effective methods for delivery of the vaccine.

Vaccination may serve a primary purpose of:

- protecting the individual from disease, or reducing the impact of infection on the individual
- reducing transmission (and multiplication) of the disease agent.

Most vaccination programs are aimed at reducing transmission and protecting the individual; some only focus on protecting the individual (Wobeser 2002). There are limited examples of successful mass immunisation of wildlife, mainly with oral bait vaccines (e.g. oral vaccination of badgers for bovine tuberculosis in the UK (Gormley et al. 2017) and rabies vaccination; see Appendix A).

Vaccination of a domestic animal species may be used to manage disease risk with some zoonotic diseases of wildlife origin, if there is an intermediate domestic animal host. For example, vaccination of Australian horses for Hendra virus (a virus carried by flying-foxes which can cause disease in horses, and also can be transmitted from horses to humans); and vaccination of domestic dogs for rabies in areas where wildlife species carry rabies; vaccination of domestic dogs is both to protect dogs from disease and also to reduce the risk that the infected dog may pass the virus on to a human.

Advantages of using this method:

- one of the most effective ways of controlling infectious disease (if can be delivered and available)
- generally non-toxic and low impact on the host, therefore socially acceptable
- low impact to non-target species if they receive the vaccination in error
- not all individuals need to be vaccinated to achieve population level disease control ("herd health" effect)
- possibility to deliver remotely and across large geographic areas, depending on delivery system
- long lasting (possibly life-long) effectiveness for individual.

Main problems/challenges:

- very limited availability of appropriate vaccines for wildlife disease (but likely to increase with new technologies and research)
- expense and difficulty in developing appropriate vaccines
- only some types of infectious agents are suitable for vaccine production (viruses, some bacteria and some parasites)
- difficulties in effective delivery of vaccines to wildlife populations; programs are therefore expensive
- hampered if there is a lack of knowledge of distribution and density of wildlife hosts
- uptake by non-target species, if remote delivery, may reduce availability of vaccine for target host
- some vaccines are not fully protective i.e. vaccinated animals may not develop clinical disease, but can still become infected and transmit the pathogen to other animals
- vaccine programs may not reduce the transmission rate across the wider ecosystem, if target hosts are not a necessary part of the disease cycle.

When and why would you use this method of disease management?

- if a safe and effective vaccine, with an effective delivery method, is available for the disease and wildlife species in question
- to prevent a specific disease from developing in a valuable group of animals.

Most likely to be useful for:

- disease agents such as viruses and bacteria with a low reproductive rate, in a long-lived host population.

4.2.2 Altering the host density or distribution

This option aims to alter the host density or distribution, thereby reducing the rate of contact between infected and non-infected hosts and the resulting disease transmission rate. Methods used include:

- dispersing hosts
- controlling host movement ("movement control")
- controlling contact between hosts (if infectious disease)
- culling the host
- controlling the reproductive rate of the host.

Dispersal means to drive or force animals away in different directions. It is generally used with the aim of reducing host density or removing host clustering from a particular area of focus (e.g. waterbody, feeding area, nest site etc.). In the past, the technique of dispersal for wildlife disease control has been primarily used for birds (e.g. avian influenza outbreak etc.). Dispersal is generally **not** recommended for infectious disease situations as the result will be to spread the host and pathogen through a wider geographic area. It may be of use in non-infectious disease situations, e.g. avian botulism outbreak or to remove animals from the site of toxic exposure (e.g. a toxic plant).

It is generally difficult to control the movement of wild animals. Efforts at relocation may be fruitless if the animals are able to return to the original location. Most techniques to discourage wild animals from entering an area rapidly become ineffective (Wobeser 2002).

Movement control means to stop the movement (often human-assisted, such as translocation or shipping) of animals, with the aim of stopping or reducing disease spread.

Methods include:

- fencing
- scaring off
- attracting animals elsewhere
- not allowing harvested wildlife carcasses to be shipped from one area to another.

Examples in the Australian situation:

- encouraging free-ranging kangaroos to move away from a pasture where they are grazing on toxic plants
- fencing off areas with high fluoride contamination of water and vegetation, to protect free-living wildlife from excessive consumption of fluoride.

Advantages:

- non-lethal to host
- generally has less impact on host compared to other techniques.

Disadvantages/challenges:

- difficult to control the movement of wild animals
- should only be used if disease is a result of a non-infectious agent
- animals may become physiologically stressed by dispersal efforts, change or loss of habitat
- techniques may become rapidly ineffective (animals avoid or become habituated).

Most likely to be useful for:

- short term solution in species that are not highly territorial
- non infectious diseases.

Culling means killing the host with the aim of reducing the host density, generally to below a level where the disease doesn't continue to spread. The aim may be simply to reduce the host density to a level so that disease spillover to humans or domestic animals reduces or ceases.

Culling may also involve complete eradication of the host from a location, particularly if it is an introduced species, or is within a contained area (e.g. island) or has a restricted distribution. [For complete eradication see "Extirpating the host"].

Culling is a well-established technique for managing significant diseases in domestic animals (e.g. highly pathogenic avian influenza, African swine fever) however there are more challenges when used in wildlife where the situation is often less contained and more complex. In these situations, culling is more difficult and costly to achieve and may not be an effective method of disease control, depending on the ecology of the disease in question. Disease modelling to better understand the likely impact of culling is strongly recommended prior to any actions being taken.

Culling is easier and more effective in domestic animals as all animals can be caught, sampled, tested and selectively culled if needed, based on their disease status. **Selective culling** means removal of the subset of infected or shedding hosts. Each animal may only need to be handled once (depending on how the disease status is to be determined) and the effect (death and removal from the population) is **immediate** and **permanent**. In wildlife, selective culling can only happen when affected individuals are readily identifiable.

Culling methods include:

- hunting (generally shooting) – more targeted and specific
- trapping (including snaring)
- gassing – flooding confined areas such as underground systems or caves with poisonous gas (e.g. for badgers, foxes, rabbits and bats)
- poisoning – non-target risks, mostly indiscriminate focus but some programs can be made highly specific with lures and baits that are attractive or accessible primarily to target species.

Advantages:

- generally, a fast and effective method of reducing host density and disease spread, in particular if selective culling can be used
- can be very effective if selective culling is used, or culling around a point of focus, or to create a barrier for control of disease movement
- may also reduce concurrent stresses in an overpopulated area.

Disadvantages:

- ecological consequences of altering host population size and density
- negative public opinion; killing wildlife is ethically unacceptable in many cases
- difficulties with logistics including disposal of carcasses
- likely to be ineffective if disease transmission relies on how frequently hosts come into contact, rather than the density of the host population.
- genetic and population level impacts on endangered/listed species
- there may be a lack of humane techniques
- non-selective culling is temporary and often has limited success in achieving disease control
- selective culling may have negative effects e.g. removal of animals with tolerance to the disease
- need for clear objectives and well-defined progress measures; these are often missing when culling is used to manage disease in wildlife.

Examples from the Australian situation:

- Tasmanian devil facial tumour (TDFT) control program (Lachish et al. 2010).
- reducing water buffalo populations in the NT as an aid to bovine brucellosis and tuberculosis control program (Cousins and Roberts 2001).

Most likely to be used for:

- host species which are easily caught or easily euthanased by remote methods (shooting, poisoning)
- for selective culling, where disease is readily identifiable once the host is “in the hand”
- density-dependent transmissible diseases which are not easily treatable
- situations where overpopulation is placing other concurrent stresses on the wildlife population (e.g. territorial fighting, insufficient food resources)
- feral, pest or unpopular host species.

4.2.3 Extirpating the host

Extirpation means local extinction, or to remove or do away with totally.

Specific examples from a wildlife context:

- extirpation of reindeer from Nordfjella (a specific region of Norway) by the Norwegian Environment Agency, to eliminate Chronic Wasting Disease and the chance of it spreading to other reindeer herds in Scandinavia www.regjeringen.no/en/aktuelt/skrantesjuke-alle-kjente-dyr-felt-i-nordfjella/id2591233.

Advantages of using this method:

- gets rid of the problem in the area.

Main problems/challenges:

- socially unacceptable in most cases – involves both culling **and** complete extirpation of a host, which can be controversial
- a strong communication plan will be required
- difficult to completely extirpate a host
- generally, not desirable if the host is a wildlife species.

When and why would you use this method of disease management?

- if the host is a reservoir or carrier of the disease agent.

Most likely to be useful for:

- "one-off" situation where a significant disease has been detected, and where "live" treatment or control options are not available
- situations where an isolated population is positive for a disease but populations elsewhere are disease-free.

4.2.4 Genetic manipulation of the host

Changes in genetics of host population as a result of disease can occur naturally, without direct human intervention. For example, European rabbit populations evolved (changed genetics) to become more resistant to myxomatosis after the widespread release of the virus in Australia as a biological control mechanism. In this section, only genetic change or manipulation that occurs via some form of human intervention or management process is addressed (Spielman et al. 2004a; Spielman et al. 2004b).

There are two mechanisms by which this can occur:

- **general** efforts to improve the overall genetic diversity of the host population, because poorer genetic diversity equates to lower "fitness" in general, including lower resilience to disease processes across the population
- **specific** efforts to change the genetic make-up of individuals so that they become more resilient or resistant to the infectious agent in question (Carter et al. 2009; Champer et al. 2016; Kosch et al. 2018). This includes engineered gene drives, or the process of stimulating the biased inheritance of specific genes. These mechanisms may also be applied to the disease agent, rendering it less infectious or less virulent, for example.

Specific examples from Australian context:

- attempts to improve resistance of Australian frogs to chytrid fungus by selective breeding and/or genetic engineering for resistance genes. For example, association of the MHC class II beta 1 domain with survival in some frogs challenged with chytrid infection (Skerratt 2019).
- suggested selective breeding of Tasmanian devils who are "resistant" to DFTD, although not considered successful (McCallum 2008).

Advantages of using this method:

- longer term or even permanent solution
- overall improving the health and welfare of individual animals
- generally, improving the resilience or functionality of the population or species may make them more resistant to future disease challenges
- may also improve the overall health of the ecosystem.

Main problems/challenges:

- the existing scientific knowledge or technology for specific genetic manipulations is not yet available, although advancing rapidly
- even general improvements in genetic diversity can be challenging to achieve in practical terms. They require either a detailed studbook including founder details, or detailed genetic fingerprinting of individuals. In most cases, when studbooks are developed, many assumptions are made about founder relationships, which may not be valid, and may skew practical outcomes or unnecessarily limit success
- traits can be controlled by few or many genes – in most cases in wildlife this knowledge is not available
- may take a long time to see effects
- there may be stakeholder resistance to the adoption of new technologies, especially those involving genetic manipulation, and communication will be required to clearly outline the benefits and dispel any misconceptions or fears
- there may be unintended consequences of genetic manipulation.

When and why would you use this method of disease management?

- anytime, to assist in general species, individual and ecosystem resilience
- every time you are working with small numbers of individuals, in a managed environment (and a population biologist should be included in the team)
- if you have the underlying knowledge of the genetic traits which need to be manipulated, and the technology to do so.

Most likely to be useful for:

- endangered species in managed situations
- when there is technology available to support genetic manipulation
- when it is known that a genetic effect is contributing to disease occurrence
- research-based situations.

Specific genetic manipulation has much potential as a tool for the future, but probably has limited practical application at this stage. General good genetic management should be applied in every case where wildlife are manipulated for any outcome.

4.3 Targeting the environment or habitat

Environments are complex systems in a constant state of flux where changes can influence how disease is expressed. The goal of this option is to identify and rectify any environmental risk factors that might be contributing to disease development, including those that may be affecting the immunocompetence of the host population. Many of the advances in human and domestic animal medicine globally have been due to improvements in the environment (nutrition, safe drinking water, sanitation, adequate shelter). Similarly, improvements in the environment of free-ranging wildlife may result in improvements in overall health and reduction in prevalence of disease.

In addition, disease impacts in free-ranging wildlife should be considered in the context of other threatening processes. Although disease alone does not usually lead to extinction of wildlife species, the contribution of disease impacts to already vulnerable species and populations (suffering from other negative impacts such as habitat degradation, predation, over-harvesting and climate change processes) may push a species to an even more perilous state. While outside the scope of these guidelines, it is always recommended that attention is paid to all factors that might be cumulatively threatening a vulnerable wildlife species or population.

Environment (in this context): the conditions in which the animal and pathogen live, including land, water bodies, natural and man-made structure, substrates and vegetation (Ward et al. 2009).

This option includes management of the environment to improve biophysical conditions:

- improving available nutrition
- improving general environmental sanitation
- improving water quality or availability
- changing other habitat factors to make them preferential for the host.

(Note: Options that are primarily aimed at targeting the host in its environment fall under "targeting the host" (4.2) and options that target the agent in the environment [such as disinfecting food tables to kill the agent or removing carcasses] fall under "targeting the agent" (4.1). For example, actions which target the agent of disease, or a vector, in the environment, are discussed in 4.1.2.)

Actions that target the environment may have significant long-term effects on disease but it is likely to take **much longer** for benefits in this area to be apparent, compared to other actions (manipulating the host or agent of disease directly).

Specific examples from Australian context:

- reducing habitat fragmentation (classification will depend on what the **aim** of this action is)
- removing weeds and noxious plants to allow a healthy natural vegetation and ecosystem to support the inhabitants
- restoring degraded habitat, encouraging habitat corridors and retaining older trees.

Advantages of using this method:

- long-term benefits
- fewer social concerns
- there are likely to be overall benefits for the ecosystem (but see caveats below).

Main problems/challenges:

- relies on a good understanding of ecosystem and host ecology; without this there may be poor success
- hosts may be highly mobile and as a result the effects of environmental manipulation on disease ecology may be unpredictable
- a more adaptable (generalist) host may be less affected by environmental manipulation
- environmental manipulation may have the opposite or other unintended effects e.g. providing food for animals during a drought, to mitigate emaciation and death, may lead to increased opportunities for predation by feral species. Removal of a predator may cause an increase in prey host density and increased disease incidence.
- it can be difficult to work out which environmental variables are best targeted, when attempting disease management.

In general, the principles of an environmental focus are that maintaining a **larger, heterogenous environment** for the host should reduce local densities and most likely reduce contact rates between susceptible and infectious individuals and therefore decrease disease incidence (if disease is density dependent).

Other ways that environment can be used to help manage disease:

- improve overall habitat quality and ecosystem function, which results in improved resources for host (see below)
- improve environmental sources of nutrition so a better nourished host has a better functioning immune system and is less susceptible to disease
- improving shelter and other necessary environmental resources (microclimate, water, opportunities for basking, pelage and skin health maintenance etc.).

However, improvements such as these can also increase host fecundity and survivability which can lead to increases in host density, which can in turn lead to increasing disease prevalence. It is important to always remember that naturally occurring disease is a helpful and essential population regulator for wildlife.

When and why would you use this method of disease management?

- as a support for any other disease management effort
- if there is no feasible option to target the host or the disease agent directly.

Most likely to be useful for:

- situations where habitats are suboptimal and ecosystems are compromised.

4.4 Targeting human activities

In many instances, effective management of disease in wildlife requires a change in human activities. This may include ensuring human activities address disease transmission and hygiene management in general, or more specifically to prevent disease incursions (e.g. undertaking a disease risk assessment prior to a wildlife translocation and then adopting practices to mitigate biosecurity risk; stopping contact between wild and domestic animals), or to help control or eradicate a disease that is already present (e.g. boot cleaning stations for walkers in Tasmanian wilderness areas, to reduce the spread of chytrid fungus on boots).

This option includes:

- encouragement of general biosecurity and hygiene measures such as hand washing and equipment cleaning when working with wildlife, or cleaning water bowls when offering water to wildlife in gardens
- increasing the community awareness and understanding of disease risks for wildlife to drive a change in behaviours e.g. improve hygiene and biosecurity if feeding wildlife birds
- change of human behaviours to reduce the risk of humans transporting parasites or agents of disease across the landscape
- disease risk assessments prior to translocation
- restriction of movement of animals or other biological products
- reducing or stopping release of toxins and environmental contaminants into the ecosystem, or active removal of contaminants already present.

Examples from Australian context:

- educating recreational cavers about risk associated with white-nose syndrome when bringing caving equipment from overseas
- educating horse owners so they change how they manage their horses in Hendra virus risk areas (e.g. vaccination of horses and fencing-off horse paddocks under trees; extending to not clearing winter fruiting trees)
- Bellinger River turtle, management of human activities such as canoeing or fishing (Spencer et al. 2018)
- "Take 3 for the sea" (www.take3.org) aiming to reduce the harmful effects of plastic pollution on wildlife by simple changes in human behaviour
- formal disease risk assessment undertaken prior to translocation and release of wildlife (e.g. Eastern barred bandicoot translocation Disease Risk Analysis[11]).

11 www.cbsg.org/sites/cbsg.org/files/documents/EBB%20Disease%20Risk%20Analysis%20Report%20FINAL.pdf (Jakob-Hoff et al. 2016)

Advantages of using this method:

- an additional way of influencing outcomes by building a sense of engagement, participation and stewardship in the public
- potentially lower cost as both the necessary action and its cost may be borne by the member of the public rather than the authority. However, the authority will need to have an effective program to communicate to the public or interest group.

Main problems/challenges:

- relies on effective human behaviour change, either voluntarily or via regulation/enforcement
- motivating human behaviour change is challenging and generally requires either an incentive or a deterrent in order to be effective, as well as emotional engagement
- need highly skilled social scientists to assist with messaging
- results may be far reaching but are often out of the direct control of the wildlife managers.

When and why would you use this method of disease management?

- when alteration of human activities is likely to have a significant impact on a wildlife disease in free-living populations
- when a highly motivated subgroup of a community is involved.

Most likely to be useful for:

- almost everything!

Appendix A

Examples of wildlife disease management programs globally

Some examples of wildlife disease management programs:

Managing and eradicating wildlife tuberculosis in New Zealand
(Warburton and Livingstone 2015)

"Tuberculosis (TB) due to *Mycobacterium bovis* infection was first identified in brushtail possums (*Trichosurus vulpecula*) in New Zealand in the late 1960s. Since the early 1970s, possums in New Zealand have been controlled as part of an ongoing strategy to manage the disease in livestock. The TB management authority (TBfree New Zealand) currently implements three strategic choices for disease-related possum control: firstly TB eradication in areas selected for eradication of the disease from livestock and wildlife, secondly Free Area Protection in areas in which possums are maintained at low densities, normally along a Vector Risk Area (VRA) boundary, and thirdly Infected Herd Suppression, which includes the remaining parts of VRA where possums are targeted to minimise the infection risk to livestock. Management is primarily through a range of lethal control options. The frequency and intensity of control is driven by a requirement to reduce populations to very low levels (usually to a trap-catch index below 2%), then to hold them at or below this level for 5–10 years to ensure disease eradication. Lethal possum control is implemented using aerial- and ground-based applications, under various regulatory and operational constraints. Extensive research has been undertaken aimed at improving the efficacy and efficiency of control. Aerial applications use sodium fluoroacetate (1080) bait for controlling possums over extensive and rugged areas of forest that are difficult to access by foot. Ground-based control uses a range of toxins (primarily, a potassium cyanide-based product) and traps. In the last 5 years there has been a shift from simple possum population control to the collection of spatial data on possum presence/absence and relative density, using simple possum detection devices using global positioning system-supported data collection tools, with recovery of possum carcasses for diagnostic necropsy. Such data provide information subsequently used in predictive epidemiological models to generate a probability of TB freedom. The strategies for managing TB in New Zealand wildlife now operate on four major principles: firstly a target threshold for possum population reduction is defined and set, secondly an objective methodology is applied for assessing whether target reductions have been achieved, thirdly effective control tools for achieving possum population reductions are used, and fourthly the necessary legislative support is in place to ensure compliance. TBfree New Zealand's possum control programme meets these requirements, providing an excellent example of an effective pest and disease control programme."

This example is included to show that wildlife diseases can spillover and impact on production animals and a country's agricultural economy. It also shows that despite what might appear as a large and insurmountable problem, with good science, appropriate resourcing and long-term commitment, control can be achieved. Clearly set and science-based goals make this an excellent example of a wildlife disease control program.

Mitigating amphibian disease: strategies to maintain wild populations and control chytridiomycosis (Woodhams et al. 2011)

"Rescuing amphibian diversity is an achievable conservation challenge. Disease mitigation is one essential component of population management. Here we assess existing disease mitigation strategies, some in early experimental stages, which focus on the globally emerging chytrid fungus *Batrachochytrium dendrobatidis*. We discuss the precedent for each strategy in systems ranging from agriculture to human medicine, and the outlook for each strategy in terms of research needs and long-term potential.

We find that the effects of exposure to *Batrachochytrium dendrobatidis* occur on a spectrum from transient commensal to lethal pathogen. Management priorities are divided between (1) halting pathogen spread and developing survival assurance colonies, and (2) prophylactic or remedial disease treatment. Epidemiological models of chytridiomycosis suggest that mitigation strategies can control disease without eliminating the pathogen. Ecological ethics guide wildlife disease research, but several ethical questions remain for managing disease in the field.

Because sustainable conservation of amphibians in nature is dependent on long-term population persistence and co-evolution with potentially lethal pathogens, we suggest that disease mitigation not focus exclusively on the elimination or containment of the pathogen, or on the captive breeding of amphibian hosts. Rather, successful disease mitigation must be context specific with epidemiologically informed strategies to manage already infected populations by decreasing pathogenicity and host susceptibility. We propose population level treatments based on three steps: first, identify mechanisms of disease suppression; second, parameterize epizootiological models of disease and population dynamics for testing under semi-natural conditions; and third, begin a process of adaptive management in field trials with natural populations."

This example is included to show that wildlife diseases can have profound and sometimes global impacts on biodiversity. As with the example above, what at first might seem an insurmountable problem can be addressed with a structured and logical approach. It also tells us that for wildlife diseases there are often no simple solutions. An approach of containment and control can be applied to buy time to enable more efficacious strategies to be developed. This may take time (decades in some cases) and the reality of the situation needs to be understood before decisions are made as to management options.

The elimination of fox rabies from Europe: determinants of success and lessons for the future
(Freuling et al. 2013)

"Despite perceived challenges to controlling an infectious disease in wildlife, oral rabies vaccination (ORV) of foxes has proved a remarkably successful tool and a prime example of a sophisticated strategy to eliminate disease from wildlife reservoirs. During the past three decades, the implementation of ORV programmes in 24 countries has led to the elimination of fox-mediated rabies from vast areas of Western and Central Europe. In this study, we evaluated the efficiency of 22 European ORV programmes between 1978 and 2010. During this period an area of almost 1.9 million km² was targeted at least once with vaccine baits, with control taking between 5 and 26 years depending upon the country. We examined factors influencing effort required both to control and eliminate fox rabies as well as cost-related issues of these programmes. The proportion of land area ever affected by rabies and an index capturing the size and overlap of successive ORV campaigns were identified as factors having statistically significant effects on the number of campaigns required to both control and eliminate rabies. Repeat comprehensive campaigns that are wholly overlapping much more rapidly eliminate infection and are less costly in the long term. Disproportionally greater effort is required in the final phase of an ORV programme, with a median of 11 additional campaigns required to eliminate disease once incidence has been reduced by 90 per cent. If successive ORV campaigns span the entire affected area, rabies will be eliminated more rapidly than if campaigns are implemented in a less comprehensive manner, therefore reducing ORV expenditure in the longer term. These findings should help improve the planning and implementation of ORV programmes, and facilitate future decision-making by veterinary authorities and policy-makers."

This example is included to show that it is important that you decide *why* intervention is required when considering an approach to managing a wildlife disease. In this case, the elimination of fox rabies from Europe is not primarily to save foxes or improve their welfare: it is to manage an important impact of the disease, which is upon people. Most emerging and many zoonotic diseases have wildlife as part of their ecology. Targeting the disease in the host may assist in managing an impact in people. This example also reminds us that control of disease in the host may be only one way of managing the impact and that other, often simple and cost effective methods also need to be considered as part of a multipronged approach to managing the impact of the disease. The use of targets for success are an essential part of any management intervention.

Rabies and Distemper Outbreaks in Smallest Ethiopian Wolf Population
(Marino et al. 2017)

"Canine diseases pose a growing threat to wildlife species of conservation concern worldwide. Although extensive oral vaccinations have eliminated rabies virus (RABV) from wild carnivore populations in some developed countries, elsewhere, the challenges to controlling diseases in endangered wildlife are many and persistent. Massive outbreaks of rabies and, more recently, canine distemper have repeatedly decimated populations of Ethiopian wolves (*Canis simensis*) in the Bale Mountains of Ethiopia, where more than half of a global population of ≈500 wolves live. Extensive efforts to control RABV in the reservoir population of sympatric domestic dogs have proved insufficient. Therefore, reactive vaccination of Ethiopian wolves, carried out in response to an outbreak in wolves, has been the primary mechanism to curtail mortality in the affected wolf populations in the Bale Mountains.

The fragile status of the Bale population highlights the conservation value of the other remaining, much smaller, wolf populations scattered throughout the highlands of Ethiopia. Models predict these small populations to be particularly vulnerable to disease outbreaks; however, no outbreaks had been detected outside Bale, either because they went unnoticed, because in small populations outbreaks die out before causing a major epizootic event, or both. We report consecutive rabies and canine distemper outbreaks among Ethiopian wolves in Delanta, in the Wollo highlands."

This example is included in contrast to the example of the elimination of fox rabies in Europe to show that in this case it is the impact on the spillover host that is to be managed, and the usual approach to rabies management (i.e. to target the maintenance host) may not be effective. Despite access to the necessary tools, eradication may not be possible and control may be the only option. It also shows the pressures and challenges of managing disease transmission in mixed populations of animals and the pressures of comingling of wildlife and domestic species. It is easy to say that prevention is the solution, either through separation or vaccination of maintenance and spillover hosts, however the reality is that in some cases a simple resolution cannot be achieved and, as is currently the case for this population, control may be the only option. This case is also good example of where deployment of the "Control" option must be supported by on-going population monitoring: an expensive and labour intensive process.

Inbreeding depression increases susceptibility to bovine tuberculosis in lions: an experimental test using an inbred–outbred contrast through translocation
(Trinkel et al. 2011)

“Disease can dramatically influence the dynamics of endangered wildlife populations, especially when they are small and isolated, with increased risk of inbreeding. In Hluhluwe-iMfolozi Park (HiP), a small, enclosed reserve in South Africa, a large lion (*Panthera leo*) population arose from a small founder group in the 1960s and started showing conspicuous signs of inbreeding. To restore the health status of the HiP lion population, outbred lions were translocated into the existing population. In this study, we determined the susceptibility to bovine tuberculosis (bTB), and the prevalence of antibody to feline viruses of native lions, and compared the findings with those from translocated outbred lions and their offspring. Antibodies to feline herpesvirus, feline calicivirus, feline parvovirus, and feline coronavirus were present in the lion population, but there was no significant difference in antibody prevalence between native and translocated lions and their offspring, and these feline viruses did not appear to have an effect on the clinical health of HiP lions. However, feline immunodeficiency virus (FIV), which was previously absent from HiP, appears to have been introduced into the lion population through translocation. Within 7 yr, the prevalence of antibody to FIV increased up to 42%. Bovine tuberculosis posed a major threat to the inbred native lion population, but not to translocated lions and their offspring. More than 30% of the native lion population died from bTB or malnutrition compared with <2% of the translocated lions and their offspring. We have demonstrated that management of population genetics through supplementation can successfully combat a disease that threatens population persistence. However, great care must be taken not to introduce new diseases into populations through translocation.”

This example is included to show that disease can have significant impacts on small and isolated populations of threatened wildlife. Loss of “fitness” through inbreeding can also have a demonstrable impact in reducing the resilience of individuals to infection and disease. However, attempts to supplement small wildlife populations must assess the risk of disease associated with translocation and release of “new” individuals into an area. Rigorous disease risk analysis should be undertaken by appropriately skilled practitioners, prior to any decisions around translocation of wildlife. In many cases, disease risks, once identified, can be mitigated to an acceptable level through management practices. In this case, individuals were tested for diseases of concern, including those known to be absent from the destination population, prior to translocation. This paper highlights difficulties which arise when tests are not sufficiently accurate and underlines the need for reliable disease tests in wildlife. This example also emphasises the need for robust baseline health and disease information on wildlife populations, so that informed decisions can be made and apparent changes in disease presence and prevalence can be quickly detected and responded to effectively.

Appendix B

Further information on global and Australian standards and processes for wildlife health management

A number of international standards and agreements recognise the importance of wildlife health, including those set by the World Organisation for Animal Health (OIE; www.oie.int) and the World Trade Organisation (WTO; www.wto.org). Australia is an OIE member country and a signatory to the Sanitary and Phytosanitary Agreement under the WTO. The implementation of adequate systems to determine Australia's wildlife health status, demonstrate freedom from specific diseases and manage wildlife disease, ensures Australia can fulfil its international obligations.

In Australia, the Commonwealth Government is responsible for quarantine at the Australian border and international animal health matters and state and territory governments for disease prevention, control and eradication within their boundaries. Activities are supported by Commonwealth (e.g. *Biosecurity Act 2015*, *Export Control Act 1982*) as well as state and territory (e.g. NSW *Biosecurity Act 2015*, Qld *Biosecurity Act 2014*) legislation.

Australia has a well-developed National Animal Health Information System, which includes wildlife and options for response and management for new, emerging or emergency and endemic diseases in domestic and production animals are well documented, understood and agreed. However, wildlife present special challenges in identifying and deploying management options commonly used in production and other animals (Woods and Grillo 2019).

References, recommended reading and useful sources of information

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Glossary

Anthelmintic: a drug used to treat parasitic worm (helminth) infections.

Antibiotic: a chemical substance that has the capacity to kill or inhibit the growth of other microorganisms.

Antiparasitic: an agent that destroys parasites and includes insecticides, acaricides and anthelmintics.

AUSVETPLAN: Australian Veterinary Emergency Plan. A series of technical response plans that describe the proposed Australian approach to an emergency animal disease incident. The documents provide guidance based on sound analysis, linking policy, strategies, implementation, coordination and emergency-management plans.

Bioaccumulation: accumulation of a compound within an animal over time because the rate of intake exceeds the rate of elimination.

Biodiversity: the variety of plant and animal life in the world or in a particular habitat (a high level of biodiversity is usually considered important and desirable).

Biology: the scientific study of living organisms.

Biomagnification: increase in the concentration of a compound at successive levels within a food chain.

Biosecurity: the management of risks to the economy, the environment and the community, of pests and diseases entering, emerging, establishing or spreading (IGAB). Biosecurity can also be defined as the set of precautions taken to minimise the risk of introducing a pest or infectious disease into an animal (or human) population, or to a group or individual.

Captive animal: an animal that lives under human control or care (in this document, permanent care, such as a zoo or fauna park).

Carcass: the body of an animal that has died.

Carrier: a human or animal which harbours a pathogen in its body without manifesting signs, thus acting as a potential source or distributor of infection.

Case definition: a set of standard criteria for deciding whether an individual of interest has a particular disease of interest.

Causation: the relation of cause to effect.

Community engagement: an approach or process by which community organisations and individuals work alongside experts and expert groups (government and non-government) for the purpose of applying a collective vision for the benefit of the community.

Contagious disease: those infectious diseases that are spread through (direct or indirect) contact with infected individuals e.g. salmonellosis. Not all infectious diseases are contagious.

Control: restraining or reducing the prevalence of individual disease; includes a range of strategies from limitation of occurrence to eradication.

Culling: killing the host with the aim of reducing the host density, generally to that below a level where the disease doesn't continue to spread.

Decontamination: the process of cleansing an object or substance to remove contaminants such as micro-organisms or hazardous materials. It includes all stages of cleaning and disinfection.

Density-dependent: factors that affect the growth of population, which are dependent on the existing population density.

Depopulation: Deliberate reduction of the number of animals (may be partial or complete).

Diagnostic test: a test or procedure applied to an individual to aid in diagnosis.

Disease: any disturbance in the health or function of an animal or human.

Disease agent: a general term for a transmissible organism or other factor that causes an infectious disease.

Disease control program: activities directed at reducing the prevalence or impact of a disease.

Disease eradication program: activities directed at elimination of clinical disease or the disease agent from a defined area within an acceptable time frame.

Disease risk assessment (analysis): the scientific process of analysing the risks of disease introduction, emergence or spread in a population and proposing measures to mitigate those risks.

Disinfectant: a chemical used to destroy infectious agents outside a living animal.

Disinfection: the application, after thorough cleansing, of procedures intended to destroy the infectious or parasitic agents of disease; applies to premises, vehicles and different objects (fomites) that may have been directly or indirectly contaminated. Disinfection inactivates most but not all microorganisms.

Dispersal: to drive or force animals away in different directions

Disposal: sanitary removal of animal carcasses, animal products, materials and wastes by burial, burning or some other process so as to prevent the spread of disease.

Ecology of disease: the relationship among animals, pathogens and their environment in a natural situation without intervention.

Ecosystem: the fundamental unit in ecology, comprising the living organisms and the nonliving elements interacting in a certain defined area.

Emergency animal disease: a disease not normally occurring in a place that requires emergency responses; an EAD is likely to have significant effects on livestock – potentially resulting in livestock deaths, production loss, and in some cases, impacts on human health, wildlife and the environment.

Emergency wildlife disease: a disease that is either exotic to Australia, a variant of an endemic disease, a serious infectious disease of unknown cause or a severe outbreak of a known endemic disease, and that is considered to be of national significance with serious social amenity or economic or environmental implications.

Endemic: the constant presence of a disease or infectious agent within a given geographic area or population group.

Endemic animal disease: a disease affecting animals (which may include humans) that is known to occur in Australia. See also Emergency animal disease, exotic animal disease.

Epidemiology: the study of the patterns and causes of disease in populations.

Epidemic: a disease that is occurring in a time or place where it is not expected or at a rate greater than expected.

Eradication: elimination of a disease from an area. Eradication is indicated by the disease no longer being detectable.

Exotic animal disease: a disease affecting animals (which may include humans) that does not normally occur in Australia. See also Emergency animal disease, endemic animal disease.

Exposure: proximity or contact with a source of a pathogen in such a manner that effective transmission of the pathogen may occur.

Extirpation: drive to local extinction, or to remove or do away with totally.

Free-living/free-ranging: living freely and independent of direct human supervision or control.

Hazard: a danger or risk; an entity that can cause disease, injury or damage.

Healthy: apparently normal in all vital functions and free of signs of disease**.**

Host: a person or animal that can become infected with and provides sustenance for another organism (such as an infectious agent in our case).

Hygiene: practices of cleanliness that help to maintain health and prevent disease.

Immune system: the collection of organs, cells and molecules that together provide the animal or human with defence against invading organisms.

Immunisation: see Vaccination.

Impact: the significant negative effects of a hazard (in this case disease) on an individual, population, environment, ecosystem, social amenity, economy and business.

Incubation period: interval between the time of infection and the onset of clinical signs.

Infection: the presence of a pathogen or infectious agent within an individual.

Infectious agent: organisms that live on or within a host and that survive at the expense of the host regardless of whether disease follows or not. This includes both microparasites (viruses, bacteria, fungi, protozoa) and macroparasites (worms and external parasites).

Infectious disease: those diseases caused by pathogens (or organisms).

Isolation: the separation of an animal (or human) from its conspecifics for veterinary, husbandry or management purposes, which generally involves confinement to a defined area.

Lay people: those without specific education and training in disease or wildlife.

Macroparasites: parasitic worms and external parasites.

Microorganism: any organism (usually bacteria or viruses) that cannot be seen with the naked eye; also called a microbe.

Microparasite: viruses, bacteria, fungi, protozoa (see also microorganism).

Mitigate: make (something bad) less severe or serious. In the context of risk management, this means to apply a treatment that lessens, or decreases the severity or likelihood of a risk occurring.

Monitoring: routine collection of data for assessing the health status of a population. See also Surveillance.

Movement control: restrictions placed on the movement of animals, people and other things to prevent the spread of disease.

Native species: a species of animal indigenous to Australia, independent of human introduction.

Opportunistic agent: a disease agent that may infect an animal, but for which infection is not required for perpetuation of the organism.

Organic material: matter that has come from a recently living organism.

Organism: any biological entity with the capacity for replication and response to evolutionary forces; includes plants, animals, fungi, protozoa, metazoa, viruses and bacteria.

Outbreak (die-off): large numbers of disease cases occurring within a short period of time

Parasite: an organism that, for all or some part of its life, lives in or on a living organism of another species (the host).

Pathogen: (sometimes called agent of disease) an infectious agent capable of causing disease in a host, e.g. viruses, bacteria, fungi, protozoa, internal parasites such as worms and external parasites such as lice and mites.

Persistence (disease): ongoing infection that is not cleared by the host; ongoing presence of disease in the population.

Personal protective equipment (PPE): barrier protection worn to reduce the risk of infection or injury.

Pest: any species, strain or biotype of the Kingdoms Animalia (excluding human beings), Plantae, Fungi, Monera or Protista that has had an impact (i.e. significant negative consequences), or poses a likely threat of having an impact (IGAB).

Physiological or biological stress: an individual's response to a stressor such as an environmental condition.

Population: a group of individuals of the same species that live together in an area.

Precautionary principle: where there is limited information, a risk is assumed (and managed appropriately) until proven otherwise.

Prevalence: the proportion of individuals within the population at risk who have the disease at a particular point of time or during a particular period.

Prevention: actions taken to stop a disease or infection from occurring, or moving across geographical barriers.

Proactive: creating or controlling a situation rather than just responding to it after it has happened.

Protocol: a system of rules that explain the correct conduct and procedures to be followed in formal situations.

Protozoa: single celled organisms; some are parasitic and cause disease (e.g. toxoplasma), others live harmlessly in the environment or assist hosts (e.g. gut flora).

Quarantine: a period of isolation, to aid in detection, management and/or elimination of infectious disease.

Reactive: acting in response to a situation rather than creating or controlling it.

Reproductive rate (R_0): for microparasites, R_0 is the average number of secondary infections that arise from introduction of one infected individual into a totally susceptible population. For macroparasites, R_0 is the average number of female offspring that live to reproduce and are produced by a single female introduced into a totally susceptible population.

Resistance (drug): when a bacteria, other microorganism or parasite changes to become insensitive to a drug that was previously effective.

Reservoir host: a species which can harbour a pathogen indefinitely with no ill effects.

Risk: the likelihood of encountering some form of harm, loss or damage, combined with the severity or consequence of the event.

Risk assessment: the process used to assess and understand risk, involving the evaluation of the likelihood and the resultant impacts of an event or hazard.

Risk factor: an attribute or exposure that increases the probability of occurrence of disease or other specified outcome.

Risk management: the process of identifying, selecting and implementing measures that can be applied to reduce the level of risk.

Sensitivity: the proportion of animals with the disease (or infection) that test positive when using a particular diagnostic test.

Social amenity: any tangible or intangible resources developed or provided by humans or nature, such as dwellings and parks, or views and outlooks.

Specificity: the proportion of animals without the disease (or infection) that test negative when using a particular diagnostic test.

Spectrum of disease: the full range of manifestations of a disease.

Strategic risk assessment: the process of identifying, assessing and managing the risks associated with a proposed management plan.

Subclinical infection: infection with a pathogen, without development of disease.

Surveillance: a systematic program of investigation designed to establish the presence, extent of or absence of a disease, or of infection or presence of a pathogen. It includes the examination and testing of animals for clinical signs, antibodies or the presence of a pathogen.

Susceptible animals: animals that can be infected with a particular disease.

Tracing: the process of locating animals, people or other items that may be implicated in the spread of disease, so that appropriate action can be taken.

Toxin: a poison, especially a protein, produced by certain animals, some plants and bacteria.

Vaccination: inoculation of individuals with a vaccine to provide active immunity.

Vector: a living organism (frequently an arthropod) that transmits an infectious agent from one host to another. A biological vector is one in which the infectious agent must develop or multiply before becoming infective to a recipient host. A mechanical vector is one that transmits an infectious agent from one host to another but is not essential to the life cycle of the agent.

Wildlife: a species of bird, mammal, reptile or amphibian native to Australia.

Wildlife carer: a person who temporarily cares for sick, diseased, injured or orphaned wildlife until it is recovered and becomes capable of fending for itself.

Wildlife disease: any disease that causes disturbance in the health or function of wildlife.

Zoonosis/Zoonotic disease (Plural zoonoses): a disease of animals that can be transmitted to humans.

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