The growing threat of vector-borne disease in humans and animals

Recommendations for optimising solutions and innovations across all species and all regions

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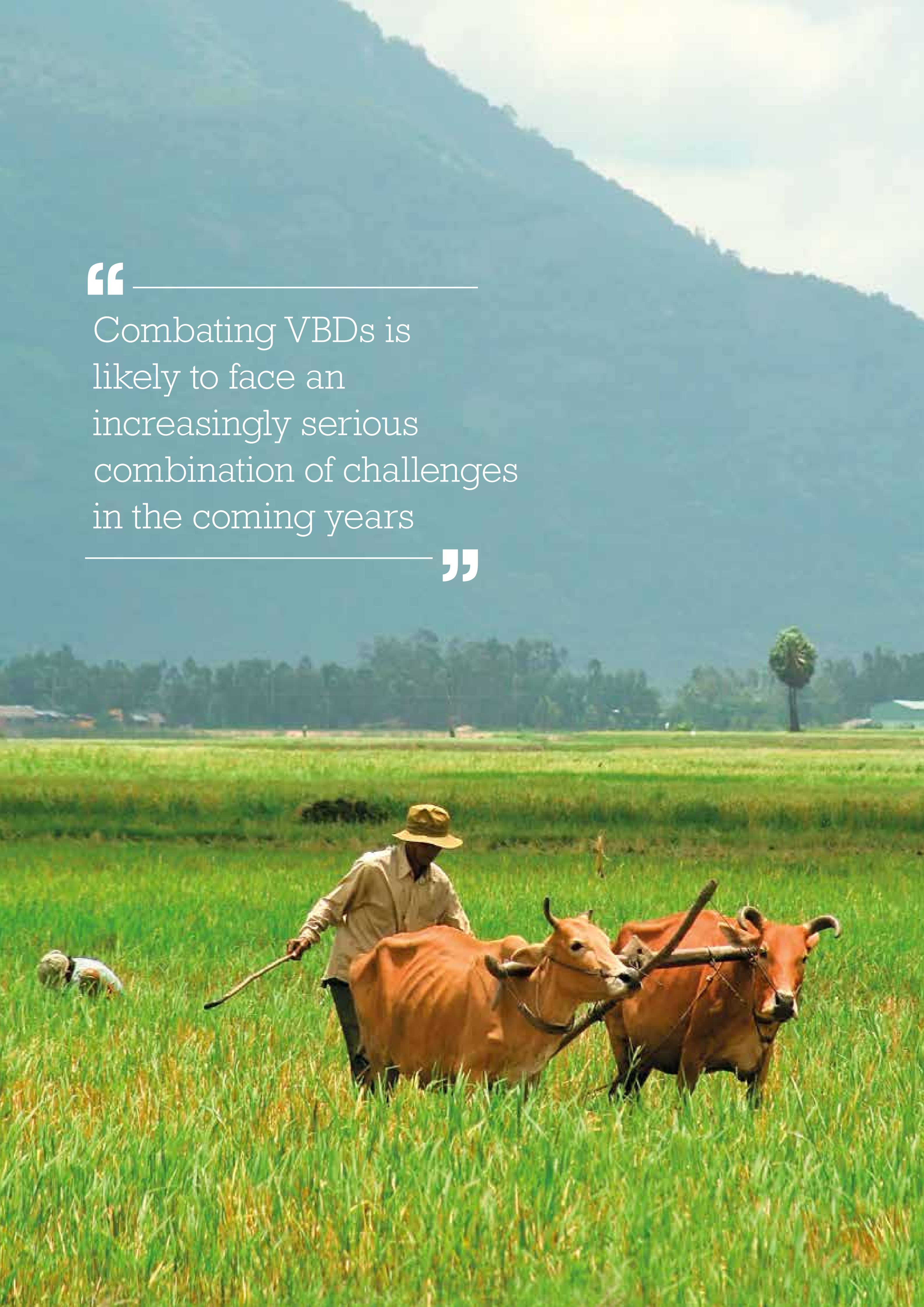

> Combating VBDs is likely to face an increasingly serious combination of challenges in the coming years

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> Local governments and local staff need to be involved in putting in place strategies to manage & control VBDs

0. Executive Summary

Overview and challenges

Insecticide resistance is probably the single greatest threat to traditional approaches to VBD management

- Arthropod vectors and the pathogens they transmit exert a major impact on the health and welfare of companion animals and livestock and the economics of their husbandry, resulting in the loss of billions of dollars annually. However, the relative significance of most VBDs is extremely difficult to quantify, because in most countries there is no formal reporting, poor diagnosis, and no surveillance or collated assessment of prevalence or economic impact. Even in highly regulated regions, such as Northern Europe, accurate statistics are elusive.

- Many VBDs currently lack effective medicines for treatment and prevention. Vaccination has the potential to be one of the most effective methods of preventing disease. However, pharmaceutical sector activity in combating VBDs is often constrained by the lack of a market. The discovery, screening, clinical trials and registration of new molecules that are effective against vector borne pathogens or the vectors themselves is a hugely expensive undertaking, often costing many millions of dollars - and can take many years. There is a clear need for more specific targeted research and development of new approaches and molecules for the management of VBDs, but unless a market exists or donor agencies are willing to invest, such developments are likely to be slow and undirected.

- Combating VBDs is likely to face an increasingly serious combination of challenges in the coming years. These include the potential impact of climate change on vector distribution and VBD incidence; habitat change introduced by humans, e.g., wetland creation; the increased movement of goods, humans, livestock and companion animals worldwide; and for many VBDs, e.g., malaria, dengue and East Coast fever, insecticide resistance. The latter is probably the single greatest threat to traditional approaches to VBD management.

Solutions

- VBD management must be based on realistic, achievable objectives, and, in general, the eradication of vectors or pathogens from a system is not one of these. Governments and funding agencies could focus their relatively limited funding for combating VBDs more on ongoing VBD management and effective control. The most successful approaches to the management of VBD of importance to humans and livestock are often multi-faceted, and include treatment or vaccines, as well as efforts to reduce the population of the vector directly.

The latter may include direct application of an insecticide to the environment or onto the host itself, or modification of the environment to make it less conducive to vector survival.

- It is important to reduce the emphasis on pathogen-targeted research, with much more research into the qualities of healthy animals, physiological and behavioural, and management systems that foster the health of animals. Especially in developing countries, improvement of basic husbandry practices can mean a significant contribution in this field.

- Effective surveillance systems need to be established for most arthropod-borne diseases across different countries to allow a detailed risk analysis, including the evaluation of the potential spread to new areas or the introduction of exotic species or diseases. Further surveillance is then needed to see if controls implemented were effective.

- Awareness of the need to manage the development of resistance must be paramount in any attempt to use insecticides to control vector populations. In addition, various types of physical barrier can be employed to protect hosts from vector feeding. These may include bed nets, and mesh netting covering windows and doors. Such techniques may often be used in conjunction with an insecticide.

- A range of novel techniques for the control of VBDs are being researched. Most of this research is directed specifically against human VBDs, such as genetic modification and the manipulation of endosymbiont bacteria, which have been largely aimed at vectors of human disease pathogens. There is little equivalent work being undertaken on VBD of livestock.

- Local governments and local staff need to be involved in putting in place strategies to manage and control VBDs. Communities need to be shown examples of success stories, and assisted in undertaking cost-benefit analysis of VBD management and control versus inaction.

- Improving levels of relevant expertise is particularly important for farmers in poorer countries, so that they can implement appropriate management and control of VBDs. For example, there should be more donor-funded information campaigns for farmers so they know when it is appropriate to use insecticides, which ones to use and how to use them.

- The One Health concept signifies a collaborative, multidisciplinary and holistic approach, looking at optimising animal, environmental and human health, which are interdependent on each other. Approaches to the control of VBDs in animals can be very different to approaches to VBD in humans, and common ground can be hard to find. However, as ever more people who work in the animal and human health sectors adopt a One Health mindset, piecemeal - but important - progress in collaboration is likely.

Communities need to be shown examples of success stories, and assisted in undertaking cost-benefit analysis of VBD management and control versus inaction

Overview of vector-borne diseases

1. Vectors and geography

1.1. Key vectors

Vectors are organisms that transmit viral or bacterial pathogens and parasites from an infected host (human or animal) to another host. The more important vector-borne diseases (VBDs) are generally found in tropical and subtropical regions. Vectors are classified as 'biological', where a phase of the lifecycle of the disease agent occurs in the vector, and 'mechanical', where the disease agent is transferred physically between hosts, such as by carriage on the vector mouthparts. The most common disease vectors are arthropods - flies (mosquitoes, midges, black flies, sand flies and tsetse flies), ticks, fleas, and lice. Many of the important arthropod-borne pathogens are viruses - these are described as arboviruses.

Tables 1.A. and 1.B. below provide an overview of the most important VBDs affecting humans and animals. Many of these VBDs fall into the portfolio of neglected tropical diseases (NTDs). While their associated morbidity causes severe impacts, a particular challenge associated with NTDs is that they may be associated with low mortality rates, which diminishes their public visibility in comparison with some high-mortality non-VBDs and consequently their urgency for attracting donor funding. However, arthropod vectors and the pathogens they transmit exert a major impact on the health and welfare of livestock and the economics of their husbandry, resulting in the loss of billions of dollars annually. Moreover, taken as a group, VBDs are also responsible for high levels of morbidity and death in human populations throughout the world.

The two most important groups of arthropod vectors are mosquitoes & ticks

The two most important groups of arthropod vectors are mosquitoes and ticks: in general, mosquitoes are relatively more influential as vectors of the pathogens that affect humans, such as malaria and dengue. Malaria is the most significant VBD affecting humans worldwide, estimated by the World Health Organisation (WHO) to have caused over 627,000 deaths in 2012, while dengue is poised to become an increasing problem in the future.

The importance of particular vectors and the prevalence and severity of VBDs vary widely across regions. For example, Chagas' disease (American trypanosomiasis) is the most serious parasitic/protozoal disease of the Americas. Ticks are particularly important as vectors of the pathogens that affect domesticated animals, transmitting the pathogens that cause diseases such as babesiosis and anaplasmosis. In addition to ticks, tsetse fly-transmitted trypanosomiasis significantly affects food production in Africa, while outbreaks of viral infections such as bluetongue and Schmallenberg, both transmitted by *Culicoides* midges, have been very disruptive to animal agriculture and trade in Europe.

Table 1.A. Main VBDs affecting humans

(ordered by vector)

VBD (and class of pathogen)	Vector	Regions affected	Features of the disease
Malaria (protozoa)	Mosquito	Africa, Asia, Pacific, Central and South America	Cycles of profuse sweating with headache and high temperature associated with the bursting of infected erythrocytes; may prove fatal if untreated, depending on the form of infection.
Dengue (virus)	Mosquito	Africa, Asia, Pacific, Central and South America	Fever, headache, rash and joint pains. Mortality is rare, but weakness and depression may be severe and last several weeks.
Yellow fever (virus)	Mosquito	West Africa	Fever, muscle pain, shivers, headache, appetite loss, nausea and/or vomiting. Jaundice, internal and orifice bleeding, and kidney failure lead to death in 50% of toxic cases.
Japanese encephalitis (virus)	Mosquito	East Asia, South Asia, Pacific	Symptoms range from fever and headache to meningitis and encephalitis, coma and death. Mortality is high (20-30%).
Rift Valley fever (virus)	Mosquito	Africa, parts of Arabian peninsula	Flu-like symptoms. Complications include haemorrhagic fever (<1%), encephalitis (<1%) and ocular (eye) lesions (0.5 to 2%). Mortality is <1%.
Malaria (protozoa)	Mosquito	Africa, Asia, Pacific, Central and South America	Cycles of profuse sweating with headache and high temperature associated with the bursting of infected erythrocytes; may prove fatal if untreated, depending on the form of infection.
West Nile virus (virus)	Mosquito	Africa, Europe, the Middle East, North America, West Asia	Asymptomatic in 80% of cases. 19% have symptoms similar to influenza. Less than 1% develop a severe neuro-invasive disease and about 10% of these patients (<0.1% of all infections) die.
Chikungunya (virus)	Mosquito	Africa, Asia, Pacific, starting in the Caribbean	Fever, rash and arthralgia can occur; mortality is rare in endemic areas.

VBD (and class of pathogen)	Vector	Regions affected	Features of the disease
Lymphatic filariasis (nematode)	Mosquito	Tropical Africa, India, Bangladesh, Myanmar, Vietnam, Papua New Guinea, Polynesia	Inflammation of the lymphatic vessels, swelling of the lymph nodes, leading over time to episodes of fever and adenolymphangitis and lymphoedema.
Chagas' disease (protozoa)	Reduviid bugs	South America	Initially asymptomatic (clinical disease usually occurring only in children); about 10-30% of infections develop into chronic disease with myocarditis or marked dilation of the oesophagus or colon.
Lyme disease (bacteria)	Ticks	Asia, Northwest, Central and Eastern Europe, the United States	Flu-like symptoms and a characteristic skin rash occurring 1-3 weeks after infection, leading to disseminated disease with neurological and/or cardiac symptoms usually weeks to months later.
Tick-borne encephalitis (virus)	Ticks	Central and Eastern Europe, Russia, northeast China	Influenza-like, with fever and non-specific symptoms, but can progress to neurological involvement, encephalitis and death.
Human African trypanosomiasis (protozoa)	Tsetse fly	Sub-Saharan Africa	Non-specific symptoms (fever, headaches and joint pains), followed by parasitic invasion of the central nervous system, characterised by behaviour changes, confusion and disturbance of the sleep cycle, resulting in fatality if untreated.
Leishmaniasis (protozoa)	Sand flies	Southern Europe, Africa, Asia, South and Central America, sporadically in the United States	Highly fatal infection leading to visceral leishmaniasis, affecting the internal organs.

Table 1.B. Main VBDs affecting livestock

(ordered by vector)

VBD (and class of pathogen)	Vector	Regions affected	Animals most affected	Features of the disease
Surra (protozoa)	Biting flies	North Africa, Middle East, Asia, Central and South America	Horses, donkeys, camels, dogs, cattle	Fatal in horses, camels, dogs. Chronic disease in cattle -- wasting, death
Bluetongue (virus)	*Culicoides* midge	Africa, Europe, Asia, Australia, North and Central America	Cattle, sheep (some breeds), goats, deer	Morbidity and mortality
Schmallenberg (virus)	*Culicoides* midge	Europe	Ruminants	Abortions, stillbirths and congenital defects in newborns
Western equine encephalomyelitis (virus)	Mosquito	Americas	Horses, poultry	Zoonosis
Eastern equine encephalomyelitis (virus)	Mosquito	Americas	Horses, poultry, pigs	Zoonosis
Rift Valley fever (virus)	Mosquito	Africa, parts of Arabian peninsula	Sheep, cattle, dogs	Zoonosis
West Nile virus (virus)	Mosquito	Africa, Europe, the Middle East, North America, West Asia	Horses, avian wildlife, occasionally food animals	Zoonosis; fever, encephalitis and death
Japanese encephalitis (virus)	Mosquito	East Asia, South Asia, Pacific	Horses, pigs	Zoonosis; encephalitis in horses, reproductive failure in pigs

Table 1.B. (continued)

VBD (and class of pathogen)	Vector	Regions affected	Animals most affected	Features of the disease
Chagas' disease (protozoa)	Reduviid bugs	South America	Dogs	Zoonosis; myocarditis, death
Leishmaniasis (protozoa)	Sand flies	Southern Europe, Africa, Asia, South and Central America, sporadically in the United States	Dogs, cats, horses, other mammals	Zoonosis; dogs - chronic disease, skin lesions, ocular abnormalities, lymphadenopathy, weight loss, lethargy
Anaplasmosis (Rickettsiae)	Ticks	South and Central America, the United States, Southern Europe, Africa, Asia, Australia	Cattle, sheep, goats, buffalo, some wild ruminants	Anaemia leading to production losses and death
Heartwater disease (Rickettsiae)	Ticks	Southern Africa	Cattle, sheep, goats	High fever, convulsions ending in death
Babesiosis (protozoa)	Ticks	South and Central America, the United States, Southern Europe, Africa, Asia, Australia	Cattle, horses, sheep, goats, pigs, dogs	Fever, anaemia, associated clinical signs and production losses, death
East Coast fever and other theileriosis (protozoa)	Ticks	Southern, eastern and central Africa	Cattle, buffalo	Fever, lymphadenopathy, anaemia, death
African swine fever(virus)	Ticks	Africa, Western Europe	Wild boar, pigs	Haemorrhagic fever, death in pigs
African animal trypanosomiasis (protozoa)	Tsetse flies	Africa	Cattle, horses, pigs, sheep, goats	Wasting
Crimean-Congo haemorrhagic fever (virus)	Ticks	Africa, Eastern Europe, Middle East, West and South Asia	Cattle, sheep, goats, horses, pigs, dogs, wildlife	Zoonosis, asymptomatic in infected animals

1.2. The economics of VBD management and control in livestock

Perceptions of the VBD problem and approaches to management and control are broadly different between livestock and humans. In livestock:

- The cost of control must be weighed against the cost of losses, and intervention should be based on quantifiable economic thresholds. In many cases, it might be economically more profitable to accept low levels of VBD production losses, where the costs of control are high. Further, in some cases, the optimum economic strategy for farmers may be to accept immediate production losses when a new disease first emerges or when animals are first moved into new areas with a high VBD challenge to which they have not previously been exposed, in the hope that immunity will be acquired rapidly in those animals that survive (although this may not happen for all diseases). It is important to ensure that attempts at vector control do not have long-term negative effects. For example, reducing the exposure of livestock to pathogens may reduce the rate at which immunity is acquired.

- The economics of VBD control also vary dramatically between the developed and less developed parts of the world; VBDs and management approaches that are cost effective to implement in the developed world may be out of reach for farmers in developing countries unless funded by donor agencies. For livestock, VBD problems, and potential solutions, need to be considered carefully in relation to economic context.

Such an economics-driven approach, which is essential in livestock management, would not be ethically acceptable when considering human VBD.

1.3. The need for a market

Pharmaceutical sector activity in combating VBDs is often constrained by the lack of a market. The discovery, screening, clinical trials and registration of new molecules that are effective against vector borne pathogens or the vectors themselves is a hugely expensive undertaking, often costing many millions of dollars - and can take many years. By the time a new molecule starts to generate revenue, a company may find itself close to the expiry of its patent. Therefore, for the pharmaceutical industry, taking a new molecule through to market will only be attempted where there is a clear potential for return on investment. This applies equally to the animal health and the human health sectors. Dengue is a good example: It is a growing problem in developing countries, but neither developed country governments nor pharmaceutical companies are devoting sufficient resources to combating it.

The major difference between human and animal health sectors in developed countries is that the market exists to support the development of human medicines

The major difference between human and animal health sectors is that, in developed countries, the market exists to support the development of human medicines, and for less developed countries international agencies such as the WHO, the World Bank or the Bill & Melinda Gates Foundation can support such developments. In the case of livestock disease, for the most part no equivalent resources are available - in either the developed or less-developed world. As a result, new products for the treatment and control of VBD in animals almost always need to borrow from research undertaken for human disease control, or in the case of insecticides for vector control, often from horticulture. It is notable, for example, that two major global products used to control animal parasites and vectors, the avermectins and the phenylpyrazole, fipronil, were first developed to control pests of crops because the horticulture market is so much larger than the animal health market.

The role of the market in driving animal health product development is clearly seen in the recent growth of new products to control fleas and ticks on cats and dogs whereas, for example, there is not a single acaricidal product registered in the UK to protect cattle against ticks. There is a clear need for more specific targeted research and development of new approaches and molecules for the management of VBDs in livestock, but unless a market exists or donor agencies are willing to invest, such developments are likely to be slow and undirected.

> “The relative significance of most VBDs in livestock is extremely difficult to quantify”

2. Impact of VBDs on food production

The relative significance of most VBDs in livestock is extremely difficult to quantify, because in most countries there is no formal reporting, poor diagnosis, and no surveillance or collated assessment of prevalence or economic impact. Even in highly regulated regions, such as Northern Europe, accurate statistics are elusive. However, certain VBDs do have a particularly significant impact on food production:

Certain VBDs do have a particularly significant impact on food production

- Babesiosis, spread by ticks, is responsible for serious losses in cattle production in Latin America, Australia and Asia; it is also locally important in parts of Europe. The importance of babesiosis was such that an extensive control programme was implemented in the United States to eradicate the tick vectors. This remains one of the very few examples of successful, sustained, area-wide vector eradication. It was successful because an area-wide approach was adopted, using a variety of management tools with strict centralised coordination, underpinned by the budget of a developed nation.

- Anaplasmosis is a tick-borne disease responsible for high levels of economic loss in the cattle industry in tropical and subtropical regions, particularly Africa and South America.

- East Coast fever is a particularly important tick-borne disease of cattle in Africa.

- Heartwater disease in cattle, sheep and goats in Southern Africa is regarded as the most important tick-borne disease in the region.

- Rift Valley fever (RVF) affects large numbers of animals in Africa, with some spillover outbreaks in the Arabian peninsula. It is severely affecting exports of animals from Africa. However, globally production losses from RVF are relatively limited. Its significance is mainly in that it is a dangerous zoonosis that could potentially spread.

- In sub-Saharan Africa, trypanosomiasis and African swine fever affect food production. African swine fever is becoming a problem in Europe and Russia; its management is complicated as it has several methods of transmission.

- Bluetongue has been one of the most feared VBDs, but its actual impact on livestock from a food production point of view may be less than most of the above diseases.

Efforts to manage and control VBDs involve a variety of different aspects, as detailed in the next section.

3. Current management & control of VBDs

3.1. Eradication

VBD management must be based on realistic, achievable objectives, and, in general, the eradication of vectors or pathogens from a system is not one of these. There are very few examples of the complete area-wide eradication of vectors or vector-borne pathogens, despite extensive efforts and the expenditure of many billions of dollars globally. Failure to eradicate vector populations often occurs because of re-invasion and repopulation. For example, attempts to eradicate tsetse flies in parts of Africa have given at best only short-term population suppression. The problems caused by re-invasion were clearly demonstrated by attempts to eradicate *Rhipicephalus (Bo.) microplus* from Australia and Papua New Guinea, which failed as the movement of ticks back into the eradication zones could not be prevented.

A basic problem for the control of VBDs is that government policy and funding is often geared towards favouring solutions that promise eradication of diseases. If it were to be accepted that eradication is in most cases unachievable, then governments and funding agencies could focus more on ongoing VBD management and effective control.

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3.2. Treatments and vaccines

Many VBDs currently lack effective medicines for treatment and prevention. However, vaccination has the potential to be one of the most effective methods of preventing disease, especially with biological vector-transmitted pathogens. It is administered to stimulate the treated host's immune system to develop antibodies against either the disease-causing pathogen or occasionally the arthropod vector itself. Some vaccines may be given as a treatment, after a pathogen has been contracted; others are given to induce immunity as a prophylaxis to prevent disease. The active component of a vaccine may be intact but inactivated (non-infective) or attenuated (with reduced infectivity) forms of the causative pathogens, or purified components of the pathogen that are able to stimulate an immune response (e.g., the outer coat proteins of a virus).

For a number of livestock vector-borne pathogens, no vaccines are available. Diseases for which vaccines have been developed include bluetongue (BTV-8), Japanese encephalitis (for humans, horses and pigs), yellow fever and West Nile virus. A live vaccine with attenuated parasites is used against babesiosis in Australia. However, despite considerable research, the immunological control of African trypanosomiasis has not succeeded because of the antigenic variation of the trypanosome parasites. The limited success of vaccines against VBDs in animal health is related to their cost, the difficulties in monitoring the epidemiology of a VBD in infected and vaccinated animals, and pathogen antigenic variability, especially when it comes to parasites.

The most successful approaches to the management of VBD of importance to humans and livestock are often multi-faceted, and include treatment or vaccines, as well as efforts to reduce the population of the vector directly

Vaccination that targets the feeding or transmission capacity of the vector may also be valuable and offers many benefits over the use of insecticides and acaricides, e.g., the lack of contamination in the environment, specificity, as well as high levels of safety for humans, ease of administration and low production costs. But despite considerable research and investment and some significant progress, the development of successful vaccines specifically against blood-feeding arthropods have been the exception.

In terms of other medicines and treatments, for some protozoal VBDs, such as babesiosis, effective medicines are available, but usually only delay the progress of clinical signs and only rarely achieve a true eradication of the infection. Even where effective treatments do exist, the VBD needs first to be diagnosed quickly and accurately. However, diagnosis is, in many cases (e.g., Lyme disease), extremely difficult.

Once diagnosed, treatment availability varies widely across regions, with developed regions more likely to have the requisite resources for effective disease management. Poor local health systems and infrastructure in certain regions prevent medicines or vaccines from being transported, stored correctly and administered, which contributes to outbreaks. Sometimes, the medicines used for the treatment of parasites may require lengthy courses and/or toxic regimens, further adding to the complexity and cost of treatment.

In general, as resistance grows, and replacement medicines become harder to identify, VBDs will become increasingly problematic. Current medicines and treatments are thus merely 'firefighting' responses.

3.3. Current approaches

The most successful approaches to the management of VBD of importance to humans and livestock are often multi-faceted, and include treatment or vaccines, as well as efforts to reduce the population of the vector directly. The latter may include direct application of an insecticide to the environment or onto the host itself, or modification of the environment to make it less conducive to vector survival, e.g., by removing water pools in which mosquito larvae develop.

One of the best examples of a multi-faceted (international) approach to the management of a VBD is the Southern Cone Initiative, designed to manage Chagas' disease in South America. In this programme, governments of the six Southern Cone countries (Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay) launched an initiative to control Chagas' disease through elimination of the main vector, the reduviid bug Triatoma infestans, by spraying houses with insecticide and large-scale screening of blood donors. Replacement of mud walls and floors with cement, and thatched roofs with corrugated metal was also undertaken to reduce the number of suitable resting places for the bugs. The programme has achieved considerable success, with transmission halted over large areas of the previously endemic regions. Similarly, some of the more successful campaigns for the control of trypanosomiasis in Africa have involved combinations of insecticide use, fly trapping, livestock movement control and treatment. However, applying such multi-faceted approaches successfully is difficult, given the many challenges facing management and control of VBDs.

4. Challenges

4.1 Government funding

Many VBDs suffer from insufficient government funding being devoted not just to incentivising the development and distribution of vaccines, but also to broader management and control. The lack of funding is partly because VBDs that affect primarily poorer countries are not prioritised by developed country governments. Public health funding in developed countries follows the pattern that the most high-profile diseases get the most funding. Moreover, many public sector funders like to support scientifically novel projects that often achieve little of immediate effect (such as genetic modification) rather than practical, low tech, but effective projects, such as bed nets. Moreover, even in developed countries, managing and controlling VBDs often requires a very large-scale effort that is difficult to achieve politically as well as financially.

4.2. Climate change

The potential impact of climate change on vector distribution and VBD incidence is of very significant and immediate concern. There is considerable evidence that changes in the phenology and distribution of a wide range of arthropod species have occurred in response to climate change worldwide. This is particularly true for ticks, and there is also some evidence of effects on mosquitoes. Since most arthropod parasites are at least as affected by humidity as by temperature, effects of climate change will depend critically on the interaction between the two. Hence, the net effect of climate change - especially for arthropod vectors - may be complex and is far from easily predicted.

The potential impact of climate change on vector distribution and VBD incidence is of very significant and immediate concern

Nonetheless, climate warming overall is likely to lead to increased numbers of vectors and prolonged periods during which conditions are favourable for vector survival and pathogen transmission. Warming may increase the potential for onward transmission, as well as the vector potential of each individual arthropod. Similarly, warming may make it more likely that tropical and subtropical species, for example ticks, will establish in more temperate regions. Some of the spread of bluetongue serotypes around the Mediterranean has also been linked to climate change. A World Bank report ('Reducing Climate-Sensitive Disease Risks'), published in August 2014, lists Rift Valley fever and East Coast fever, as well as bluetongue, as VBDs that are especially susceptible to geographic expansion as a result of climate change.

4.3. Social and economic pressures

Change in social and economic conditions is often an important influence on VBD incidence patterns. Livestock numbers change in line with human population: high levels of population growth, or economic collapse or civil unrest, often result in major movements of people and their animals. Unplanned urbanisation, in combination with inadequate housing often shared with domestic animals, and poor quality water, sewage, and waste management systems, produce conditions in which high densities of hosts and poor animal and public health allow for increased transmission of VBDs in and between human and animal populations.

4.4. Habitat change

Habitat change can have a significant impact on VBD incidence, e.g.:

- Major irrigation and flood prevention systems, such as the southeastern Anatolia irrigation project, have been built in the past 50 years without regard to their effect on vector-borne disease.

- In parts of Europe there are large-scale plans for wetland creation to mitigate the effects of climate change on biodiversity loss, as well as coastal wetland creation to mitigate sea-level rise. The potential exists that these will create new aquatic habitats for mosquitoes, often in locations where land had previously been drained for agriculture.

- Tropical forests are still being cleared at a high rate, and conversion of land to intensive agricultural production, such as rice, continues - increasing breeding sites for insect vectors, as well as the exposure rate between mosquitoes and animals.

- In some areas of the world initiatives are being undertaken to increase woodland management for biodiversity. Wildlife populations and their distributions are increased as a result of these initiatives, for example deer numbers are increasing throughout Northern and Central Europe and their incursion into urban areas is becoming more common. These developments have considerable significance for VBDs, since they increase the interaction between humans and wild animals, which are important reservoirs of a range of disease pathogens, such as Lyme disease.

4.5. Pressure for eco-friendly solutions

In the past, people often have done whatever it takes to control outbreaks, such as applying insecticides to vector populations. In developed countries, environmental and health concerns have led to restrictions on the types of chemicals that can be used to control outbreaks. These concerns are now spreading to the global level. Increasingly, insecticides can only be applied if all their consequences are evaluated. This is a big change in many developing countries. For example, in Africa, to control tsetse flies, insecticide used to be sprayed from planes, covering national parks. In some cases this had a devastating impact on other parts of the ecosystem. In future, such indiscriminate large-scale spraying will be scrutinised more closely at an international level, whether by governments, NGOs, or individual activists or journalists.

4.6. Insecticide resistance

For many VBDs, e.g., malaria, dengue and East Coast fever, insecticide resistance is a huge and growing problem. It is probably the single greatest threat to traditional approaches to VBD control. At the recommended doses, modern insecticides are highly effective, but the development of resistance may reduce the effectiveness of the treatment applied, increase the use of insecticides, increase the costs and add to the environmental impact.

When an insect population develops resistance to one insecticide, it may also prove to be resistant to similar compounds that have the same mode of action. This phenomenon, known as class resistance, occurs frequently in vector populations that develop resistance to organophosphate, carbamate, or pyrethroid insecticides. In some cases, a population may develop a form of resistance that protects it from compounds in more than one chemical class. This is known as cross-resistance, and may result in a vector or pathogen population that can no longer be controlled with chemical insecticides.

Monitoring for insecticide resistance is difficult, expensive and incomplete. Understanding the geographical range of different levels of resistance in different vector species is also problematic, since patterns of resistance may be highly spatially heterogeneous. Patterns of resistance seen in livestock disease do not necessarily match those seen in human disease. For animal VBD, there is almost no coordinated surveillance anywhere in the world and the sharing of information is patchy. For human VBD, there have been greater attempts to evaluate and map different levels of resistance in different areas. For example, the online platform www.irmapper.com, launched in 2012, aims to provide this for malaria, but for other VBDs such mapping is less advanced. The WHO has guidelines for insecticide resistance monitoring and choice of insecticides (see www.who.int/whopes/resistance/en), but it is questionable how widely these guidelines are being followed in practice.

Links
www.irmapper.com
www.who.int/whopes/resistance/en

4.7. Travel and trade

The increased movement of goods, humans, livestock and companion animals worldwide is also an important mechanism for the introduction of new vectors and disease agents. Container shipping and air transport have had major impacts on the rate of vector introduction. However, while novel vector introductions probably occur relatively frequently, for this to be of significance, the introduced vectors must either be carrying pathogens, or find a source of endemic pathogens at their new location. They must also be able to survive long enough to become infectious and be able to disperse and breed under the climatic conditions of their new location. This chain of probabilities is usually sufficiently low that in most instances introduced arthropod vectors quickly die out or are identified and eliminated.

Patterns of resistance seen in livestock disease do not necessarily match those seen in human disease

Notable examples of the movement and introduction of novel vectors or pathogens are the incursion of bluetongue virus into Northern Europe from sub-Saharan Africa and the introduction of West Nile virus into New York in 1999. Also, the arrival and establishment of invasive mosquitoes in Italy, coupled with international travel of humans infected with tropical pathogens, led to the first documented outbreak of chikungunya virus in humans in Italy in 2007.

The alternative route is the introduction of animals infected with pathogens for which endemic arthropods are competent vectors. Again, this is a relatively rare phenomenon. However, there have been significant cases: Movement and importation of livestock have been important in contributing to and initiating arbovirus outbreaks such as Crimean-Congo haemorrhagic fever and Rift Valley fever. Although the World Organisation for Animal Health (OIE) has restrictions on trading livestock to prevent spread of diseases from country to country, these are not always adhered to. Moreover, companion animals (e.g., dogs and cats) can cross borders more freely than livestock and may also carry vectors.

Another emerging challenge related to trade is the spread of non-indigenous livestock populations. For example, indigenous cattle in West Africa, such as N'Dama, are relatively resistant to endemic disease.
But new breeds of cattle have been imported into the region that have higher productivity but lower tolerance to the endemic pathogens; as a result, the incidence of VBDs increases.

> “World Organisation for Animal Health restrictions on trading livestock ... are not always adhered to”

5. The way forward

5.1 Build resilience in animals

The development of a more sophisticated approach to disease management is required that makes livestock more resilient to VBDs. Animal health and productivity may have less to do with the presence of a particular pathogen and more to do with the susceptibility of the individual animals. Disease does not necessarily result from contact with a pathogen, but from an animal's inability to deal successfully with pathogen invasion. Individuals vary in this ability according to their genetic constitution and their conditions, such as nutrition and stress levels. If these factors can all be controlled, the result is a healthy animal that is more inherently resistant to pathogens. For example, in areas of Ethiopia, indigenous Borana cattle are highly adapted to arid and semi-arid regions and, through natural and artificial selection, are able to survive and reproduce in conditions of poor feed quality, water shortage and disease -- including tick infestations.

Therefore, the basis of sustainable disease management is acceptance that the aim of eliminating pathogens is unrealistic and that a more sophisticated, multi-pronged approach is needed. For this, it can be argued that it is important to reduce the emphasis on pathogen-targeted research, with much more research into the qualities of healthy animals, physiological and behavioural, and management systems that foster the health of animals. Especially in developing countries, improvement of basic husbandry practices can mean a significant contribution in this field. There should be a change in the emphasis on disease management, from pathogen-eradication to management for the development of long-term, sustainable health.

Disease does not necessarily result from contact with a pathogen, but from an animal's inability to deal successfully with pathogen invasion

Given the growing appreciation that greater emphasis should be placed on the ability of healthy animals to resist disease, a realisation is building of the importance of breeding for resilience in livestock. The ability to select for such traits depends in part upon the heritability and reliability of the markers for disease resilience and on whether there are economic trade-offs with other important traits, such as reduced productivity. Deliberate selection for disease resilience has the potential to improve animal health, welfare and productivity. For example, a few breeds of cattle in West and Central Africa, namely N'Dama and West African Shorthorns, as well as Djallonke sheep and goats, are less affected by infection with trypanosomes than other breeds and are said to exhibit trypanotolerance. Studies have shown that trypanotolerance has a genetic basis and that the attribute is enhanced further by continued exposures to the parasite. Institutions such as INRA (Institut national de la recherche agronomique) are now researching genetic polymorphisms, using high-throughput genotyping and sequencing tools to identify the polymorphisms responsible for trypanotolerance, which can then be applied in cattle genetic improvement and crossbreeding programmes. Similarly, in South Africa, relatively small-framed Nguni cattle are more resilient to tick infestation

Awareness needs to be created for emerging VBDs in regions in which they have not been known. The scope of existing surveillance programmes needs to be adapted to such changes

compared to larger Bonsmara and Angus cattle. Nguni cattle also have lower internal parasite loads. As a result, they can be reared on natural pasture without the use of acaricides, anthelmintics or dietary supplementation. Crosses between Nguni with other breeds are being used to attempt to produce offspring that are both large but will remain disease-tolerant. Similarly, the indigenous Namaqua Afrikaner (NA) fat-tailed sheep are less susceptible to tick infestation than the commercial Dorper and Merino breeds and can be used to breed for greater disease resilience.

5.2. Improve diagnosis and surveillance

Arthropod-borne diseases of livestock remain far less well researched than diseases of human concern (e.g., malaria, lymphatic filariasis or dengue). This is mainly due to the fact that surveillance and diagnostics of livestock are often poorly developed in the regions in which these diseases primarily occur. In particular, there is limited survey data on the distribution of arthropods and arthropod-borne diseases in many areas of the world, in part as a result of the difficulties in diagnosis. Hence, changes in distribution, particularly if subtle or at the early stages of an epidemic curve, are hard to spot. Awareness needs to be created for emerging VBDs in regions in which they have not been known. The scope of existing surveillance programmes needs to be adapted to such changes.

Therefore, it is important that effective surveillance systems are established for most arthropod-borne diseases across different countries to allow a detailed risk analysis, including the evaluation of the potential spread to new areas or the new introduction of exotic species or diseases. Further surveillance is then needed to see if controls implemented were effective. The OIE issues recommendations on how to monitor some diseases, e.g., bluetongue. Countries that do that can implement better early detection and early warning systems.

Farmers themselves are generally not best placed to undertake effective surveillance. They are not trained and do not have incentives to do it, given that most of the time it may be unnecessary. Farmers may also be reluctant to report outbreaks if they fear that the authorities will cull or quarantine all of their animals.

5.3. Implement multi-faceted protection from vectors

Some VBDs affect vast areas, and given that wild animals often act as reservoirs, it can be extremely difficult to control the vectors themselves, let alone eradicate them from an area. Instead, multi-faceted protection from vectors, for example as described in the Southern Cone Initiative above, is required. This can involve:

5.3.1. MANAGING RESISTANCE

Awareness of the need to manage the development of resistance must be paramount in any attempt to use insecticides to control vector populations. There are three general approaches that can be used to reduce the rate of resistance development:

- Management by saturation involves heavy or frequent use of a pesticide that is designed to leave absolutely no survivors.
- Management by moderation uses only the minimum control necessary to reduce a population below an acceptable level. This strategy tries to ensure that genes susceptible to pesticides are never eliminated from the population.
- Management by multiple attack involves the use of several control tactics that work in different ways. By rotating insecticides with different modes-of-action or by alternating chemical with non-chemical control tactics, a pest population is exposed to selective pressures that change from generation to generation.

The approach adopted depends on the vector in question, the epidemiology of transmission and the environment. In general, for most vectors, management by multiple attack provides the most sustainable result.

Where reliance on synthetic insecticides needs to be reduced, a range of management practices and non-chemical methods may be utilised in an integrated manner to reduce vector abundance. Techniques should be integrated with each other to form components of a general vector management programme.

5.3.2. REDUCING VECTOR CONTACT

Various types of physical barrier can be employed to protect hosts from vector feeding. These may include bed nets, and mesh netting covering windows and doors. Such techniques may often be used in conjunction with an insecticide. Grazing practices can also be adapted to reduce contact with the vector, e.g., avoiding specific areas at particular times of the year when tick activity is likely to be high.

5.3.3. MODIFYING THE ENVIRONMENT

Simple modification of the environment may reduce pest abundance significantly, e.g., removing resting sites for triatomine bugs in houses, or more complex modifications such as reconsidering choices of crops planted. Flies also can be effectively controlled through simple procedures such as the removal of moist bedding and straw, food waste, heaps of grass cuttings and vegetable refuse in which they breed. Improved sanitation and drainage are important in controlling the larval stages of a wide range of insect vector species. Water management and irrigation schemes can also be adapted to make the habitats for vectors less widely available.

In general, for most vectors, management by multiple attack provides the most sustainable result

5.3.4. BIOLOGICAL CONTROLS

Predators, parasites, competitors and pathogens of some insect pests can be used as biological controls. Considerable interest is currently being given to the use of entomopathogenic fungi and the bacterium *Bacillus thuringiensis* as biopestides. However, the use of these techniques can be complex and costly and, as yet, cannot be attempted routinely in most circumstances.

5.3.5. NEW TRAPPING TECHNIQUES

The physical trapping of vectors is an approach that is showing considerable promise for the future. For example, the development of traps for the tsetse vectors of trypanosomiasis in Africa has been highly successful, though not adopted on a large scale; traps can be based on identifying and exploiting appropriate visual shapes and colours in combination with host-mimicking chemical odours to attract and catch the vectors.

5.4. Develop innovative techniques

A range of novel techniques for the control of VBDs are being researched at present. Such research is complex and expensive. Hence, given the very limited funding available for research on VBDs that is available, most of this research is directed specifically against human VBDs, such as the examples highlighted below of genetic modification and the manipulation of endosymbiont bacteria, which have been largely aimed at vectors of human disease pathogens. There is little equivalent work being undertaken on VBDs of livestock.

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5.4.1. GENETIC MODIFICATION

It is becoming possible to genetically modify insects to be resistant to certain types of viruses, or to reduce the lifespans of known vectors. Potentially, genetically modified insects could be used to prevent the spread of pathogens; work is focused particularly on mosquitoes and malaria. However, although theoretically appealing, to date this technology for controlling VBDs is far from being made widely available, particularly due to the high development and production costs and uncertain efficacy; at present, these techniques offer no immediate prospect of effective field use.

5.4.2. MANIPULATING BACTERIA

The recent discovery of a number of different species of endosymbiotic bacteria inhabiting the gut of arthropods such as ticks has opened the way for new control strategies of VBDs. Antibiotic treatment of ticks results in reduced numbers of bacteria and, as a consequence, lower survival. (See Case Study on *Wolbachia* below.)

5.4.3. GEOGRAPHICAL INFORMATION SYSTEMS (GIS) AND REMOTE SENSING (RS)

Geographical information systems (GIS) and Remote Sensing (RS) allow the integration of environmental, vector and disease data, providing an assessment of spatial and temporal interactions. Prediction models generated by GIS enable users to identify ecological and environmental factors that favour specific vector habitats, allowing rapid identification of at-risk areas for the spreading of the arthropod vector and hence VBDs. For example, GIS analysis has been demonstrated to be a powerful tool for the study of *Phlebotomus argentipes* and *L. longipalpis*, vectors of (visceral) leishmaniasis in India and Brazil respectively, as well as for the vectors of Lyme disease and trypanosomiasis. Spatial modelling of sheep scab mite infection has produced maps of expected disease hotspots in the UK, which could be used to direct control efforts; this approach could be extended to map a range of animal VBD vectors.

5.4.4. ESSENTIAL OILS

There is a growing body of evidence indicating the potential value of essential oils as control agents against a range of arthropod parasites and vectors of livestock disease, particularly lice, mites and ticks. Toxicity is due to both neurotoxic and mechanical modes of action. A possible advantage of essential oils over conventional ectoparasite treatments may be their environmental safety and low cost; however, they do have a relatively short-lived residual activity, which may be limiting. Nevertheless, the use of essential oils in the control of livestock VBDs is an area of current research that may hold considerable potential for the future.

5.5. Local involvement

Local governments and local staff need to be involved in putting in place strategies to manage and control VBDs. In developing countries there is often a lack of health and distribution infrastructure, a resistance to change, and belief in traditional practices over new interventions. Communities need to be shown examples of success stories, and assisted in undertaking cost-benefit analysis of VBD management and control versus inaction. This is critical to improving basic vector control, e.g., use of bednets or avoidance of stagnant, dirty water.

5.6. Improve education

Improving levels of relevant expertise is particularly important for farmers in poorer countries, so that they can implement appropriate management and control of VBDs. For example, there should be more donor-funded information campaigns for farmers so they know when it is appropriate to use insecticides, which ones to use and how to use them. However, donor-funded education campaigns often are not sustained; funding may run out after one year, following which farmers often stop using the required insecticide regime. Also, education on herd health management may improve the overall health of the farmed animals and their resilience to disease. Such education is especially difficult in developing countries, where communication can be difficult and because sometimes farmers are nomadic. However, in the developed world there are similar problems of farmers lacking expertise, information or incentives.

5.7. 'One Health'

The One Health concept signifies a collaborative, multidisciplinary and holistic approach, looking at optimising animal, environmental and human health, which are interdependent on each other. Transfer of knowledge needs to happen, for example through international and national meetings and also through the media. Consideration of One Health principles has been common in veterinary health for decades. Among medical doctors, there is less understanding and appreciation for it. The medical profession is much larger than the veterinary profession, and is itself subdivided into many different specialisations.

Transfer of knowledge needs to happen, for example through international and national meetings and also through the media

There has recently been increasing interest in One Health principles, e.g., the United States now has a One Health office and there is funding from USAID for One Health. In countries where government functions are more fluid than in others, there may be more scope to operationalise One Health concepts. A good example of One Health being implemented is regarding H5N1 avian influenza - an infectious disease but not a VBD - which has a high fatality rate in humans. The OIE and the Food and Agriculture Organization of the United Nations (FAO) have created a partnership called OFFLU - a network of expertise on animal influenza. Animal health authorities coordinated by OFFLU present data from the animal health sector, e.g., on the antigens in their antigen banks, to help determine how vaccines will need updating.

More broadly, the WHO and the OIE are increasingly collaborating to identify high priority issues in the One Health space. However, approaches to the control of VBDs in livestock can be very different to approaches to VBD in humans, and common ground can be hard to find. One Health is unlikely to contribute to a step-change in VBD management, but as ever more people who work in the animal and human health sectors adopt a One Health mindset, piecemeal - but important - progress in collaboration is likely.

Case Studies

1 Trypanosomiasis: A threat to both humans and animals

Disease impact

Human African trypanosomiasis (HAT) - also known as sleeping sickness - and African Animal trypanosomiasis (AAT) - also known as Nagana - are vector-borne diseases that have occurred in 37 sub-Saharan African countries. They are caused by protozoan blood parasites known as trypanosomes. An estimated 60 million people are at risk of HAT, with some 20-30,000 current cases. AAT affects a range of livestock species including cattle, sheep and goats. Around 50 million cattle and 70 million sheep and goats are at risk of AAT and some three million cattle die from the disease annually.

There are two forms of HAT, a chronic West African form and an acute East African form. In both cases, patients initially develop non-specific symptoms (fever, headaches and joint pains). The second stage of disease begins when parasites invade the central nervous system and is characterised by behaviour changes, confusion and disturbance of the sleep cycle, resulting in fatality if untreated. In cattle and small ruminants, AAT leads to a slow deterioration in health associated with anaemia, weight loss, hair loss and paralysis and can result in death. AAT can have a profound impact on the food security and financial wellbeing of farmers in sub-Saharan Africa due to reduced production of milk, meat and manure and a weakening of working animals. The economic losses in cattle production are around 1.0-1.2 billion dollars annually.

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Management and control

HAT and AAT are spread through the bites of tsetse flies, and vector control plays a major role in curtailing transmission. The deployment of traps and targets impregnated with insecticide provides a simple and low cost control method. Direct application of insecticides to animals allows for 'integrated control' of multiple livestock diseases as the insecticides kill ticks and biting flies as well as tsetse flies. More expensive methods include the sterile insect technique (SIT), where male tsetses are rendered infertile though irradiation and then released into the wild. SIT has been used successfully to eradicate tsetse flies from Zanzibar, but has limited application on mainland Africa because of the huge size of contiguous landmass. More widespread use of 'trypanotolerant' breeds of cattle, sheep and goats, which tolerate the parasites and do not demonstrate the anaemia and production losses shown by other breeds, would improve management of AAT. Case finding and treatment is a key control measure for West African HAT, and treatment of animals (curatively and prophylactically) is also important for control of AAT. As cattle are carriers of East African HAT, treatment of cattle can significantly reduce human cases in countries where this is endemic.

Challenges

The integrated use of different control measures adapted to local ecology, together with improved coordination and collaboration between HAT and AAT control programmes, is vital for control of trypanosomiasis

Current treatments for HAT can be toxic and difficult to administer, but are provided free of charge to endemic countries through public-private partnerships between the WHO and pharmaceutical companies. The three medicines available for treatment of AAT have been in use for over 40 years. A major concern is the development of medicine resistance, which has been reported in 13 sub-Saharan African countries. The 'Drugs for Neglected Diseases' initiative is developing new therapies for HAT, but there is currently insufficient financial incentive for pharmaceutical companies to develop new medicines for AAT.

The integrated use of different control measures adapted to local ecology, together with improved coordination and collaboration between HAT and AAT control programmes, is vital for control of trypanosomiasis. HAT is currently showing a reduced incidence in the human population, but there is no evidence for such a decline of AAT. A major initiative, funded by the African Union and EU, started in 2002, aimed at eradicating the disease. Eradication was not achieved (again demonstrating that programmes aimed at eradication of VBDs are almost always ineffective). Apart from the resources needed, major obstacles were the lack of communication, co-ordination or cooperation between governments, the need to target several species of tsetse fly simultaneously, the impenetrable nature of much of the habitat, with no transport infrastructure and political instability, and the lack of involvement by the people affected.

"The integrated use of different control measures adapted to local ecology, ... is vital for control of trypanosomiasis"

2 Bluetongue: Strong response in Europe

Disease impact

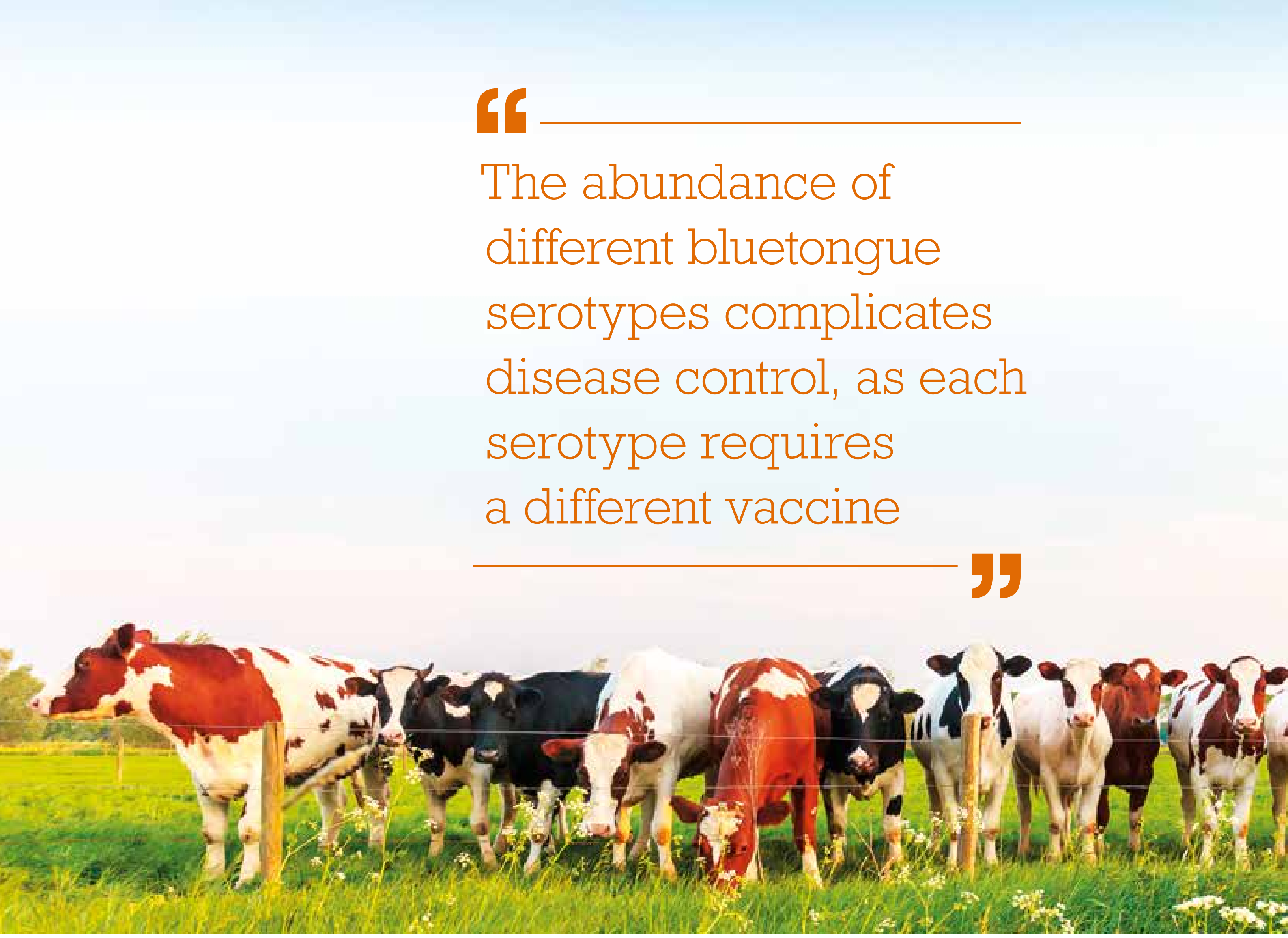
Bluetongue is a vector-borne, non-contagious, viral disease affecting ruminants. Bluetongue virus (BTV) is a pathogenic virus of the *Reoviridae* family, and has 26 recognised serotypes worldwide, with recent evidence suggesting that up to 29 serotpyes may exist. It is spread through biting midges of the genus *Culicoides*, which become infected with the virus after ingesting blood from infected animals. BTV has also shown to be transmitted vertically from mother to calf (causing various deformities) and horizontally in goats, via an oral route and can even infect some carnivore species. Bluetongue affects all domestic and wild ruminant animals and camelids, posing a particular threat to sheep and cattle. The disease is non-zoonotic. Its geographic spread covers all continents except Antarctica and New Zealand, due to lack of vectors. An outbreak of bluetongue can cause significant economic losses due to morbidity and mortality of animals, loss of production and milk yield, trade embargoes and vaccination and surveillance costs, particularly for a region to re-claim freedom from infection.

In the case of bluetongue, it remains difficult to identify midge breeding grounds, hindering the application of measures such as insecticide

Management and control

For bluetongue - as with many other VBDs - vector control is problematic due to the difficulty in tracking vector populations, as well as the ubiquitous nature of adult Culicoides during the 'vector' seasons (usually late summer). However, bluetongue provides an example of the effective use of vaccination to prevent the spread of the virus. Alongside ancillary measures such as movement restrictions and surveillance, inactivated vaccines have been effective in preventing the spread of bluetongue, most notably in the case of the outbreak of BTV-8 in Northern Europe, which reached a climax in 2008.

Management of the BTV-8 outbreak in Northern Europe testifies to the importance of early prevention strategy. Initially, response to the virus was slow -- in 2006 a 'wait and see' approach was adopted by the countries affected. Once the BTV-8 virus started to be recognised, restricted zones were created to isolate animals, and restrictions were placed on the movement of animals. These were accompanied by EU action to coordinate the response. In spring 2008, a vaccination campaign for BTV-8 was launched, when the veterinary industry provided a serotype-specific vaccine.. Cost-benefit considerations and expertise from a previous bluetongue outbreak in Southern Europe in 2000 had demonstrated that using any type of vaccine would be preferable to experiencing the disease. In some countries, vaccination became mandatory, whereas in the UK and the Netherlands it was kept voluntary, but still resulted in high take-up. The timeliness of vaccination was important in limiting the bluetongue epidemic in continental Europe.



Challenges

While vaccination has been an effective control measure for bluetongue, challenges lie ahead. The abundance of different bluetongue serotypes - up to 29 worldwide, with ten different ones appearing in Europe alone over the last 15 years - complicates disease control, as each serotype requires a different vaccine. This raises the development costs of vaccines. Moreover, live attenuated vaccines can carry a risk of generating the disease they intend to prevent. The live vaccines can also infect and be transmitted by the Culicoides vectors and are detected as positive infections in ruminants, preventing or complicating surveillance programmes. If properly produced and administered, the more recently commercialised inactivated vaccines avoid these risks.

Furthermore, the development of vaccines for bluetongue was largely made possible by favourable conditions in Europe. Government funding for research and farmer demand for the vaccine created a viable market and provided adequate incentives for pharmaceutical companies to invest. Effective coordination among governments proved key, and enough visibility was given to the issue. However, given that bluetongue continues to affect other geographic regions that have less favourable conditions than Europe, a universally viable control method is still missing. However, it should be noted that on the basis of the successes of the inactivated BTV-vaccination campaigns in Europe, India has initiated a pentavalent inactivated vaccination campaign.

3 Schmallenberg: Mitigation is best available option

Disease impact

The origin of Schmallenberg virus (SBV) is still unknown. In November 2011, the Friedrich-Loeffler-Institute in Germany first detected a novel virus in samples from cattle with fever and reduced milk yield. SBV affects ruminants and is mainly transmitted by insect vectors of the species *Culicoides*. It can also be transmitted during pregnancy from the mother to offspring. There is no indication that humans can be infected with SBV.

Clinical signs are mainly associated with reproduction problems. Depending on the time of infection, there may be abortion, stillborn animals, premature deliveries and various intra-uterine congenital malformations. SBV has been detected in malformed foetuses, stillborn and newborn lambs, calves and goat kids born at term, as well as offspring born with a normal outer appearance but with signs such as blindness or deafness. Because of malformations, SBV may cause difficult deliveries that can have negative impacts on animal welfare and in the worst case lead to culling or death. In adult cows, the acute infection can result in transient and non-specific symptoms, namely diarrhoea, inappetence, fever, and a reduction in milk yield, usually followed by a full recovery. Clinical signs are not commonly observed in adult or growing sheep.

If the infection of pregnant animals falls into a critical time period, where reproductive problems and damage to the offspring can occur, a farm may suffer considerable losses due to malformations, abortions or death because of delivery complications. Hence, farmers may lose the value of adult animals, and incur losses due to revenue foregone from offspring that cannot be sold (e.g., fattening calves or spring lambs). Moreover, farmers need to spend extra money on buying replacement animals and paying for veterinary treatment, care of the animals affected and disposal in the event of animals dying.

The profitability of livestock businesses can be seriously affected and production may become inefficient

The impact at the farm level differs depending on the production system and management type, factors that may have an impact on exposure to the virus (such as late gestations matching high vector density population), and flexibility of a farmer's decision making (e.g., a closed herd may fail to reach self-sustaining replacement rates if there are reproduction problems). Additionally, trade of cattle semen and pure-bred breeding animals has been restricted in several countries, causing drops in export and losses across Europe. The profitability of livestock businesses can therefore be seriously affected and production may become inefficient. Such extra costs cannot always be absorbed and may cause farmers to quit their livestock business.

Management and control

The elimination of the virus from populations may prove challenging and the focus therefore lies on interventions to mitigate the negative impact of disease

Since its discovery, various epidemiological, immunological and virological investigations have been conducted in several European countries. It is believed that the virus has been present in Europe since spring-summer 2011, as examination of archived samples did not indicate prior SBV circulation. Once present, SBV spread very rapidly and by September 2013 the disease had been confirmed in 27 European countries.

A European network of veterinary organisations, agricultural ministries, research institutes, national animal health institutes, farmers' organisations and food safety agencies was swiftly established to test potentially infected animals and assess the number of SBV disease cases. However, due to the novel nature of the disease, technical interventions such as vaccines were not available and the spread of the disease could not be stopped. The rapid spread may have been exacerbated by the high density of animal trade networks in Europe.

Some protection against SBV may be achieved through natural immunisation of affected herds. However, there is currently very limited data available on the duration of immunity in cattle (protection seems to last up to one year) and none for sheep. The elimination of the virus from populations may prove challenging and the focus therefore lies on interventions to mitigate the negative impact of disease.

Vaccines for SBV in ruminants have been developed in Europe and licences have been approved in some EU countries for marketing of the vaccine. The purpose of SBV vaccines is to induce an immune response that prevents the virus from reaching the foetus. New data on biological and economic impact now becoming available will help farmers and their veterinarians to take an informed decision on whether the additional investment needed to protect their herds or flocks is justified by the resulting loss avoidance.

Challenges

Apart from vaccination, there are limited options to control the disease effectively. Experts have suggested measures to reduce exposure to the vector through disruption of vector breeding sites, pesticide use, housing and protection of ruminants by repellents. Additional measures could be a breeding system that manages the timing of the reproduction process or insemination of animals depending on the season and concentration of midges, thereby reducing exposure to the virus in the critical period. However, such a strategy may prove difficult where production and management systems are targeted towards the seasonality of grass growth and market demand.

4 Tick-borne diseases: A diverse and expanding challenge

Disease impact

Ticks are blood-feeding parasites of vertebrates, which feed on a wide range of mammals and birds, including domesticated animals and humans. There are two types of ticks, hard ticks (which are the most important) and soft ticks. Species of ticks occur in a variety of habitats but are most abundant in tropical humid climates. In temperate habitats, feeding and generation cycles of hard ticks are closely synchronised with periods of suitable temperature and humidity. Generally, ticks are most active during the warm season, provided there is sufficient rainfall. This affects the duration and timing of tick control programmes.

Hard ticks are temporary parasites, with most species spending relatively short periods on the host. Ticks can be described as one, two or three-host ticks depending on the number of host species they feed on, which in turn will influence both the potential for disease transmission to occur and the ability to control tick numbers and thus reduce disease risk.

Tick bites may be directly damaging to animals and humans, causing irritation, inflammation or hypersensitivity, and, when present in large numbers, can cause blood loss leading to anaemia and debilitation. The salivary secretions of some ticks may cause toxicosis and paralysis; however, more importantly, when they attach and feed they are capable of transmitting a number of pathogenic viral, bacterial, or bacterial-like diseases, as well as protozoal diseases.

Some of the most important tick-transmitted diseases in humans are viral tick-borne encephalitis (TBE) and diseases caused by bacterial-like organisms that include typhus, such as Mediterranean and Rocky Mountain spotted fevers (rickettsiosis); tick-borne fever (ehrlichiosis); tick-borne relapsing fever; and Lyme Disease. Ticks also transmit a wide range of economically important blood parasites affecting livestock, such as East Coast fever, babesiosis and anaplasmosis.

Ticks transmit a wide range of economically important blood parasites affecting livestock, such as East Coast fever, babesiosis and anaplasmosis

Management and control

Some of these diseases can be difficult to treat, so control is often aimed at either preventing ticks from attaching and feeding, or at reducing their numbers through the implementation of local tick control measures. Tick control in livestock is largely based on the use of chemicals (acaricides) applied either by dipping, showering or spraying. Some chemicals can be given to cattle or sheep by injection or by pour-on. In companion animals (dogs and cats), tick treatments can be applied topically to the skin either by spray or spot-on. In some animals and humans, control may involve the manual removal of attached ticks.

Traditional control methods such as burning of cattle pastures, particularly where there is bracken, are still used in some countries and are generally practised during a dry period before rains, when ticks are inactive. Cultivation of land and improved drainage can help to reduce tick populations, but in most circumstances these are impractical. Pasture 'spelling' -- in which domestic livestock are removed from pastures during peak risk periods -- has been used, but will work only where there are no wild hosts, such as deer.

A commercial vaccine, TickGARD®, has been developed against the tick *Rhipicephalus (Bo.) microplus* in Australia. For optimal response, cattle should be in nutritionally good condition. This is one of the few examples of the successful development of a vaccine against a tick. There is also ongoing research on the use of entomopathogenic fungi that attack resting ticks in the environment.

Challenges

Overall, tick-borne VBDs are spreading, e.g.:

- New areas of TBE virus have been reported in Scandinavia. TBE has also been found recently for the first time in mountainous regions of the Czech Republic. These changes are thought to be related to the expanding range of the tick vector, possibly associated with climate change.

- The prevalence of Lyme disease appears to be increasing in association with the expanding range of its tick vector and growing deer populations; again climate change may also be important. The distribution of ticks in the UK is estimated to have expanded by 17% and human cases of Lyme disease have increased 30-fold between 1999 and 2008. Lyme disease has also seen an increase in incidence in the United States (30-40,000 cases per year) and many European countries, with some rates increasing two- or threefold. It can be treated with antibiotics, once diagnosed, but diagnosis can be difficult.

For farmers in tropical climates, the complexity of treatment of livestock can be high. Weekly treatments of livestock during the tick season may be required. In temperate climates, less frequent treatments are given during the tick season. Since many ticks occur on less accessible parts of the body, such as the groin and axilla, the udder and around the ears, care must be exercised to ensure that the treatment is properly applied.

There is also ongoing research on the use of entomopathogenic fungi that attack resting ticks in the environment

Moreover, many of the older acaricides used in cattle and sheep contained organochlorines or organophosphates, but these are now banned in many countries because of environmental or human health concerns. This means that the availability of suitably effective tick treatments can be limited. Many new acaricidal products have recently become available in the companion animal market, but as yet these are not licensed for humans or livestock likely to enter the food chain.

5 Malaria & dengue: The promise of Wolbachia

Disease impact

Mosquito-borne diseases are among the most serious of VBD found in humans - and may be locally important vectors of some diseases of livestock. Malaria and dengue impose the greatest cost on human health. Malaria has long been problematic across Africa as well as in the Middle East, the Asia Pacific region and Latin America. Dengue has made a rapid emergence, and has caused several outbreaks, mostly in tropical areas.

Management and control

Despite urgent need, disease control strategies for malaria and dengue have not been entirely successful. On the vaccination front, little progress has been made. For malaria, different kinds of vaccines have been tested, but none are very effective. Commercial medicines are available, but medicine resistance often presents a problem, and malaria medications require a fairly strong regimen that may be difficult to follow. Dengue has no available vaccines. Control for both diseases has therefore focused on vectors - combating vector populations through measures such as bednets, insecticides, and other insect-repellent techniques. Recent international research efforts have also shown promising developments with regard to the use of *Wolbachia*, bacteria with various strains that can infect many different arthropods.

Laboratory studies have shown that strains of *Wolbachia* bacteria can temporarily infect mosquitoes and make them immune to spreading malaria and dengue pathogens

Wolbachia is found in insects, and is transmitted between generations through the insects' eggs. It passes only from females to their offspring and, in some insects, can kill male embryos or produce males that have impaired breeding. *Wolbachia* is found naturally in up to 60% of all insect species, but this excludes the Anopheles species of mosquitos, which carries malaria and the *Aedes aegypti*, which carries dengue. Laboratory studies have shown that strains of *Wolbachia* bacteria can temporarily infect mosquitoes and make them immune to spreading malaria and dengue pathogens. In 2005, it was discovered that one strain of *Wolbachia* could make mosquitos resistant to dengue. In 2013, it was found that a strain of *Wolbachia* could stop the spread of the malaria parasite by the *Anopheles stephensi* mosquito. Researchers are currently working on effective ways to turn the *Wolbachia* infection from temporary to permanent in order that it might be passed from generation to generation and persist in these mosquito species.

Wolbachia could offer a significant step forward in vector control by offering direct control over pathogen transmission. It differs from traditional vector control methods, which act mainly on breeding grounds or on the host and externally to the vector, offering potentially greater certainty against the spread of the disease. *Wolbachia* could be used in combination with other available tools to increase efficiency rates in vector control.

Challenges

Despite its potential, challenges remain for the effective use of *Wolbachia* in vector control. On the entomological research side, problems include the observation that females infected with *Wolbachia* produce fewer eggs than non-infected females, thus diminishing the reproductive capacity of the infection. Studies are also needed to determine the quantity of infected mosquitoes that need to be released in order to have a fast enough impact. More importantly, in the case of malaria, experiments have been successful only with the *Anopheles stephensi* mosquito, which carries malaria in the Middle East and South Asia. However, it is a different mosquito, *Anopheles gambiae*, that affects Africa, and it may require a different *Wolbachia* strain to become resistant.

Scientific progress on *Wolbachia* has been possible thanks to funding and collaboration efforts at the international level. The high visibility of malaria and dengue - given their large human impact - has facilitated efforts to align incentives of entomologists and medical researchers in developing methods of vector control. According to the WHO, the resources available for malaria control globally were estimated to be 2.5 billion dollars in 2012, which is significantly higher than other VBDs. Funding, as well as collaboration among stakeholders, will be essential to future prospects for *Wolbachia*, both in developing current findings and exploring potential uses in other vectors.

> “Funding will be essential to future prospects for *Wolbachia*, both in developing current findings and exploring potential uses”

6 African swine fever: Dangerous disease with VBD and non-VBD characteristics

Disease impact

African swine fever (ASF) is a non-zoonotic, highly contagious disease caused by a virus (*Asfivirus*, *Asfarviridae* family) that affects domestic pigs, wild boar, and African wild suids (warthogs, bush pigs, and giant forest hogs). The disease is mainly characterised by haemorrhagic fever leading to high mortality in domestic pig and wild boar populations. Although the disease cannot be transmitted to humans, it poses serious issues for the affected countries, since it leads to strict bans imposed on international trade and to control measures, often including culling policies. There is currently no vaccine or treatment against ASF.

The disease has historically been endemic in most sub-Saharan African countries, as well as Sardinia and Madagascar. In 2007, it was introduced from Africa into Georgia by international ships containing infected swill that was fed to pigs. Since then, it has spread to several neighbouring countries, including Russia, Armenia, Azerbaijan, Ukraine, Belarus, Poland, Lithuania and Latvia. The presence of the disease in Eastern Europe has raised concerns regarding the risk of further spread within the EU.

ASF is most often transmitted by direct contact between infectious and susceptible animals. The virus can also spread through indirect contact, via contaminated fomites (e.g., surfaces of transport vehicles, or clothes of animal workers). Because the virus is stable, it can persist for several months in slurry and uncooked meat. Therefore, contaminated pork products fed to pigs have been shown to contribute to the spread of the disease. Some tick species are also known to transmit the disease in Africa. However, their role in Eastern Europe is still unclear.

ASF is most often transmitted by direct contact between infectious and susceptible animals. The virus can also spread through indirect contact, via contaminated fomites

Management and control

Since no effective vaccine or treatment is available, early detection of outbreaks and rapid interventions are essential for controlling ASF. Surveillance is based on reporting of suspicions by pig farmers followed by a laboratory test. If an outbreak is confirmed, culling is usually implemented in the affected area, and movements of pigs and humans are restricted around the outbreak. These measures are used to prevent the disease from spreading further and to limit subsequent outbreaks. Surveillance of ASF in wild boar is encouraged via clinical inspections of hunted animals, virus detection, serology and reporting of wild boars found dead. Preventive measures involve quarantine and the implementation of high biosecurity on farms. Bans of swill feeding practices and monitoring of pigs and pork product movements are also essential to limit the spread of ASF.

Challenges

Controlling the disease spread is challenging due to the lack of effective vaccine or treatment, the contagiousness of the virus, its potential long survival in the environment and the epidemiological role of ticks and wild boars. Because the virus is known to be highly contagious, early reporting of suspicions is critical to control effectively the disease. Therefore, all factors delaying the timely reporting of suspicions can be seen as barriers to control. ASF clinical signs are unspecific and lesions can be misdiagnosed, especially if other haemorrhagic diseases such as classical swine fever are present. This can potentially result in delays for ASF detection. In the currently affected countries, illegal trade of pigs or pork products and inappropriate financial compensation to farmers represent additional obstacles for the control of the disease.

7 Leishmaniosis: A growing concern for humans & dogs

Disease impact

Infection with protozoan parasites of the genus *Leishmania* cause a range of distinct diseases in humans and domesticated animals, which are collectively known as leishmaniosis (plural leishmanioses). Infection is insect-borne; the known vectors are phlebotomine sandflies, which are distributed throughout the Mediterranean region, parts of Asia and Africa and the Indian subcontinent. Related sandfly species that also transmit leishmaniosis are found in Central and South America.

In humans and dogs, the most important species are Leishmania donovani and Leishmania infantum (part of the L. donovani group) respectively, causing highly fatal infection leading to the condition known as visceral leishmaniosis ('kala azar'), affecting the internal organs. The incubation period may be several months with spasmodic fever. An enlarged liver and spleen follow with high mortality. Other species of *Leishmania* cause mainly chronic cutaneous (skin) leishmaniosis at the site of the insect bite.

In dogs, the most important species, Leishmania infantum causes a highly fatal infection known as canine leishmaniosis. Leishmania is zoonotic in general.

Dogs are the principal urban reservoir, with high infection rates in some countries, and are the most important source of human *Leishmania* infection. It is probable that most dogs in endemic areas are exposed to the pathogen and will either develop clinical or subclinical infection, or become immune and resistant to infection and disease. Leishmaniosis is also diagnosed in dogs in countries where sandfly vectors do not occur, suggesting that alternative methods of transmission exist.

In dogs, infection with *Leishmania* may cause either visceral or cutaneous lesions, the latter being more common. It may take many months, or even years, for infected dogs to develop clinical signs, so that the disease may only become apparent long after dogs have left areas where the disease is endemic. The disease is usually chronic with low mortality, although it can manifest as an acute, rapidly fatal form. Recovery depends on the proper expression of immunity; if this does not occur, the active infections persist, leading to chronic enlargement of the spleen, liver and lymph nodes with persistent skin lesions.

In the cutaneous form in the dog, lesions are confined to shallow skin ulcers often on the face or legs, from which recovery is often spontaneous. In the visceral form, dogs initially develop hair-loss around the eyes and this is followed by generalised loss of body hair and eczema, the parasites being present in large numbers in the infected skin. Intermittent fever, anaemia, weight loss and generalised lymph node enlargement are also typical signs. Long periods of remission followed by the re-appearance of clinical signs are not uncommon.

Management and control

Factors such as climate change and increased global trade and travel may lead to spread of some vector species, even to more temperate regions

Several medicines are used for treating leishmaniosis in both humans and dogs. These include antimony-based medicines, used either alone, or in combination with other medicines, particularly allopurinol (a medicine also used for treating human gout).

Insecticide-impregnated collars offer prolonged protection of dogs from sandfly bites and appear to decrease the rate of infection in dogs and people in endemic areas. Such collars are recommended for travelling pets, particularly dogs from non-endemic countries that visit endemic regions. Two different vaccines have also been developed for use in dogs; one in South America for the control of visceral leishmaniosis, and a second that is commercially available in Europe.

Challenges

Sandflies are susceptible to commonly used insecticides, and in some regions the populations of sandflies have been reduced as a result of mosquito control measures for malaria, leading subsequently to decreases in the incidence of leishmaniasis. But overall, chemical control of sandfly vectors has had only limited success. From the public health aspect, the destruction of infected dogs and stray dogs in countries where the disease is endemic is advocated, although this approach is clearly disconfirmed by scientific data and is generally considered unacceptable.

Increased mobility of dogs with their owners, and the re-homing of stray dogs from endemic areas threaten the spread of leishmaniosis to countries and regions considered free of the disease. While the sandfly vectors generally have focal distribution in subtropical regions of the world, probably a result of ecological restraints and the availability of mammalian hosts on which they feed, factors such as climate change and increased global trade and travel may lead to spread of some vector species, even to more temperate regions. Finally, the fact that direct transmission of leishmaniosis without sandfly involvement has been suspected suggests that other factors may also play a part in future spread of the disease.

8 Rift Valley fever: High potential for spread

Disease impact

Rift Valley fever (RVF) is an arthropod-borne disease caused by a virus of the genus *Phlebovirus* (*Bunyaviridae* family). It was first isolated in the 1930s in the Rift Valley region of Kenya and is now considered endemic in most of sub-Saharan Africa; outbreaks have also occurred in Egypt and the Arabian Peninsula (Saudi Arabia and Yemen).

It is spread by a range of biting vectors; primarily *Aedes* and *Culex* species (spp.) mosquitoes. *Aedes* spp. are associated with temporary fresh water bodies and are reservoir hosts, whereas *Culex* spp. mosquitoes' habitats tend to be more permanent water areas and are important amplification hosts during disease outbreak. Outbreaks occur intermittently after heavy rainfall and flooding. The disease remains dormant for long periods of time and is thought to survive in the eggs of *Aedes* spp. and via low level transmission to hosts.

RVF can affect livestock (e.g., cattle, sheep and goats), wildlife and humans. The disease causes economic losses through abortions, lowered milk yield, reduced weight gain and mortalities. Mortality rates are highest in young livestock; in lambs mortality rates have reached 95% during outbreaks, with goats and cattle usually experiencing a milder form of the disease. Livestock are often important for rural livelihoods and food security in endemic areas; funding for disease control is sometimes lacking and technical capacity low, so RVF can have a devastating impact in these communities.

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In humans, the disease is characterised by flu-like symptoms including fever, muscle pain, joint pain and headache. A minority of patients experience complications including haemorrhagic fever (<1%), encephalitis (<1%) and ocular (eye) lesions (0.5 to 2%). The mortality rate in humans is low (<1%) and mostly occurs in patients with the haemorrhagic form, although the mortality rate in the Saudi Arabia/Yemen outbreak was around 14%. Transmission of the disease is via direct contact with infective tissues, eg, blood, and risk factors for infection include occupational contact with ruminants, particularly slaughtering and butchering. There are also some reports of infections by consumption of raw milk.

Management and control

There is no effective treatment for RVF in animals and humans. Diagnostic tests exist with varying technical requirements, cost, sensitivity and specificity. Vaccines for livestock are available; however, live vaccines can have pathogenic effects, e.g., abortions and there are concerns regarding the risk of transmission from RVF contaminated needles. These vaccines are usually designated for use in non-pregnant animals in endemic areas when outbreaks are predicted. An inactivated vaccine is available but has a lower level of protection and requires boosters. Vaccines in humans have been developed and trialled in high-risk populations, although they have not been licensed for commercial use. Other control strategies include vector control, e.g., targeting mosquito breeding sites with larvicide, or insecticide treating livestock, quarantine/movement restriction, controlled slaughter and prevention of mosquito bites. Suitable import controls may prevent the disease crossing borders.

Challenges to RVF control include a lack of knowledge of the role of wildlife and importance of different vectors in the transmission of the disease, and the absence of a vaccine that confers good protection and is non-pathogenic

Challenges

Challenges to RVF control include a lack of knowledge of the role of wildlife and importance of different vectors in the transmission of the disease, and the absence of a vaccine that confers good protection and is non-pathogenic. Several candidates for vaccination are under development, including the MP12 for use in humans and livestock; however, their development is slow, which partly reflects a lack of investment in RVF research and control.

Climate change, increased travel and trade, and the presence of competent RVF vectors in other territories including the United States and the European Mediterranean, means this virus has the potential to emerge in areas previously free of the disease. The outbreaks in Egypt and Yemen have demonstrated ability to cross natural geographic barriers. As livestock populations in the United States and the European Mediterranean would be highly susceptible, introduction of the disease may lead to huge losses. These concerns are leading to increased funding for RVF research.

9 West Nile virus: One of the most widespread VBDs

Disease impact

West Nile virus is a mosquito-borne virus in the genus *flavivirus* and family *Flaviviridae*, which includes many other important human viruses such as dengue and yellow fever. It was originally isolated in 1937 from the blood of a woman with a fever in the West Nile province of Uganda. It infects a wide variety of vertebrates including birds, mammals, reptiles and amphibians. The transmission cycle of the virus is primarily maintained by birds and mosquitoes. Other vertebrates, including humans and horses, can become infected (and ill), but generally are dead-end hosts - meaning they do not transmit the virus to biting mosquitoes.

West Nile virus is one of the most widely distributed mosquito-borne viruses, with transmission now occurring seasonally on all continents except Antarctica. Prior to 1999, its distribution was limited to Africa, Asia, Southern Europe and northern Australia. However, it was introduced into North America in New York in 1999 and spread throughout North, Central and South America in the subsequent seven years. The virus is spread over large distances by migrating and dispersing birds, but is likely to have been brought to the Americas in 1999 through an infected mosquito on an aeroplane.

West Nile virus is one of the most widely distributed mosquito-borne viruses, with transmission now occurring seasonally on all continents except Antarctica

The extent of human and animal illness from West Nile virus varies substantially both from year to year and geographically. Transmission in many parts of Africa is relatively intense. However, in Africa, Asia, Central and South America it is mostly overlooked as a cause of illness, due to the presence of many more serious infectious diseases, including malaria and dengue.

Approximately 80% of humans infected with West Nile virus show no symptoms at all, while about 19% have symptoms similar to influenza that develop 3-14 days after infection, including fever, headache, malaise, fatigue, skin rash, vomiting, and diarrhoea. Less than 1% develop a severe neuro-invasive disease, where the virus infects the brain - including meningitis, encephalitis, and acute flaccid paralysis - and about 10% of these patients (<0.1% of all infections) die. The risk of severe illness is substantially higher in patients older than 50 years of age.

Management and control

Efforts to control West Nile virus in humans consist primarily of mosquito control targeting larval mosquitoes. However, during epidemics in the United States, some regions have used trucks and aeroplanes to spray insecticides to kill adult mosquitoes. Control efforts also include public health outreach to encourage people to avoid exposure to mosquitoes by wearing insect repellent, avoiding being outside from dusk to dawn, and wearing clothing that minimises exposed skin. Currently there are no vaccines for humans that have been approved by the US Food and Drug Administration, although several vaccines have passed initial stages of clinical trials.

West Nile virus is a larger concern for livestock, and particularly horses. The fatality ratio of unvaccinated horses infected with West Nile virus can be as high as 30%. In the United States, most horses are vaccinated against West Nile virus, and four vaccines have now been licensed by the US Department of Agriculture.

Challenges

These vaccines have also been shown to be effective in several species of wild birds, which may suffer up to 100% mortality from infection. Vaccination of wild birds to control West Nile virus has been proposed but has not been attempted because of the challenges in effectively reaching a large enough fraction of the bird population to be effective - and because of the relatively small public health burden of the disease. A further challenge in controlling West Nile virus stems from difficulties in reducing mosquito abundance or lifespan sufficiently to reduce or stop transmission.

> "The extent of human and animal illness from West Nile virus varies substantially both from year to year and geographically"

Notes

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