AUSTRALIAN WILDLIFE HEALTH NETWORK

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Foot and Mouth Disease (FMD) Risks Relating to Wildlife – Scope, Gap Analysis and Future Priorities

For Australian Wildlife Health Network (Taronga Conservation Society Australia)

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> Foot and mouth disease is seven separate diseases, clinically indistinguishable, caused by seven antigenically distinct serotypes. And even within each serotype there is a spectrum of strains with their own antigenic and epidemiological characteristics, which make it impossible to generalise about what to expect in an outbreak.
>
> (Kitching 1998)

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You must not rely on the information in the report as an alternative to legal /government advice.

Executive Summary

As part of Australia's continuing vigilance in FMD preparedness a report, '*A review of Australia's preparedness for the threat of foot-and-mouth disease*' (October 2011), was commissioned and an FMD Taskforce formed within DAFF to provide national leadership for necessary activities, including a review and assessment of FMD risks relating to wildlife[1]. The risk assessment was to consider the potential role of wildlife in or around those areas identified by the Animal Health Committee (AHC) General Surveillance Epidemiology Working Group as at "higher-risk" of an FMD incursion." This report addresses the first step in the process: to identify gap areas that need to be addressed to help inform a risk assessment for wildlife in Australia.

FMD is a significant disease for Australia. However, despite having been widely researched over many years, the role of wildlife remains indeterminate. Australia's emergency plan for FMD currently considers that wild and feral populations of animals (apart from African buffalos) pose a low risk of transmitting infection to domestic livestock (Animal Health Australia 2012) and there is good evidence that most FMD infections in wildlife in many parts of the world have been the result of transmission from livestock. The risk from wildlife is not whether they can become infected but how important are they in potentially spreading the disease. This report emphasizes that the risk of spread is lower than the prevailing paradigm.

The key gaps in our knowledge relate to the ecology of wild animals, in particular the frequency contact between groups of the same species and the frequency and extent of interactions between domestic and feral animals.

Earlier models, by not including ecological factors overstated the ability of wildlife to spread disease.

The priority is to address these issues and develop a robust risk analysis.

A number of other activities could potentially significantly improve Australia's knowledge and ability to manage FMD should it involve our wildlife. These include:

- arrangements for establishing proof of freedom in wildlife. If an FMD outbreak occurred in Australia, feral animals (especially pigs) would only be tested if required, as part of a proof of freedom program. This is requires a change of policy, and an update to AUSVETPLAN is implied (page 41);
- potential for contact between groups of wildlife and with domestic species (see page 38);
- an assessment/analysis of water buffalo and the risk they present in Australia (page 11);
- maintaining our knowledge of the location and density of key feral species (page 38), and;
- training opportunities (page 42).

[1] For the purpose of this report, wildlife are undomesticated animals living in the wild, including feral animals.

Key points/findings

- Wildlife (key species being feral pigs, goats and buffalo in Australia) are likely to be of little risk in maintaining and spreading FMDV (although the situation with water buffalo needs further analysis, given specific risks associated with the carrier status in buffalo). However wildlife should not be ignored as questions will likely be raised by overseas sources.
- If testing of wildlife is required during an outbreak the policy should be to demonstrate 'proof of freedom' rather than undertaking surveillance.
- The key gaps in our knowledge relate to the carrier status and ecology of wild animals:
    - What transmission risk does carrier status represent, particularly in buffalo?
    - How often do contacts occur between groups of the same species?
    - How often and to what extent do interactions occur between domestic and feral animals?
- The involvement of native wildlife in an outbreak is extremely unlikely but cannot be completely ruled out. This is due to a lack of field evidence (page 25).
- Carrier status and transmission risk, density (stocking rate) and frequency of contact among groups are key host and environmental factors that would influence maintenance and spread of the virus.
- Making an assumption that random and homogenous mixing of feral pigs occurs in Australia causes a substantial overestimation of the rate and spread of FMD that would occur in an outbreak.
- The problem with FMD viral plumes is overstated. To cause airborne virus spread pigs need to be at high stocking rates.

Recommendations[2]

- More knowledge is required about the likelihood for contact between wild animals (especially deer) and commercial properties in high-risk areas. A simple project is proposed that could address this knowledge gap. This work should occur in peacetime (page 39).
- Exactly how close pigs must be before virus transmission can successfully occur is not known. While this will vary according to virus strain, temperature and humidity, research or investigations into this issue would be useful. This work would need to occur overseas.
- Misleading statements about the risk posed by wild animals that appear in fact sheets should be clarified (page 8.)
- Further work needs to occur to examine the length of time FMD virus can survive in a carcass destroyed under field conditions (page 32).
- A lack of data considerably hinders the further development of accurate models. Especially important is knowledge of actual contact rates within and between species, and knowledge of movement patterns for species of interest along with seasonal influences.
- In order to include information such as spatial contiguity and interaction with other species smaller, more detailed models should be encouraged. These models should include an ecology component. Watering points are especially important. Generation of these models could be available during an incursion.
- Codes of practice and standard operating procedures for the humane capture, handling and destruction of feral animals have been produced, but are currently under review and not readily available. These codes need to be more readily available and their return to the internet should be given high priority. Consideration also needs to be given to incorporating these documents as a reference paper under AUSVETPLAN.

[2] It is difficult to list priority, as some recommendations may have lesser priority but are more easily achievable.

- If an FMD outbreak occurred in Australia, feral animals (especially pigs) would only be tested if required, as part of a proof of freedom program. This requires a change of policy, and an update to AUSVETPLAN is indicated.
- An incursion into Australia involving wild buffalo appears to have received little consideration. The current situation with buffalo would benefit from further study, including numbers of wild buffalo, location, contact with livestock and feral pigs, ecology and potential for containment or local eradication subsequent to an incursion of FMD in northern Australia. This is not a difficult exercise and should be accomplished as a priority through a workshop with relevant people. Further research is also required relating to carrier status and risk of transmission from water buffalo given the high risks posed with African buffalo. This research would have to take place overseas, most probably in South East Asia, building on initial studies on water buffalo carrier status undertaken in Laos and Myanmar (Verin 2011).

Introduction

Foot-and-Mouth Disease (FMD) is an extremely contagious viral disease, primarily of cloven-hoofed animals. FMD is characterized by fever, vesicular lesions, and subsequent erosions of the epithelium of the mouth, tongue, nares, muzzle, feet and teats. Although FMD is not found in Australia, it is of concern because of the impact it would have on Australia's trade, market access and economy should it become established. A recent report estimated that over a ten-year period there would be severe direct economic losses to the livestock and meat-processing sector from an outbreak of FMD. These losses ranged from $7 billion for a small three-month outbreak, to $16 billion for a large 12-month outbreak (expressed in current dollar terms). Estimates of control and compensation costs range between $25 million for the small outbreak, and $600 million for the large outbreak. Reflecting international experience, the economic impact of trade restrictions (export market closures) would be far greater than the cost of controlling the disease (Matthews 2011).

FMD does not confine itself to domestic animals: all cloven-hoofed animals (which include many wildlife species and feral animals), and some others are susceptible. The potential role of wildlife in FMD spread and persistence has been a matter of discussion for many years. Of concern to FMD-free nations, is the complication that arises if wild animals are infected during an outbreak. Under such circumstances, response coordinators must consider whether the species involved are a risk as intra- and inter-species transmitters of infection, whether these species could become a virus reservoir and whether further action is required.

However, countries that have eradicated FMD from domestic animals often did little to control FMD in wildlife and with no recurrence of the disease. The only exception is the documented experiences in South Africa with carrier African buffalo *(Syncerus coffer)* in the Kruger National Park where FMD viruses (SAT types - see below) have been transmitted from the buffalo to domestic cattle and perhaps to other wildlife.

As part of Australia's continuing vigilance in FMD preparedness a report, '*A review of Australia's preparedness for the threat of foot-and-mouth disease*' (October 2011), was commissioned and an FMD Taskforce formed within DAFF to provide national leadership for necessary activities, including a review and assessment of FMD risks relating to wildlife. The risk assessment was to consider the potential role of wildlife in or around those areas identified by the Animal Health Committee (AHC) General Surveillance Epidemiology Working Group as at "higher-risk" of an FMD incursion." This report addresses the first step in the process: to identify gap areas that need to be addressed to help inform a risk assessment for wildlife in Australia.

Some current views

Outlined below are a number of published opinions regarding the risk posed to livestock by wildlife and feral animals from FMD in Australia. The role of wild animals remains sensitive and differing views on the FMD risk exists in a number of statements. For example:

"Exotic wild animals could play a role in the spread and establishment of many exotic diseases in Australia, including rabies, foot-and-mouth disease, rinderpest and classical swine fever" (Bomford 2003).

"Feral pigs have the potential to play a role in the spread of foot-and-mouth disease should this disease ever establish in Australia. Their involvement in an exotic disease outbreak could delay disease detection; increase the rate and extent of disease spread; make disease eradication measures expensive, time-consuming or impossible; and have severe repercussions for Australia's livestock industries" (Choquenot, McIlroy et al. 1996).

"However, if a feral pig became infected through eating an infected carcass, the virus could spread in the feral pig population" (Animal Health Australia 2012).

"Feral pigs also host serious diseases with the potential to devastate livestock operations. It is estimated that a year-long outbreak of foot-and-mouth disease (FMD) would reduce export revenue by more than $9 billion. Furthermore, feral pigs range close enough to domestic swine facilities to pose a significant biosecurity risk" (Lapidge, Braysher M et al. 2011).

"*Cattle are most susceptible, though pigs spread the disease fastest. If an outbreak did occur, its spread could be so rapid that controls would not prevent the loss of our export livestock, meat and dairy produce markets"* (Department of Agriculture Fisheries and Forestry 2007).

Comment, "its [FMD] spread could be so rapid that controls would not prevent the loss of our export livestock, meat and dairy produce markets" (DAFF)

"This nation is sitting complacently on a menace that, if ignited, could bring our economy to its knees for a decade. ......No feral livestock pool in the world presents such a threat to its domesticated livestock. More than 20 exotic diseases can affect pigs. ......These include many transmissible to other domestic species, such as foot-and mouth disease .." (Gee 2002).

Despite these views, Australia's emergency plan for FMD currently considers wild and feral populations of animals (apart from African buffalos) pose a low risk of transmitting infection to domestic livestock (Animal Health Australia 2012) and there is good evidence that most FMD infections in wildlife in many parts of the world have been the result of transmission from livestock. Once FMD is eliminated from domestic animals, FMD disappears from wildlife (Torres 2008).

Stock take of current knowledge and an assessment of current risks

Potential Wildlife Host Species

The following section provides a stocktake of wildlife and their potential involvement with FMD. Some species are exotic to Australia but demonstrate behaviour that may be important in developing a future risk assessment or act as models. For example the influence of animal densities on the persistence and spread of FMD in African Bovidae.

General

FMD is an extremely contagious viral disease, primarily of cloven-hoofed animals. It does not confine itself to domestic animals: all cloven-hoofed animals (which include many wildlife species and feral animals), and some others are susceptible. The role of wildlife in FMD spread and persistence has been a matter of discussion for many years.

As with domestic livestock in extensive production systems, infection of wildlife with FMD results in a relatively mild disease from which affected animals recover in a week or two. The significance of the disease for wildlife lies largely in the potential that cloven-hoofed wild animals have for transmitting the disease to domestic livestock. Especially in intensive farming situations, where the disease may be severely debilitating and result in serious economic losses for producers. Perhaps more significant is the effect that the presence of the disease (more precisely, the infection) could have on international trade in livestock and livestock products.

Some wild ruminants also have the potential to become active carriers of the infection. These animals, albeit extremely rarely, transmit the infection to cohorts of the same or other species with which they are in close contact (Thomson, Vosloo et al. 2003). Buffalo are the classical example (see box page 10).

FMD and Carrier Animals

FMDV may cause a prolonged, asymptomatic but persistent infection in ruminants. The carrier state has been defined as animals being virus positive for at least 28 days. Persistent infection could be induced in cattle, sheep and goats with live virus being isolated from the pharynx area of such animals**. Pigs, however, cleared the infection in 3–4 weeks and so do not become carriers**.

In cattle, the maximum duration of the carrier state is 3.5 years; in sheep, 9 months; in goats, 4 months; and **in African buffalo, 5 years In water buffalo, the carrier status exists, however the duration is unknown but is likely to be more than 2 years (Verin 2011)**.

The factors determining the development of persistent FMDV infection are poorly understood; however, the carrier state can develop either after the acute stage or without any clinical disease, for instance in vaccinated animals (Alexandersen, Zhidong et al. 2002).

All animals, including humans, have the potential to be passive carriers of FMD.

The following section reviews and presents brief discussion on the range of animal species both present and exotic to Australia that may be considered susceptible to FMD. It includes laboratory investigations and field experiences regarding the various taxa. The aim is not to provide an exhaustive review, but to provide information and insights that may indicate gaps in our knowledge and consideration of the potential outcomes if FMD were present in Australia, based on experience with other species overseas.

It is also important to consider the possible differences in behaviour influenced by the virus types or sub-types involved when considering the host range of FMD it is very Important to distinguish between animals that:

a. Play a role in the natural epidemiology of the disease e.g. water buffalo, pigs.
b. May play a role under certain conditions e.g. deer.
c. Are susceptible to infection, and may even develop the disease under experimental conditions, but appear unimportant under field conditions e.g. rabbits (Alexandersen and Mowat 2005).
d. Are not involved, except possibly in passive transfer of the virus.

Below is a review of the literature, related by taxonomy potentially involved with FMD in several countries under differing conditions.

Order Artiodactyla

Family Bovidae

Bovidae is the zoological family to which domestic ruminants belong. It includes feral and wild ruminants such as banteng, buffalo and antelope. Even if not all species have been tested in laboratory conditions, it is likely that all species of the *Bovidae* family can be infected with FMD virus. The nature of the infection, whether clinical signs develop and if there is a carrier state, are dependent upon the specific species and the FMDV strain involved. Animals of some species may become carriers.

Buffalo

(a) Play a role in the natural epidemiology of the disease.

There are two types of buffalo, the African Cape buffalo (African buffalo - *Syncerus caffer*) and the Asian water buffalo (*Bubalus bubalis*).

African buffalo

Three SAT FMD serotypes predominate in southern Africa. They are maintained by African buffalo, which can be a source of infection for susceptible livestock and wildlife (especially impala) in close proximity. (Michel AL and Bengis RG 2012)

Infection in adult buffalo is usually sub-clinical. Infection normally occurs in calves as soon as maternal antibodies wane at 2-6 months of age (Vosloo 2008). Very few animals, if any, develop clinical disease.

All animals in Family Bovidae may be susceptible to FMD.

It is not known whether buffalo in Africa are carriers of the O and A type viruses (Vosloo 2008).

A study of the duration of the virus-carrier state in individual animals was made with a small group of African buffalo *(Syncerus caffer)* calves, demonstrated to be carrying FMDV when captured at 4-6 months old. They were held for 5 years in isolation on a peninsula at Lake Kariba in northern Zimbabwe, 45 miles from the nearest cattle. One individual was demonstrated to carry FMDV (type SAT 3) for at least five years and others for lesser periods (Condy, Hedger et al. 1985).

The study of virus persistence in a small free-living population was carried out in a herd of buffalo isolated in 1960 by the rising waters of Lake Kariba on an island of approximately 2000 acres. FMDV has been maintained for at least 24 years through several generations, in a small free-living population of 30 to 100 buffalo, where breeding took place (Condy, Hedger et al. 1985).

The results indicated that the duration of infectivity in individual buffalo is more than adequate to cover the normal periods between calving peaks.

In 2012, two separate incursions of SAT-2 into Egypt and Libya occurred. In Egypt, there were at least 40,000 cattle and water buffalo affected with over 4,500 animals (the majority calves) dying (Food and Agriculture Office 2012).

*Asian swamp buffalo (*Bubalus bubalis*)*

Asian water buffalo (*Bubalus bubalis*) (AWB), are highly domesticated and widespread. The suspected native domain of AWB is from Central India to southern Nepal in the west and to Vietnam and Malaysia in the east. True wild populations may still survive in parts of India, Nepal, Bhutan, and Thailand. Domesticated and feral populations are very widespread. River or Riverine buffalo (a domesticated type) are found more in the west and reside in Indochina, the Mediterranean, and parts of South and Central America. Swamp buffalo (another type under domestication used more as draft animals) are more easterly in distribution and inhabit Indochina and Southeast Asia as well as Australia.

As part of the South-East Asia and China FMD (SEACFMD) program, major studies have been undertaken to understand the role of Asian swamp buffalo (ASB) as a carrier for transmitting FMD virus in the region (Verin 2011).

In south-east Asia, the ASB, is important for livestock systems and communities. These studies confirmed that ASB might become persistently infected with FMDV and carry the virus for at least up to 20 months (end date of study) after the infection. Several sero-negative animals for FMDV in the first study were detected as positive in the subsequent studies, which further supports the transmission of virus from these carrier animals at a sub-clinical level.

Further research is needed to understand the mechanisms and the epidemiological significance of carriers in the maintenance and transmission of FMD. This will require a more comprehensive longitudinal study; and controlled studies to clarify the mechanism for the establishment of carriers, the factors influencing transmission and to demonstrate the rates of transmission from FMD carrier ASB (Verin 2011).

The occurrence of FMD in domesticated swamp buffalo in South.-east Asia is widespread. Types 'O" and "A" are involved. A major outbreak of FMD in Japan in 2010 originated from a water buffalo farm (Anonymous 2011).

Buffalo in Australia

Water buffalo *(Bubalus bubalis)* were imported to Australia in the 19th century to supply meat to remote northern settlements. The settlements and the buffalo were abandoned in 1949. Despite harvesting for meat, hides and as hunters' trophies, feral buffalo spread across the northern floodplains. The Brucellosis and Tuberculosis Eradication Campaign reduced feral buffalo numbers significantly in the 1980s and 1990s but numbers are again high (estimated population 150,000 in 2008) across northern Australia (Department for Sustainability 2011).

Buffalo taxonomy is confusing. Two broad types of domestic water buffalo are recognised: the river-type from western Asia and the swamp-type from eastern Asia. While swamp buffalo have 48 chromosomes and riverine buffalo 50 chromosomes, their genetic material is very similar and the two types are inter-fertile. To add to the confusion there are at least 16 breeds of domesticated water buffalo identified (Wikipedia 2013).

Buffalo occur in floodplain, woodland and sandstone escarpment habitats in areas where surface water is available. The range of buffaloes in the Northern Territory is restricted mainly to areas that receive greater than 1000 mm of rainfall annually.

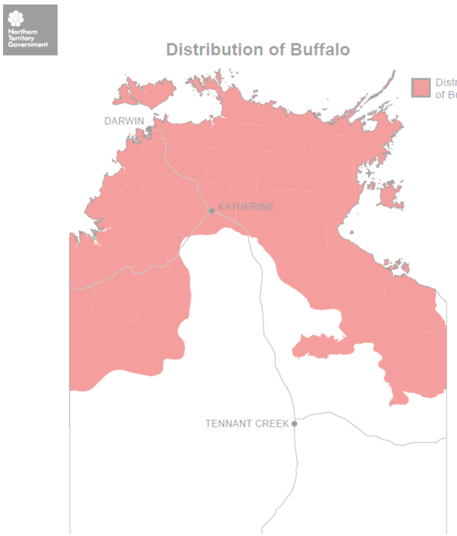

Figure 1 Distribution of WaterBuffalo (Northern Territory Government 2012)

The range occupied by feral buffaloes in the Top End of the Northern Territory appears to be increasing with the majority of the Territory herd in Arnhem Land (Northern Territory Government 2012). A small number of water buffalo occur in Queensland. Unrestricted they are likely to extend further into Queensland and Western Australia.

Australia has a mixture of the two types of buffalo: the river type from western Asia, with curled horns, and the feral swamp type from eastern Asia, with swept-back horns.

Riverine Buffalo were imported from North American herds, although this species is actually a native of Asia. The American herds were the only animals permitted into Australia. The first buffalo arrived in 1994 and crossbreeding programs began immediately between the Australian swamp buffaloes and the US riverine buffaloes. Farmed buffalo exist in all Australian States but expansion is currently restricted by the lack of abattoir outlets.

Given what we know about the central role of buffalo in FMD maintenance and epidemiology an assessment of the current risk posed by water buffalo for Australia is a priority, particularly the risk they present as carriers capable of viral transmission and maintenance within herds. This would reflect the risk they present as an ongoing source of infection to domestic species, similar to the epidemiological situation with African buffalo and FMD SAT serotypes in Kruger National Park in South Africa.

The Asian situation demonstrates that the buffalo in Australia could be carriers of FMD, and serotypes other than SAT could be involved. The African situation provides management considerations in the context of the ecology of the animal and their role in maintenance of the disease in not just this species but also other in-contact wildlife and domestic animals. Similar models should be considered for the Australian situation.

Impala (*Aepyceros melampus*)

(a) Play a role in the natural epidemiology of the disease.

Impala are another medium-sized antelope that are common throughout many African countries.

Aerosols containing as little as one cell culture infective dose have established infection in impala. (R.G. Bengis and G.R. Thomson, unpublished data quoted in (Thomson, Vosloo et al. 2003).

This sensitivity to infection may contribute to the epidemics of FMD in impala in the Kruger National Park (KNP) of South Africa (described below) and explain why this species alone suffers regular epidemics of disease.

African buffaloes in the KNP in South Africa have been shown to be the usual source of infection for impala based on sequencing studies. Most outbreaks of FMD in impala occurred within the months of June to November. This period coincides with the time at which buffalo calves are likely to become infected for the first time, plus shared grazing and drinking areas together with high population densities of both species (Bastos, Boshoff et al. 2000). Persistent infection in impala has not been demonstrated (Anderson, Anderson et al. 1975).

FMD in impala occurs commonly in localities where high population densities of the species occur. The population density of buffalo in the area does not influence outbreaks. In addition, because the impala depend on water, infection has frequently spread along watercourses in the KNP, i.e. the virus is not transmitted through the water itself but by contact between animals congregated along rivers and streams.

> This example highlights the influence of species, time of year, topography and contact with reservoir populations in disease expression. Many feral animals in dryer regions of Australia utilise watercourses as part of periodic movements in their home ranges.
> In addition, Australian feral animals have been shown to congregate in high numbers around waterholes during times of drought.

Mountain gazelle (*Gazella gazella*)

(a) Play a role in the natural epidemiology of the disease.

Mountain gazelles are antelopes belonging to the *Bovidae* family.

Mountain gazelles have been present in Israel and its environs since prehistoric times. The species became almost extinct during the late 1940s. To prevent its total extinction by hunting or poisoning, the mountain gazelle was officially declared a protected species in Israel in 1955. Consequently, the population began to multiply swiftly in its natural habitat in northeastern Israel, due to the absence of effective predators and hunting activities. The gazelle population reached a record density (40 per km^2) in 1984.

In 1985, an extensive outbreak of FMD occurred among the densely populated gazelles. Many lame or immobile animals as well as fatalities were reported. The disease affected all age groups and both sexes. Typical, severe oral lesions of FMD were observed. Foot lesions characterised by interdigital elongated erupted vesicles were seen in many cases. Separation of the hooves was frequent. Except for a few cases in young, unvaccinated cattle and sheep and goats in adjacent farms, the disease did not spread. This was probably due to the strict disease control measures taken, and the immune status of the local domestic livestock, which had been vaccinated (Shimshony 1988).

It was concluded that this unusually malignant form of FMD resulted from the high virulence of the particular virus strain (Type O) combined with an extremely susceptible host, present in a very high population density (Shimshony 1988). It is assumed that the origin of the infection, in the mountain gazelles, was outbreaks of FMD in Jordan, reported earlier in 1985.

Comment: This example highlights the marked influence of density of a vulnerable species on the establishment and spread of the FMD virus.

Cattle (*Bos taurus*)

(a) Play a role in the natural epidemiology of the disease.

Feral cattle are widespread in the rangelands, occurring mainly north of the Tropic of Capricorn, in national parks, and on grazing leases that are not adequately fenced. Their number and range are difficult to determine because they occur in regions that also carry domesticated cattle. The distinction between feral and domesticated cattle often blurs, because in some areas, domestic cattle regularly go feral, and in other areas, feral cattle are regularly mustered.

Feral cattle have been reported in the Hamersley Ranges and the Ashburton and Fortescue drainages of the Pilbara; the King Leopold Ranges of the southern Kimberley; the Gulf Country of the Northern Territory; and north-western Queensland.

Banteng cattle are indigenous to South East Asia. A small herd of them were released into the remote Cobourg Peninsula in the Northern Territory during the 1840s. Today they are endangered across most of their home range but the Australian population is large, healthy and stable within the national park.

Many national parks, reserves, and indigenous-owned lands in Australia are populated with feral cattle. These cattle are most obvious when they occupy national parks and other reserves, although branded domestic cattle often feed in parks as well (Department of Environment and Water Resources 2007).

Goats (*Capra hircus*)

(a) Play a role in the natural epidemiology of the disease.

The goat, a member of the family Bovidae is closely related to sheep. Both species are in the goat-antelope subfamily Caprinae.

Domestic goats occur on all continents (except Antarctica), but their feral descendants are much less prevalent, occurring widely only in Australia, New Zealand, and on many small islands. There are about three million feral goats in Australia but this number has fluctuated widely under the influence of extended dry periods and the effectiveness of management programs.

In Australia, most feral goats live in the semi-arid pastoral areas used for sheep farming where food is usually abundant and regular water provided. Interaction between feral goats and commercial sheep/goat flocks is not an unusual event.

The home range of feral goats with good supplies of food and water is only about one square kilometre. An inverse power function has been found to be an excellent descriptor of the relationship between mean annual rainfall and female home range size (Fleming 2004). In drier areas, movements are centred around permanent water and their home range is much larger at 70 to 250 km^2. Males have larger ranges than females. During dry times, the size of their home range decreases as feral goats have to regularly visit water points to drink. This dependence on water can be used to help control them. For example, trapping at water points or harvesting animals that are concentrated around remaining waters during drought.

Feral goats are highly social animals and can form very large herds. The basic social unit is an adult nanny and her recent offspring. These usually associate in the herd area with similar, often related, social groups. When sexually mature, young males leave their mother’s group to form loose groups with similar-aged males or larger mixed-aged groups. These associate with the home range of females during the main breeding period, but roam more widely at other times (Invasive Animals Cooperative Research Centre 2013a).

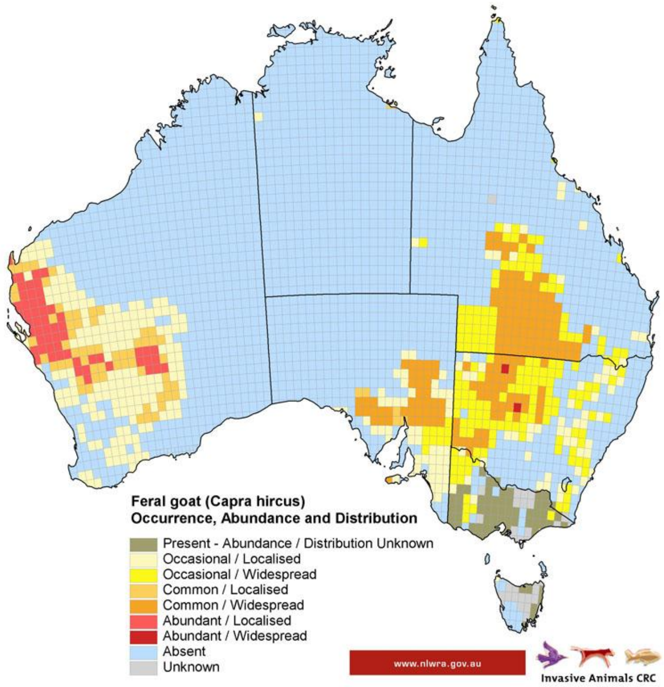

Figure 2 Distribution of feral goats (West 2008)

FMD in goats

Direct transmission of FMD occurs from infected to susceptible animals. Cattle are more susceptible to infection by airborne plumes than either sheep or goats. There is general agreement that the disease in naturally acquired infections **often takes on a milder form in goats** and sheep, than in cattle and pigs and in many cases the clinical signs are vague. In contrast, mortality is often seen in lambs and kids in the absence of any clinical signs and is generally the result of myocarditis or myocardial lesions. The disease may only be apparent when mortalities become apparent in juveniles (Barnett and Cox 1999). Sheep movements were a significant method of spread in the large UK FMD outbreak of 2001. Although this is unlikely to be relevant in Australia Fleming's study indicates interaction between feral goats and commercial sheep flocks is not unusual.

By undertaking serological investigations estimates of antibody prevalence in goats in India to both non-structural (NSP-Ab) and structural proteins (SP-Ab) of FMD resulted in overall NSP-Ab and SP-Ab sero-prevalence of 38% and 20.7%, respectively. This signified a very high level of FMD virus circulation in the goat population despite the lack of clinical signs (Ranabijuli, Mohapatra et al. 2010).

Modelling by Fleming predicted that FMD would die out in a mixed sheep and feral goat population in less than 90 days because of feral goats being relatively sedentary with a low rate of herd-to-herd contact and herd to flock contact. Because feral goat home ranges overlap and are centred on one or two small water catchments, a containment ring of feral goat control, set to encompass the home range of a target group should be sufficient to limit the spread of FMD (Fleming 2004). A recent publication outlines eradication of feral goats from an island by effective co-operation and good planning using the Judas goat technique (Invasive animals cooperative research centre 2013b).

However, feral goats may play a role in the epidemiology of FMD due to their potential to be virus carriers (four months) and their masking of clinical signs.

Family Suidae *(Pigs)*

(a) Play a role in the natural epidemiology of the disease.

Pigs are generalist omnivores. Apart from the domestic pig (*Sus scrofa),* Family *Suidae* includes the African warthogs (*Phacochoerus africanus*) and African bush pig (*Potamochoerus larvatus*).

Transmission

Pigs usually become infected with the virus by

- eating FMDV-contaminated products,
- direct contact with another infected animal,
- being placed in a heavily contaminated environment.

Pigs are considerably less susceptible to aerosol infection than ruminants. Recent studies have demonstrated that pigs require as much as 600 times more exposure to aerosol virus than by a bovine or ovine, to cause infection (Kitching and Alexandersen 2002).

Rarely, FMD has been transmitted over long distances by air-borne aerosols, but this requires high concentrations of infected domestic pigs to generate a plume of virus-containing aerosols. There is no reason to believe that wildlife, including warthogs, are capable of generating significant levels of aerosolised virus (Thomson, Vosloo et al. 2003).

Information is sparse about transmission of FMDV between wild pigs or between wild pigs and other species.

In Israel, infection has been found in wild boars present on premises where an outbreak of FMD had occurred in cattle (AVIS College 2002). Under experimental conditions, wild boars infected by contact with infected domestic pigs developed small vesicles along the coronary bands of the feet and in the interdigital spaces.

Because the control of FMD in the Middle East depends predominantly on vaccination, unvaccinated wild animals are excellent sentinels for circulating virus. Between 1986 and 1994, wild pigs in Israel were monitored for FMDV antibodies and FMDV in oro-pharyngeal tissue. Of 153 blood samples from wild boar, 19% had FMDV antibodies and 13% oro-pharyngeal tissue samples yielded FMDV. However, seropositive samples were collected only in 1992 and 1993. Only in the case of the wild boar sampled in 1992 (36% seropositive, and virus isolated from six animals), was there an epidemiological link between the infection in the wild boar and an outbreak of FMD in a beef cattle herd in the vicinity. In Western Europe, there have been no reports of a spillover of FMDV to wild boar in the last 80 years (Elbers, Dekker et al. 2003).

A common pattern of FMD outbreaks reported in temperate zone countries is that disease initially occurs when pigs contract infection by ingestion of uncooked meat scraps. Pigs then act as amplifiers of the virus as the disease spreads among this species with transmission principally by the oral route. Spread from these pigs to cattle is then by aerosol transmission through infection of the upper respiratory tract.

For many years, outbreaks of FMD have been common in Southeast Asia. The involvement of pigs during outbreaks and their role in the spread of FMD was investigated frequently. For example, a five-year study in

Thailand concluded that the source of 49/60 (82%) outbreaks was attributed to either recent purchases of infected cattle and buffalo or co-mingling of cattle and buffalo with stock from an infected neighbouring village(Chamnanpood, Cleland et al. 1995). No clinically affected pigs were observed in 11 outbreak investigations. Investigators concluded that pigs did not commonly become infected when there were outbreaks of FMD in village cattle and buffalo in northern Thailand. Compounds for cattle and buffalo were commonly close to, but not adjacent to, pig pens. During outbreaks, aerosols from infected cattle and buffalo could potentially convey an infectious dose to pigs. However, as described above pigs are less susceptible than cattle to aerosol infection, and virus in aerosols is likely to be rapidly inactivated by the high environmental temperatures and intense sunlight in northern Thailand. These factors may work to limit spread of virus from cattle and buffalo to pigs in the village production (Chamnanpood, Cleland et al. 1995).

The Cathay topotype, serotype O causes disease only in pigs. Spread of disease is by close contact, and investigation of outbreaks in the Philippines, where it was restricted to ‘backyard’ pigs, has shown that **the virus does not transmit even between neighbouring backyards as an aerosol** (Kitching 2005).

This should be compared with the following statement from a recently published paper:

> “Pigs are highly susceptible to infection by FMD virus and can act as amplifiers in disease outbreaks, excreting large amounts of the virus. The high density of feral pigs in southern Texas (>50 km $^{-2}$ in areas), for example, would provide an ideal mechanism for spreading the infection” (Ward, Laffan et al. 2007).

Transmission of FMDV is discussed further under the section relating to modelling (page 26).

Clinical Signs

Suids, which have a high ratio of body-weight to foot-size, and which root with the nose, tend to have the most severe lesions on the feet and on the rostrum of the snout. In warthogs, which tend to ‘kneel’ while grazing, lesions are common in the skin covering the carpal joints (R.G. Bengis personal communication). In Bulgaria during an outbreak of FMD involving wild boar, no dead animals or animals with clinical signs were found in the surveillance area. The original case showed about 14 day-old lesions on all feet. (Alexandrov T, Stefanov D et al. 2013).

Feral Pigs in Australia

Approximately up to 23.5 million feral pigs are spread across about half of the continent from western Victoria, through New South Wales into Queensland, and across northern Australia. Isolated populations can also be found on a few offshore islands.

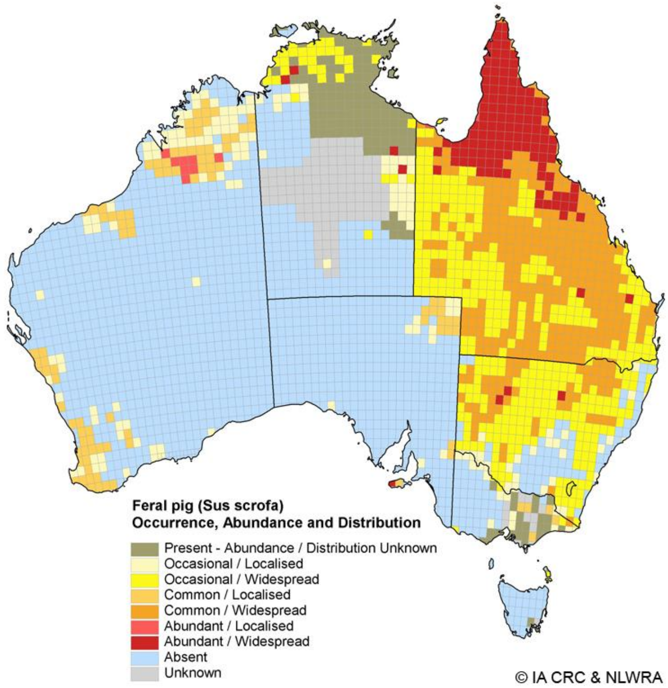

Figure 3 Feral Pig distribution (2007) http://www.feral.org.au/feral-pig-distribution-national-map-200607/

Feral pigs are not found in the dry inland. In hot weather, they are usually found within two kilometres of water. Densities vary depending on conditions, with about one feral pig per kilometre square in eucalypt woodland, forest and grazing land, and as many as 10–20 per kilometre square in wetlands and seasonally inundated floodplains (Department for Sustainability 2011).

Family **Camelidae**

Feral Camels (Camelus dromedarius)

(c) Are susceptible to infection, and may even develop the disease under experimental conditions, but appear unimportant under field conditions.

Many different types and breeds of camels arrived into Australia; most were from India. They included the large, fleece-bearing, two-humped Bactrian camel of China and Mongolia, the elite Bishari and Bikaneri riding camels of Arabia, and the powerful, freight-carrying lowland Indian camels, capable of moving huge loads of up to 800 kilograms. The feral camels found in Australia are a meld of these breeds (Department for Sustainability 2009). (Note: although described as a meld, camels in Australia are usually described as the one-humped dromedary species.)

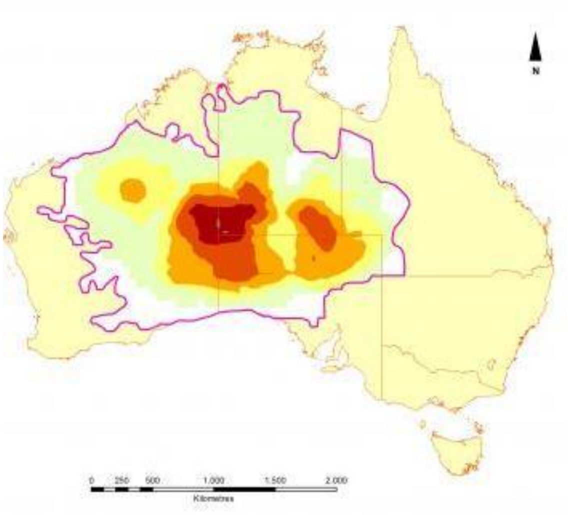

Figure 4 Distribution of feral camels (maximum density 1-2 km²)
source: http://www.feralcamels.com.au/maps

Feral camel numbers in Australia were estimated in 2004 at more than 500,000 with approximately half of them in Western Australia. Current estimates place the population at closer to one million, and a doubling time of about nine years is likely.

Feral camels live in non-territorial groups of three main kinds: year-round groups of bulls, summer groups of cows and calves, and winter breeding groups that include a mature bull and several cows and their calves. Only old bulls tend to be solitary. Herds are generally around ten individuals but larger herds may form in summer when groups congregate around limited water resources.

Feral camels may damage pastoral enterprises through competition with stock for limited forage, and by damage to the property infrastructure — fences, windmills, water troughs, etc. (Department for Sustainability 2009).

Camels are often recognised, along with cattle, sheep and pigs, as being affected by FMD. For example, a DAFF fact sheet states; "*Foot and mouth disease (FMD) is a viral disease and is one of the most contagious diseases of livestock. It affects cloven-footed animals including cattle, buffalo, camels, sheep, goats, deer and pig."(Department of Agriculture Fisheries and Forestry 2007) .* However, observations on natural and experimental FMD, have failed to show convincingly that dromedaries have the same susceptibility to FMDV as ruminants or pigs (Larska, Wernery et al. 2009).

In 2000 in Mongolia, the type O virus infected cattle, sheep, goats and Bactrian camels (*Camelus bactrianus*) in which typical FMD lesions were seen. However, clinical signs only were recorded in the Bactrian camels and no specimens were submitted (Wernery and Kaaden 2004).

In a recent study, eight dromedary camels and two Bactrian camels were inoculated with FMDV type A. The inoculated dromedary camels were not susceptible to FMDV type A infection. None of them showed clinical signs of FMD or developed viraemia or specific anti-FMDV antibodies despite the high dose of virus inoculated. Characteristic FMD lesions developed in the Bactrian camels, accompanied with severe lameness in the hind feet. The results indicated that the two closely related camel species possess noticeably different susceptibility to FMD virus (Larska, Wernery et al. 2009).

Although, new world camelids (llama and alpaca) can be infected with FMDV by direct contact, they are not very susceptible and do not pose a risk in transmitting FMD to susceptible animal species (Wernery and Kaaden 2004).

The 2012 OIE Terrestrial manual states, "Among the camelidae, Bactrian camels and new world camelids have been shown to be susceptible."

Although camels are ruminants, they would appear to be of no significance in transmitting FMD in Australia.

Family Cervidae *(Deer)*

(b) May play a role under certain conditions.

In *Cervidae*, the severity of the disease can vary from mild or inapparent in some species to more severe in others (Table 1). For example, the disease is mild in red and fallow deer but more severe and sometimes fatal in western roe and muntjac deer (Gibbs, Herniman et al. 1975). After exposure in a laboratory, for two hours to cattle with FMD virus, each of five species of deer became infected. Clinical disease was typical — severe in the roe and muntjac deer, with some animals dying, less severe in the sika deer, and usually subclinical in the fallow and red deer. Each species transmitted disease to its own species and to cattle and sheep. The amounts of virus present in the blood, and in oesophageal/pharyngeal samples and excreted as an aerosol during the course of the infection in the deer were similar to those recorded for the sheep and cattle in the same experiment. The fallow and sika deer commonly carried virus in the pharynx beyond 28 days after exposure; some red deer also became carriers (Gibbs, Herniman et al. 1975).

A recent study comparing the infection of FMDV, strain O1 Manisa, in bison (family Bovidae) and elk (family Cervidae) with that in cattle showed marked differences in susceptibility to the infection and efficiency of transmission in the bison and elk. Bison were readily infected when exposed to infected bison or cattle. Clinical signs and lesions in bison were similar to those in cattle. Inoculation of the same virus in elk (*Cervus elaphus nelsoni*), however, produced only mild clinical disease, and elk were neither susceptible to infection by exposure to infected cattle or elk nor efficient at transmitting the infection to cattle (Rhyan, Deng et al. 2008).

In 2001, when an outbreak of FMD was detected in the UK, the disease spread to the Netherlands. Farmers reported lame deer in the reserve within the centre of the epidemic. As part of the disease emergency program, a serological survey was conducted in wild deer and wild boar. Wild deer were blamed by farmers, but extensive investigations always concluded that wildlife could not be incriminated and that infection came from other cattle and direct contacts. In Eastern Europe, outbreaks occurred in the late 19th and 20th centuries in reindeer, antelopes and various deer species. This was at a time when pastures on which these animals lived were used continuously by domestic cattle.

> ***"Wildlife could not be incriminated (in transmission of FMD) and that infection came from other cattle and direct contacts (Elbers et al 2003)."***

Because of the separation of species in Western Europe, the belief is that wild deer are very unlikely to be an important factor in the maintenance and transmission of FMDV (Elbers, Dekker et al. 2003).

Deer in Australia

Eighteen deer (Family *Cervidae*) species came to Australia in the late 19th and early 20th centuries, mainly by acclimatisation societies. The majority of these animals perished. However, six of the liberated species - chital, red deer, rusa deer, fallow deer, hog deer and sambar - survived and went on to form viable wild populations. Escapes from deer farms and translocations of deer since the 1980s have seen the number of wild deer in Australia increase to about 200,000 in approximately 218 populations (Department of Agriculture Fisheries and Forestry (Queensland) 2011) (Saunders and West 2003).

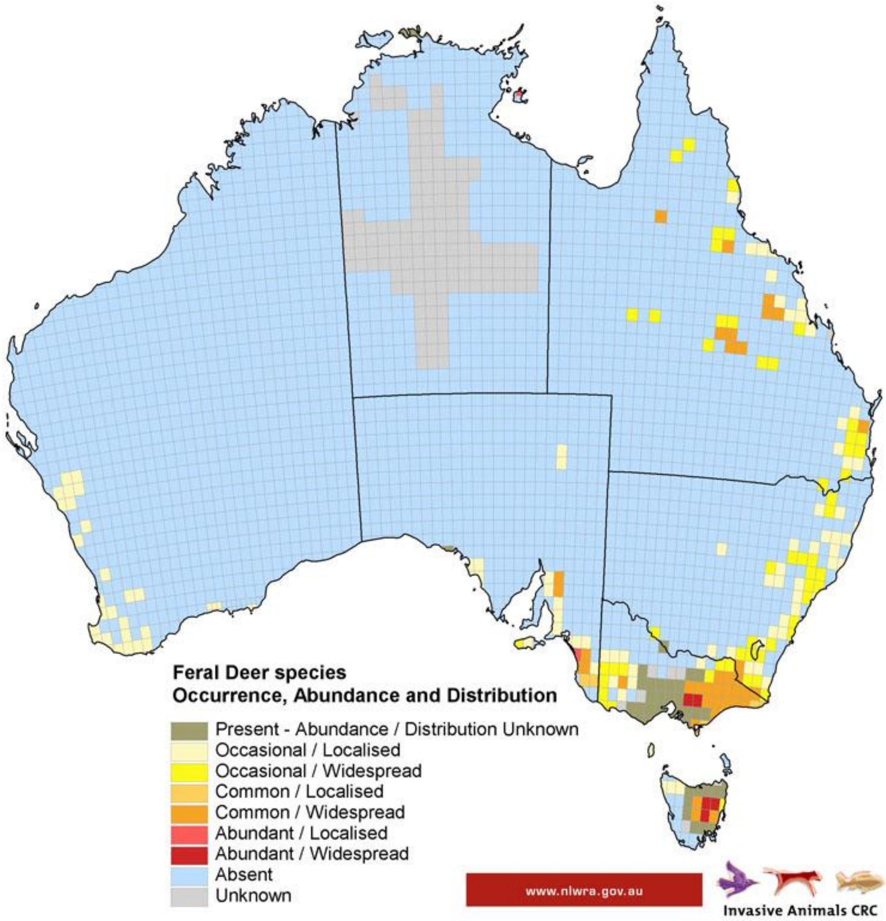

Figure 5 Distribution of feral deer (West 2008)

Adapted from (Arzt, Baxt et al. 2011). Table 1 demonstrates the variation that can occur with clinical signs and lesions among deer species.

Table 1. Characteristics of foot-and-mouth disease in selected deer species

Species	Clinical disease	Viraemia	Lesions	Mortality	Carrier	Present in Australia
Red (Wapiti or elk) (*Cervus elaphus*);	Mild to sub-clinical	Yes	Yes	None	28 days	Yes
Fallow deer (*Cervus [Dama] dama*)	Mild to sub-clinical	Yes	Yes	None	28 days	Yes
Chital, axis or spotted deer (*Cervus [Axis] axis*)	Yes		Yes	low		Yes
Roe (*Capreolus capreolus*)	Severe	Yes	Yes	None	No	No
Sika (*Cervus nippon*)	Mild	Yes	Yes	Low	28 days	No
Muntjac (*Muntiacus reevesi*)	Severe	Yes	Yes	High	No	No

In Australia due to the isolation of feral deer into small groups and with separation of deer from livestock means, that infection of cattle from deer is an unlikely phenomenon. However, more knowledge is required about the likelihood for contact between wild deer and commercial properties in high-risk areas.

Birds (Class Aves)

(d) Are not involved, except possibly in passive transfer of the virus.

Birds do not seem to be at all susceptible to FMD virus. However, during the British epidemic of 2001, racing pigeons were forbidden over the Channel, because they were regarded as potential passive carriers of the virus, possibly over long distances (Moutou 2003).

Order Eulipotyphla ('Insectivora')

European hedgehogs (Erinaceus europaceus)

(b) May play a role under certain conditions.

The occurrence under natural conditions of FMD in hedgehogs was reported in connexion with outbreaks of the disease among cattle in Norfolk (England). Transmission could have been in both directions and there may have been some spread among the hedgehogs (McLauchlan and Henderson 1947). The hedgehog was also found to have serious and fatal FMD lesions during the 2001 outbreak of FMD in the UK (Pinto 2004). No control actions against the hedgehogs were taken during the outbreak (Moutou 2003).

European hedgehogs are common in New Zealand but do not occur in Australia.

Order Rodentia

Capybara (*Hydrochoerus hydrochoeris hydrochoeris*)

(b) May play a role under certain conditions.

In a 1984 study, two capybaras and two cattle were exposed by contact to a capybara inoculated intramuscularly with FMD virus. Both pairs of exposed animals were then used as a contact source with another two cattle and two capybaras, respectively. All the animals became infected prior to the appearance of clinical lesions in the respective donor animals, and developed generalized FMD clinical lesions (Gomez and Rosenberg 1984).

Native to South America, the capybara inhabits grasslands and dense forests and lives near bodies of water. It is a highly social species, and can be found in groups as large as 100 individuals, but usually lives in groups of 10–20 individuals. The rodents' close coexistence with cattle in FMD areas suggested that the species might play an important role in the epidemiology of FMD.

Points of interest are that:

- No instance of natural infection has ever been recorded.
- As far as has been reported, eradication of FMD from South American countries has not been impeded by infected capybaras.
- Some publications do not clarify that natural infection has never been recorded. For example the OIE technical fact sheet states: .... “Capybaras and possibly hedgehogs are susceptible”(OIE 2009).

Other Rodents

(c) Are susceptible to infection, and may even develop the disease under experimental conditions, but appear unimportant under field conditions.

Australia has a large number of indigenous rodents, all from the Family *Muridae*. These are presumed to have arrived within the last 4 million years from Asia.

Laboratory mice (*Mus musculus*) and guinea pigs (*Cavia porcellus*) are highly susceptible to infection with FMD virus following needle inoculation, and neonatal mice frequently develop fatal disease. There is no evidence that mice or other small rodents have been involved in the spread of FMD in the field (Thomson, Vosloo et al. 2003).

Australian marsupials

(c) Are susceptible to infection, and may even develop the disease under experimental conditions, but appear unimportant under field conditions.

Laboratory studies with Australian native animals were undertaken by Snowdon (1968). Many of the species were susceptible in the sense that virus multiplication took place and antibody was produced but lesions were seen in just one tree kangaroo, four water rats, two echidnas and possibly one red kangaroo. Viraemia was observed in addition in grey kangaroos, wallabies, wombats, possums, and potoroos.

Although in one case infection spread by contact from inoculated kangaroos to cattle, the chain of transmission, cattle-kangaroo-cattle, was not established and it is probable that susceptibility at this level implies little chance of transmission in the field (Snowdon 1968).

Native animals involved in the studies were:

Red kangaroo (*Megaleia ruja*)
Grey kangaroo (*Macropus giganteus*)
Tree kangaroo (*Dendrolagus matschiei*)
Wombat (*Vanitatus hirsutus*)
Brush-tail possum (*Trichosurus vulpecula*)
Long-nosed bandicoot (*Perameles nasuta*)
Potoroo (*Potorous tridactylus*)
Water rat (*Hydromys chrysogaster*)
Echidna (*Tachyglossus aculeatus*)
Brown-marsupial mouse (*Antechinus stuartii*)
Bennett's wallaby (*Macropus rufogriseus*)

A zoological garden in Alipore, India reported sloughing of footpads and lameness in one of three adult grey kangaroos (*Macropus giganteus*). The foot lesions were severe and sufficiently painful to prevent the kangaroo from standing. Two days after the onset of clinical signs, the kangaroo died (Bhattacharya, Banerjee et al. 2003). The attending veterinary surgeon subsequently noticed signs of lameness in two barking deer (*Muntiacus muntjak*) and strongly suspected FMD. Only heart muscle was available for sampling from the carcase of the buried kangaroo. A positive reaction to the FMD virus (typing ELISA) and the histopathological observations strongly suggested that the kangaroo had been infected with FMD virus. The major possible source of the infection was the cattle market adjacent to the boundary wall of the zoo. During the time of the outbreak, FMD was prevalent in the surrounding locality. The FMD virus from this area was identified as being type 0 (Bhattacharya, Banerjee et al. 2003). The case was briefly reported in an OIE publication (Bhattacharya, Banerjee et al. 2005).

It is essential to differentiate laboratory studies from field observations when evaluating the potential risks from wildlife due to the artificial conditions, which are unlikely to occur under field conditions. The situation that could occur in the field is unknown with Australian marsupials.

Order Lagomorpha Family Leporidae

(c) Are susceptible to infection and may even develop the disease, but appear unimportant under field conditions.

The intranasal and oral exposure of European wild rabbits *(Oryctolagus cuniculus)* resulted in the multiplication of the FMD virus with detectable viraemia in 2 of the 6 rabbits exposed, but no clinical signs were observed (Snowdon 1968). Some vaccines have been produced, up until very recently, by multiplying the virus in young rabbits 1968. This does not mean however that rabbits have an importance in the natural history of FMD (Moutou 2003).

Conclusions

Except in southern Africa, FMD does not persist in wildlife, unless the disease is also present in domestic livestock e.g. wild boar in Israel. Outbreaks of FMD in gazelles in Israel and impala in Africa demonstrate the significance of high stocking densities. In addition, the spread of disease in impala along watercourses provides a practical example of the predictions made from spatial modelling (see below).

The significance of the carrier state in buffalo is a major reason for the disease persisting in Africa and possibly Southeast Asia.

Better understanding of potential contacts between wild animals and commercial holdings is required.

Finally, it is essential to differentiate laboratory studies from field observations when evaluating the potential risks from wildlife due to the artificial conditions, which are unlikely to occur under field conditions.

Assessment of FMD/wildlife models

Disease modelling is a tool used to study diseases such as FMD to understand better, potential disease spread and control under different conditions. Disease modelling of wildlife and FMD has been prominent over the last twenty years. In time, the increasing power of computers has led to more sophisticated models being produced, to the extent that the earlier models are misleading in their predicted outcomes (yet they are still often quoted in the literature).

This section is not a review of the modelling that has been undertaken, but will look more at the assumptions devised and the gaps that exist when developing models. A relatively recent review has been published (Cowled and Garner 2008).

Most models involving wildlife and FMD utilise feral pigs as the host species.

Basic disease and ecological data

Cowled et al. (2012) identified the following as the key disease behaviour information required for modelling:

- Latent period

- Infectious period (to this should be added the carrier status)
- Immune period
- Probability of transmission between individuals/herds
- Proportion of mortality within herds

Transmission is the key process in a host-pathogen interaction. Although several modes of transmission of FMD are possible, direct contact between pigs is likely to be the major factor and this will be determined by behaviour patterns. Apart from older boars and farrowing sows, feral pigs tend to form small, loosely associated groups, which move through overlapping home ranges.

Due to the infectious nature of FMD, infection with FMD is likely for all pigs within a group containing an infectious individual, but the rate of disease transmission in the overall population is limited by the contact rate between individuals from different groups.

How close must pigs be before virus transmission occurs?

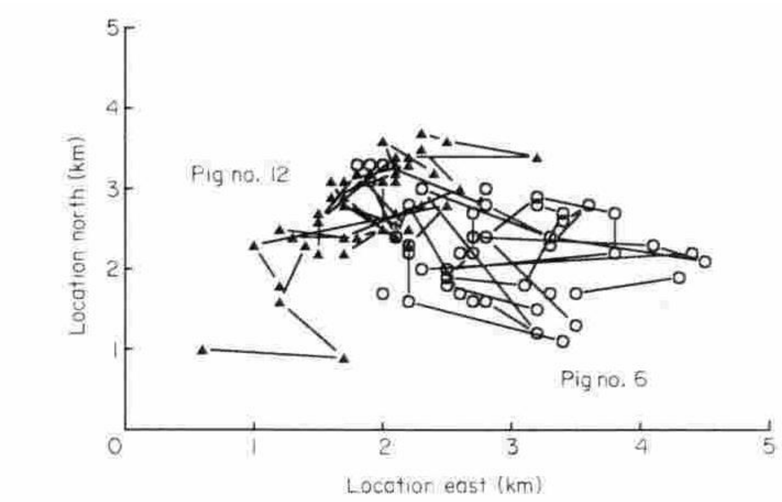

Figure 6 Movements of two of twenty-four feral pigs whose locations were recorded at three hour intervals over one week (Pech and McIroy 1990)

Clearly, the tendency of feral pigs to remain within fairly well defined home ranges[3] is inconsistent with rapid movement of infection through the feral pig population.[4] Exactly how close feral pigs must be before virus transmission can be successfully transferred is not known.

In a 2006 laboratory study, the within- and between-pen transmission of FMD virus in groups of pigs was investigated by estimating the daily transmission rate β, i.e. the number of secondary infections caused by

[3] Daily home ranges are generally small (0.7–1.4 km^2).

[4] *Brucella suis* a pathogen of feral pigs is known only to occur in a geographically discrete region in Queensland. By studying the mechanics of distribution insights may be gained into how other infectious diseases may behave under natural conditions.

one infectious pig during one day. At the time of challenge, inoculated and contact pigs were separated and the groups reunited 24 hours later. In the four groups in which the within-pen transmission was observed, the contact pigs were housed in the same pen as the inoculated pigs and thus had direct contact with the inoculated pigs. In the group in which the between-pen transmission was observed, the contact pigs were housed in the same animal room but were separated from the inoculated pigs by a wall of 1.50 m high, so that the only contact of the inoculated and contact pigs was indirect. The airflow in this experiment was directed from contact to inoculated pigs. The between-pen transmission rate β_b was estimated to be 0.59 per day (0.083 – 4.18), which was significantly lower than the within-pen transmission rate β_w of 6.14 (3.75 – 10.06). Time for the first direct contact pig to become infected was 1.6 hours, compared with between transmission of 16 hours (Ebléa, de Koeijerb et al. 2006).

Appraisal of Models

Pech and Hone (1988) constructed a non-spatial deterministic FMD disease model for feral pigs. The population was divided into categories according to disease status: susceptible, latent, infective or immune. An important prediction was that below a certain threshold density of susceptible animals, the disease will die out naturally, and at densities above the threshold, the disease will persist indefinitely. Their results suggested that, for floodplain habitat in semi-arid eastern Australia, the threshold feral pig density for the disease to persist is 2 3-14 km^2 (Pech and Hone 1988). The large uncertainty is due to limited data for estimating the disease transmission coefficient. One of the key concepts in mathematical models is the existence of a threshold level of host abundance required for invasion or persistence of infection. This originated in human health and is poorly supported by evidence from wildlife disease studies. Persistence of disease increases gradually with population size, and depends strongly on the timescales of demographic and transmission processes (Lloyd-Smith, Cross et al. 2005).

Pech and McIroy expanded on the mathematical model (above) and estimated that the velocity of FMD across the landscape in pigs would be 2.8 km/day (Pech and McIroy 1990).

A stochastic[5] model of feral pig population dynamics, with death rate linked to vegetation and rainfall was linked to Pech's deterministic model of FMD in feral pigs. Unlike the fully deterministic model, the stochastic model predicted inevitable extinction of the disease. When the transmission coefficient for FMD was set at the mean value of 9 km^{2}pig^{-1}day^{-1}, the mean persistence time of the epizootic (in 1000 simulations) was 3338 days, with a maximum persistence time of 8439 days (Dexter 2003).

To what extent do feral pig home ranges overlap?

A key assumption is that density-dependent disease transmission occurs in a homogenously distributed and randomly mixing population (Cowled and Garner 2008). Another major problem with these models is that when determining the values for the transmission coefficient, a contact was recorded (by radio-tracking) when the distance between a pair of pigs was within 200 metres.

Later researchers used a susceptible-infected-recovered approach, implemented within a cellular automata model, to assess the potential spread of FMD through two areas in Queensland, Australia (Doran and Laffan 2005). These authors divided their study areas into a lattice of grid cells and allowed for communication based on probabilities among neighbouring cells. The aim of the research was to model the spatial dynamics

[5] Having a random probability distribution.

of a FMD outbreak in feral pig and livestock populations to examine how such an epidemic would spread through time and space. A cell size of 29 km^2 (5.385 x 5.385 km) was chosen to represent the average feral pig home range size for both boars and sows in tropical Australia. Feral pig home ranges overlap and using an average size implicitly accounts for this in the modelled interactions because the larger ranges will overlap with adjacent smaller ranges. In the model, the herds in a cell could pass, sequentially, through four model states: from susceptible to latent, to infectious, to immune and then to susceptible again.

The first transition (secondary infection) depended on contact rates between susceptible and infected herds in the previous time step. "Herds" within cells were assumed to come into close enough contact to transmit the virus every 1–6 days (Pech and Hone, 1988; Pech and McIlroy, 1990). They assumed complete contact between all pigs in a cell after 6 days, and complete infection of the cell after that. Only after that period was an infected cell capable of infecting its neighbours. One of the main assumptions of this approach is that homogenous mixing of herds took place within cells but not between cells.

The probability of interactions between cells depended on the density of susceptible herds and not on the connectivity of natural habitat. In addition, as in the previous studies, it assumes a contact of <200 meters is sufficient to transmit the virus. The paper also infers that airborne spread by pigs is probable in a tropical location, which is extremely unlikely.

Airborne transmission

Under specific epidemiological, climatic and meteorological conditions, short-distance aerosol transmission may be extended to airborne transmission over a significant distance. This is particularly a risk when large numbers of pigs are infected because pigs excrete large quantities of airborne virus (up to 10^5-10^8 $TCID_{50}$ per pig per day), whereas ruminants excrete less virus in their breath (10^4-10^5 $TCID_{50}$ per day) but, in contrast to pigs, are highly susceptible to infection by inhaled virus. It has been established that ruminants can be infected experimentally by airborne exposure to only 10 $TCID_{50}$, whereas to infect pigs by this route requires more than 10^3 $TCID_{50}$ and infection only occurs if virus is delivered at a high concentration. Therefore, often the pattern of airborne spread of FMD is from pigs to cattle and small ruminants downwind. Because cattle are larger than sheep/goats, they inhale more air in a given time and are therefore likely to be more readily infected than sheep/goats by the airborne route. FMDV isolates vary in the amount of virus released in the breath of infected animals. Long-distance airborne spread is only likely to occur when conditions are relatively stable because of the specific climatic and topographical conditions, i.e. a relative humidity above 55% and minimal mixing of the air. Mixing of air may occur from the turbulence following passage of wind over hills, trees or buildings. Conditions favourable to transmission occur under a continuous steady or slight wind, cloud cover and a level topography such as the passage of the plume over, e.g. large tracts of water (Alexandersen and Mowat 2005).

Ward et al. (2009) designed a geographic automata model, to increase understanding of the potential spread of FMD virus through time and space in deer, pigs and domestic cattle. It functions by simulating population densities of susceptible deer, cattle and pigs by estimating ecological carrying capacity of various land use categories. The model related data to be associated with particular locations. Animals moved through susceptible, latent, infected and immune states, with movement from susceptible to latent being based largely on distance and relative densities between neighbours. The probability of transmission from one herd to another is the product of the relative animal densities of the two herds, modified by the distance (km) by which they are separated. Transmission probabilities are reduced, as neighbouring herds are located further away from each other. The model was constrained to some extent by crude estimates of the distribution of wild species (Ward, Laffan et al. 2007).

In further studies, they found a lack of continuity within the feral pig herd distribution across the landscape made predicting disease spread more difficult than for deer, which in their study were assumed to be distributed more homogenously across the landscape. However, this is not the case in Australia where deer exist in discrete communities.

Critical resources for wild pigs are water, riverine habitat for thermal protection and plant food resources Pigs are highly social animals that do not establish and defend territories, and as such have overlapping home ranges. Distribution across a landscape depends on resource availability; but is also driven by local spatial, social, density and individual factors as well (Cowled, Ward et al. 2012). Models that do not take realistic spatial structures into account (e.g. river systems) may overestimate the rate at which a disease will spread and vastly overestimate the size of an outbreak (Cowled, Garner et al. 2012).

Feral goats

Fleming (Fleming 2004), for his thesis studied feral goats and domestic sheep in relation to exotic disease transmission. He investigated the ecological and behavioural characteristics of feral goats and their interactions with sheep in central eastern NSW. He compared a deterministic temporal model and a spatial stochastic model. The spatial model incorporated the use of habitat by herds of goats. Daily contact rates were estimated from observed contacts in the field (a contact being within one body length). Contacts between sheep and feral goats occurred at a rate of 2.8 contacts per day. Contacts between herds of feral goats were not common and those between adjacent populations were less than once per year.

The deterministic temporal models of FMDV transmission showed that the rate of contact within and between species was such that FMD was predicted to spread rapidly. The spatial model predicted that FMD would die out in a mixed sheep and feral goat population within 90 days, because of the low rate of herd-to-herd contact and herd to flock contact. Therefore, all that should be required is the removal of the commercial sheep to achieve eradication. Feral goats, being relatively sedentary, are unlikely to spread to adjacent populations and the disease will die out (Fleming 2004).

Conclusions

- The rate of disease transmission in the overall population of wild animals is limited by the potential contact rates between individuals in different groups.
- Transmission by direct contact (in pigs) was significantly quicker than transmission between pens.
- Results from deterministic models and stochastic models usually deliver differing outcomes.
- Distribution of wild animals across a landscape depends on resource availability; but is also driven by local spatial, social, density and individual factors as well. Models need to consider such factors. Significantly, less confidence can be put in the earlier models that do not consider these factors.
- Contact between feral and domesticated animals does occur and from comments received occurs more frequently than is currently believed. Due to the difficulties involved, the gathering of this information during peacetime is, however, problematic.

Recent Australian research findings

Below is a précis of the key findings from selected papers originating from the organisations mentioned in Appendix 2.

Wildlife and exotic disease preparedness in Australia — Feral herbivores
Henzell, R., Caple, P. and Wilson, G. (1999) cited in Henderson (2008).

Herbivores are difficult to survey and contain
Populations are highly mobile, evasive, and unpredictable
More scrutiny is needed on the role of scavengers in spreading disease

Further research is required in the areas of:

- Distribution and movement of feral and semi-feral animals in high disease risk areas.
- Intra- and inter-specific contact between susceptible feral animals and how this varies with control operations, population density and breeding and environmental factors.
- Improvements to surveillance, containment and control techniques for wildlife, in order to be effective against low-density populations and to allow dispersing animals to be controlled.
- Computer software for mathematical techniques likely to be used by wildlife biologists, to facilitate surveys of distribution, movement, abundance, etc.
- Factors and techniques that cause wild animals to disperse, to allow risk to be more accurately assessed.
- Persistence of pathogens in carcasses. (See report below *Destroy and Let Lie* Williamson et al 2010.)

*Aerial baiting of feral pigs (*Sus scrofa*) for the control of exotic disease in the semi-arid rangelands of New South Wales* (Fleming, Choquenot et al. 2000) cited in Henderson (2008).

The authors conclude that aerial baiting could be a useful way of reducing or immunising feral pig populations in the event of an outbreak of exotic disease such as FMD. However, different threshold density values in the available predictive models, and a general lack of information on FMD transmission by pigs overseas made it difficult to draw further conclusions.

Efficacy of manufactured PIGOUT® baits for localised control of feral pigs in the semi-arid Queensland rangelands (Cowled BD, Gifford E et al. 2006)

Results demonstrated that a manufactured feral pig bait containing 72 mg of sodium fluoroacetate (PIGOUT®) produced a population knockdown of at least 73% in localised feral pig populations. Camera observations revealed no non-target consumption of baits. Almost all feral pigs were killed relatively rapidly after ingestion of sodium fluoroacetate and the signs observed in a small number of poisoned feral pigs did not indicate a significant welfare concern.

Additional toxins for feral pig (Sus scrofa) *control: identifying and testing Achilles' heels* (Cowled, Elsworth et al. 2008).

Following an in-depth literature review and animal trials, the authors identified sodium nitrite as a cost-effective, readily available methaemoglobin-forming compound that is highly toxic to domestic pigs. The findings demonstrated the potential of sodium nitrite as an additional feral pig toxin.

The socio-genetic structure of a controlled feral pig population (Spencer, Hampton et al. 2005).

The authors collected demographic data and genetic samples from 123 feral pigs from a number of pastoral properties undertaking control programs in Queensland. They found that mobs generally comprised related individuals. Boars, however, that had produced young were on average 42 km from their progeny. The relatively high levels of intermob relatedness could have been the result of control operations in the study population.

Illegal translocation and genetic structure of feral pigs in Western Australia (Spencer and Hampton 2005).

The molecular ecology of feral pigs was investigated to understand their social and population genetic structure. They identified seven inferred feral pig populations that had moderate heterozygosity.

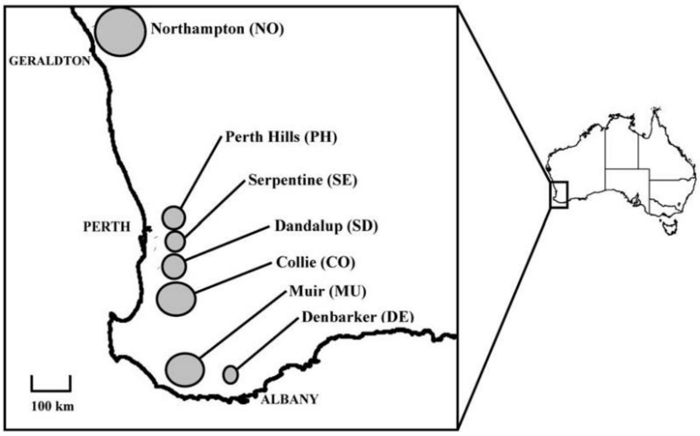

Figure 7 Study areas in the southwest of Western Australia, indicating the seven genetically differentiated populations of feral pigs inferred from the study. The enclosed circles provide a general relative size of each population.

A preliminary genetic study of the social biology of feral pigs in south-western Australia and the implications for management (Hampton, Pluske et al. 2004).

Feral pigs in south-western Australia have been consistently shown to exhibit very low dispersal levels and small home ranges (0.3-2.3 km^2) by the few field-based studies that have been carried out in this region (Choquenot, McIlroy et al. 1996). However, the fact that a number of boars in this study have been shown to disperse over large distances (>30 km) from their juvenile offspring indicating that long-distance dispersal events among feral boars maybe more common, and occur over larger distances, than has been previously documented.

Destroy and let lie (Williamson, Wingett et al. 2010).

The study addressed the question – “Will the physical conditions in a decomposing carcass inactivate FMDV in a timely manner?” The project aimed to investigate the physical conditions in carcasses of field shot animals left *in situ* under various environmental conditions with respect to infective agent survival. Temperature and pH readings of field shot carcasses of various species were recorded at regular intervals in the first 24 hours after death. Two sites were sampled on each animal – typically a deep site (abdomen or chest) and a more peripheral site (hind limb muscle or intracranial). Temperature probes attached to a data-logger were employed with success. However, there were problems with use of in-dwelling pH probes, which necessitated a change to manual readings.

There appeared to be a direct relationship between the physical activity of the animals prior to being destroyed and the rate of decline of pH. The trend appears to indicate that pH will control FMD virus in a carcass within 24 hours of destruction, and in many cases within 12- 15 hours (after physical activity?).

Temperature does not appear to be a reliable mechanism for virus control but may be useful in supporting the influence of pH.

The initial project proposal included a plan to monitor predation of animals destroyed in the culling operation. However, safety concerns with continuing shooting activities ruled this out.

The authors felt more work needs to be done. The initial project aim became more complex to achieve than was first planned.

The report recommends a number of areas for further investigations. For example the influence of ambient temperature, species factors and factors such as coat colour and density. For instance, a small number of heavily wooled sheep rapidly achieved target pH. Can decomposition be accelerated by shooting into the abdomen? How long will virus survive in skin and skin lesions? Finally, the role of predation as a means of disease spread is still not clear.

A recommendation from this report will be for this work to continue with more funding.

Surveys

A number of surveys have been funded by the Wildlife Exotic Disease Preparedness Program (WEDPP) identifying key risk areas. In 2003, a state-wide survey of wildlife pest species in NSW demonstrated, for example, that feral pigs and deer had increased in abundance while feral goats had slightly decreased in density (Saunders and West 2003). Western Australia undertook a similar survey a few years later (Woolnough, Gray et al. 2005). In 2009 an ambitious comprehensive study, based on information presented in import risk analysis documents from Biosecurity Australia and other relevant sources, was commenced to collate national data on potential sites of exotic disease incursions (West 2009).

These reports and other actions have culminated in the establishment of a comprehensive web site: http://www.feral.org.au. This site provides access to various maps that report information on the occurrence, distribution and abundance of significant invasive animal species throughout Australia.

We cannot expect, in a country the size of Australia, to have absolutely up to date data on the real time distribution of feral animals in fine detail. However, the information we do have is now excellent, and within a short time for any specific outbreak, we would have accurate data on pest animals in the area (Saunders pers. comm.).

Conclusions

Most of the work above has aimed to enhance and refine technologies for the surveillance, containment and control of wildlife in order to improve Australia's animal disease preparedness capability against an exotic disease. Australia has moved on from a lot of this type of work, especially if in future we consider the aim to be eradicating the disease and not the pest animal (Saunders and Bryant 1988).

Other work has investigated social and population genetic structure, which gives useful insights into the potential pattern of spread of an infectious agent in a feral animal population.

Specific areas of high priority include:

- Research in collection of samples and laboratory testing analogues such as *Brucella suis* could be used.
- Maintenance of survey information.
- Monitoring of subtypes occurring pre-border and in overseas situations involving wildlife.
- Modelling better defining contacts between animal groups, both intra and interspecific.

Response Plans

Australia has AUSVETPLAN— the Australian veterinary emergency plan (Animal Health Australia 2012).

The wild animal response strategy (WARS) is a guide to the strategic planning needed for a response to an emergency animal disease when wild animals may be implicated or pose a risk of disease transmission. There are four parts within the process:

risk assessment — immediate to short term
surveillance — short to medium term
operational decisions — medium to long term
evaluation — long term.

The checklist is not definitive; rather, it is a logical sequence that should be followed to its ultimate conclusion. There are grey areas. Many of the operations and decisions may be concurrent, and they are often not mutually exclusive (e.g. population survey and disease sampling).

The other related plan is the AUSVETPLAN FMD strategy. The plan suggests that globally wild and feral populations of animals (apart from African buffalos) pose a low risk of transmitting infection to domestic livestock. The main section of relevance is 3.2.13.

The NSW Department of Primary Industries was contracted by the Australian Government Department of the Environment and Heritage in 2004 to undertake a Natural Heritage Trust project to develop Codes of Practice and Standard Operating Procedures for the humane capture, handling and destruction of feral animals. These documents are currently under review and are not available. They should be a valuable resource in an emergency, either in original or abbreviated form. Their website (when available) is at: http://www.dpi.nsw.gov.au/agriculture/pests-weeds/vertebrate-pests/codes-of-practice/operating-procedures/humane-pest-animal-control

Compartmentalisation and zoning

Recognising the difficulty of eliminating animal diseases from a country as a whole and maintaining an animal disease free status, the World Organisation for Animal Health (OIE) has introduced the concepts of zoning and compartmentalisation. Countries can establish disease-free areas (zones/compartments) by defining an animal subpopulation with a distinct health status within its boundaries. Countries may then resume trade from parts of the territory.

Compartmentalisation is defined as one or more establishments under a common biosecurity management system and is not appropriate for wild animals. Zoning applies to animals with a distinct health status *based on geographical separation*. The first basic principle of defining a zone is the clear definition of the animal subpopulation belonging to the zone or compartment. For a zone, this means that the extent, i.e. its geographical limits, including a buffer area, should be clearly defined. In the case of zoning, the veterinary authority will be primarily responsible for providing this biosecurity plan (Bruschke and Vallat 2008). Through our knowledge of wild animal distribution, we are in a position to declare, if necessary, zones free of wild animals an important management tool during any response.

For example, using the map below we could define western Victoria free of feral pigs.

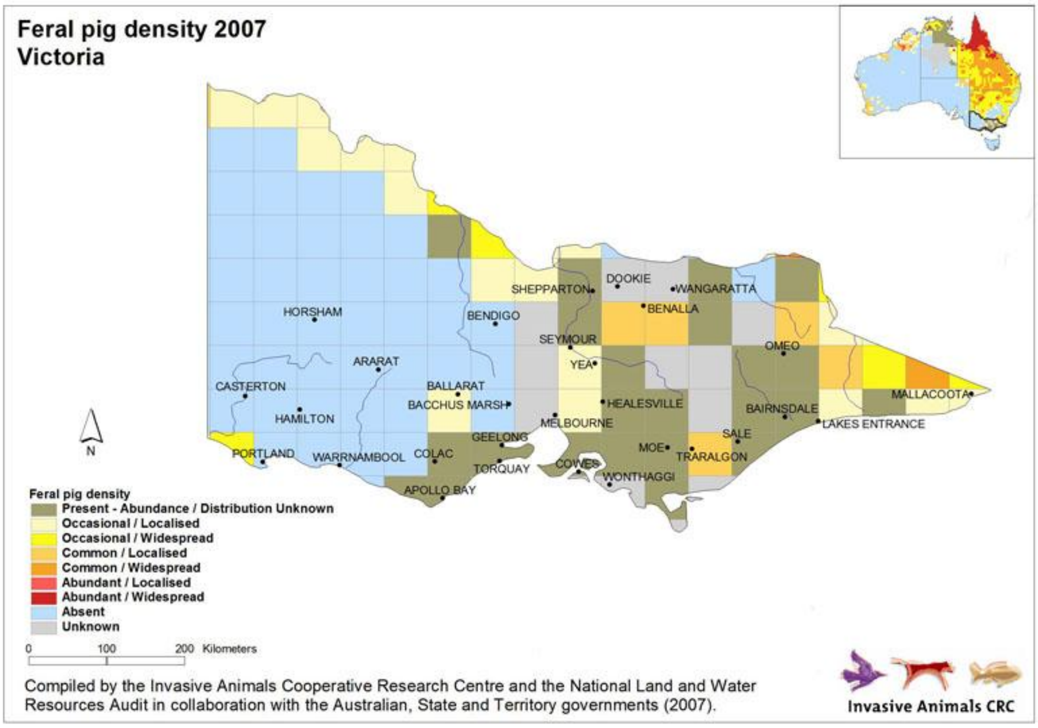

Figure 8 Feral pig density in Victoria
Source: http://www.feral.org.au ("pestmaps")

Conclusions for Australia

- Making an assumption that random and homogenous mixing of feral pigs (and other animals) occurs, causes a substantial overestimation of the rate and spread of FMD that would occur in an outbreak.
- The influence (if any) of other susceptible hosts e.g. deer, buffalo and how these species could affect the configuration of disease should be developed.
- A lack of data considerably hinders the progression of accurate models. Especially important, is knowledge of actual contact rates within and between species, and knowledge of movement patterns along with seasonal factors.

In order to include information such as spatial contiguity and interaction with other species smaller area models should be encouraged. There is relatively little fine scale local data on pig distributions across Australia (Cowled and Garner 2008).

Discussion of Risk Assessment Needs based on Expert Elicitation

A summary of the views captured after interviewing experts in feral animals, wildlife and FMD is presented below. Some of the comments may not only be at variance with other parts of this report, but also between various experts as well. This demonstrates a diversity of views and reflects the need for more discussion in the appropriate forums e.g. animals health officers meetings. A summary of their comments is provided below:

Proof of freedom

If an FMD outbreak occurred in Australia feral animals (especially pigs) would only be tested, if required, as part of the proof of freedom program[6].

- However, depending on specific circumstances at the time some testing of wild animals may occur during the investigatory phase.
- Proof of freedom testing would involve collecting samples for ELISA testing. Current plans are aimed at standardising (or achieving high-level harmonisation of) the cELISA (theoretically applicable to all species) and real-time PCR tests for FMD across all interested state/NT labs (William Wong pers. comm.). Do we know what false positive or negative percentages to expect when testing some species? This may be difficult to validate, but at least we would know that animals have not been vaccinated.
- Surveillance should include collecting information from local farmers about feral animal movements and densities when preparing for proof of freedom.

Proof of freedom assumes wild animals are not involved and testing occurs from the outer part of the zone towards the outbreak. Surveillance will tend to be the reverse and test close to the outbreak then spreading outwards.

Wild animal considerations

- Feral pigs may become infected but rarely spread the virus any distance. (This statement excludes products derived from feral pigs, and if infected feral pigs were physically transported elsewhere.) “Any distance” needs further definition.
- Density matters along with the degree of contact between wild animals and livestock. Both are important.
- Wild buffalo are potentially significant in Australia as carriers of FMD.
- The virus will spread only if sufficient contact occurs. Consider especially what occurs around water points in low rainfall areas.
- Our data on the distribution and abundance of wild animals is not good. We should consider using farmer-based surveys in certain areas.
- Feral pigs acting as scavengers could potentially spread the disease to themselves and to other species.
- The quality of our data on the distribution and abundance of wild animals varies by States and species.
- Deer numbers are on the increase and deer are exposed to cattle and sheep.

[6] This occur as part of entire population surveys (involving domestic animals) and be guided by epidemiological analysis.

- There are three million feral goats. Numbers are stable. There is close correlation between rainfall and home range size. In dry conditions, home range reaches a maximum size then goats become semi-nomadic. We have good knowledge of feral goats.
- Pigs have home ranges but are not territorial.
- Groups of feral pigs have irregular contact with one another.
- Groups of feral goats have irregular contact with one another.
- Aggregations occur with sows in season and around waterholes.

Modelling

- Models should have an ecology component. Watering points are especially important in northern Australia.
- Look closely at the contact rates used in models. Compare differing contact rates.
- Need to look at multiple species when modelling and doing risk assessments.
- Look at behavioural changes e.g. sick animals.
- Social behaviour is more important than density dependence. Frequency of contact is more important than density.
- Investigate interactions with wildlife and domestic stock at a 'local level'.

Planning

- AUSVETPLAN policy for FMD and wild/feral animals was discussed. While coverage of wildlife is appropriate the view was expressed that AUSVETPLAN policy in relation to wildlife could be more assertive. While the risk of spread by wild animals is minimal, wildlife cannot be ignored. Emphasis should be stated that most testing would be done to establish '*proof of freedom',* rather than eradicate feral animals from a location.
- The problem with viral plumes is overstated. Pigs to cause airborne virus spread need to be at an intensive stocking rate.

Training

- Training of wildlife biologists has been lacking for many years. The main need is for the integration of wildlife biologists into the emergency management structure and for all personnel to understand and use the AUSVETPLAN wildlife animal response strategy (WARS).
- Support Australians investigating epidemiological Southeast Asia studies of FMD. i.e. not just see lesions of FMD but also consider the origin and spread of the FMD virus. (This has already started with Australians going to Nepal.)

Potential Priorities for Future Activities

Introduction

In Australia, the three most important wildlife species to consider in relation to FMD are pigs, goats and buffalo[7].

Feral pigs being omnivores could easily be exposed to introduced virus (e.g. discarded food scraps on rubbish dumps) but it is unlikely to spread, because pigs are not carriers, have small home ranges and are present in insufficient densities to produce a plume of virus under Australian conditions.

For example, in recent modelling (Ward, Laffan et al. 2007) in a substantial number of model runs, (in Texas USA) an outbreak of FMD failed to develop in either wild deer or feral pigs, and therefore a cattle outbreak did not occur. This was particularly noticeable when the incursion occurred at four or fewer feral pig herd locations. Their finding supports the conclusions that if susceptible animal population densities are low, then FMD virus might become extinct within specific localities before it is able to infect a critical number of animals. Thus, if FMD virus were introduced at only one or a few feral pig locations, an outbreak in cattle might not occur.

Goats usually show few symptoms of FMD. Due to their low respiratory volume, they are less susceptible to infection from aerosols than cattle, and they produce negligible amounts of these aerosols. This species could possibly maintain an epidemic at a low level.

Buffalo in Australia could act as carriers of the virus for a considerable time (for many years). **More work is needed to evaluate the risk to Australia from buffalo**.

What conditions might lead to an FMD outbreak in domesticated livestock, when the incursion of FMD virus occurs via wild or feral animal populations?

To answer the above question, three areas appear poorly understood. Two of these areas relate to contact rates.

1) *What is the contact rate within groups and between groups of feral animals?*

Most studies, including modelling, have been done on the macro-level i.e. covering areas of many square kilometres. To answer the first question (even if only partially) requires tracking individual animals within groups and between groups (Figure 6 page 27). Satellite transmitters have been used for tracking feral pigs on islands in New Zealand (Department of Conservation New Zealand). Selected locations either would relate to animal densities or defined high-risk areas for FMD.

[7] Whether macropods could become naturally infected is unknown, but extremely unlikely to be of importance for the livestock industry.

2) *How often does wildlife encounter[8] livestock?*

Such a question is self-evident. Feral pigs can reduce lambing numbers by 40% and more. Nevertheless, how often do feral pigs mingle with domestic pigs? Feral goats with domestic sheep and goats? Deer with livestock? Buffalo with northern Australian cattle and feral pig populations? According to information told to the author it is more common than many people would believe.

In modelling, wildlife interactions with domestic animal populations should be included, to assist in analysing the role that native or feral species might play in the spread of diseases in Australia (Garner and Beckett 2005).

From a better understanding of the above two questions we can generate a more accurate risk analysis.

3) *What is the potential risk from the carrier status of FMD in Australian water buffalo?*

Water buffalo prefer to live in swamps and floodplains across the wet parts of northern Australia, Females and calves, led by one of the older females, occupy the forested plains where food and shade are most plentiful. Males live in more open plains with little shade, or slopes with dryer vegetation. When the wet season breaks, the older males join the females and drive away younger males. There is a peak of mating in about March and pregnancy lasts about ten months (Department for Sustainability 2011). In Africa Infection in buffalo is sub-clinical and normally occurs in calves as soon as maternal antibodies wane at 2-6 months of age. They are a source of infection for susceptible species in close proximity (Vosloo 2008). Could Australian water buffalo act as a maintenance host?

Considerations

1 Satellite track individual animals, using the expected home range x3 to study contact rates between groups of feral animals.

2 Within a small high-risk district(s) carry out in person questionnaires gathering information about wildlife contacts with livestock, covering for example the frequency and intensity of contact. Such surveys should be carried out in times of peace, as people may not wish to report such activities in an outbreak situation. Develop similar survey questions as part of the planning process (in AUSVETPLAN) and have it readily available to apply in an outbreak. The framework could be established through a small workshop.

3 Develop a workshop to examine the ecology and risk wild water buffalo present for Australia, by inviting the appropriate persons.

[8] We need to understand clearly, what we mean by contact. This may vary dependent on strain and local conditions. For example, is coming within 3 metres sufficient to transmit the virus?

Procedure when an FMD incursion occurs

What is the likelihood that wildlife species could play a significant role in an incursion of FMD virus?

A general observation has been that wherever in the world FMD has been eradicated from livestock, it has also disappeared from wildlife in those regions (Thomson, Vosloo et al. 2003).

A case study wild boar in Bulgaria

Following a case of FMD serotype O in wild boar in Southeast of Bulgaria, in January 2011 and eleven FMD outbreaks in livestock, a control and eradication plan according to the EU legislation was implemented. Based on the epidemiological considerations a ''Cordon Sanitaire'' along the border to Turkey, consisting of a defined infected area (1240 km^2) and two areas of risk (2160 km^2) was established. Within these areas a total of 812 wild boars, 68 roe deer, 7 red deer and 2 mouflons, hunted between February 2011 and January 2012, were tested for the presence of FMD. No FMD virus could be detected. Sero-positive animals were found in wild boar (6.9%) and roe deer (4.4%), the highest sero-prevalence was found within a 10km radius of the outbreak (13.1%). Further away 5.8% were seropositive (11-20kms) and beyond this distance only one male wild pig was positive at about 46kms (Alexandrov T, Stefanov D et al. 2013). In a limited number of samples collected from wild boar in the same habitat in Turkish Thrace antibodies against non-structural proteins of the FMD virus were detected, indicative of a previous infection. Surveillance carried out in livestock in Turkish Thrace did not reveal circulation of the virus.

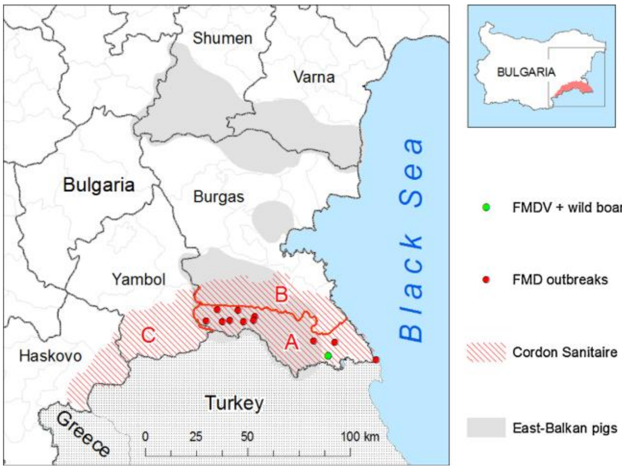

Figure 9 Location of a positive wild boar

Locations of the shot FMDV positive wild boar and the 11 outbreaks in domestic livestock within the surveillance area comprising sampling areas A, B and C (Alexandrov T, Stefanov D et al. 2013).

The authorities requested a model-based assessment of the spread and maintenance of FMD in wildlife populations inhabiting the Bulgarian-Turkish border in Thrace region.

In the simulation study, deer were found to have no influence on the spread and maintenance of FMDV in wildlife. Wild boar could spread the infection successfully under certain climatic conditions: However, wildlife populations alone were not able to maintain the infection beyond the primary epidemic wave spreading once through the area populated by naïve susceptible host. Thus, although epidemics could be produced where the infection affected a large share of the simulated population, no endemicity was observed. Accordingly, continued maintenance of FMDV cannot be expected from the wildlife host system alone but cross-transmission between wildlife sub-populations due to human movement or cross-transmission from the domestic sector would be needed for continued circulation of the virus in the wild (Lange 2012).

AUSVETPLAN

Section 3.2.13 of the AUSVETPLAN for FMD states:

> *"Entry spread and maintenance of FMD in feral animal populations will be subject to ongoing risk assessment to ensure that feral animals are fully considered in the design of the eradication program. Risk mitigation programs will be implemented in feral animal populations that are assessed to pose an unacceptable risk. Assessment will require information about:*
> *• density and distribution of the animals*
>
> *• social organisation, including home ranges* (Note this information could be assisted by fine detail scoping as recommended above)
>
> *• habitat*
> *• perceived contact with domestic species*
>
> *• strain of FMDV*
>
> *• length of time feral animals could have been exposed to the virus*
>
> *• potential exposure of feral animals to risk materials, such as at landfill sites, in paddocks on which milk has been sprayed, or in areas used for composting.*
>
> *This information will help to determine the level of measures to be applied, including:*
> *• containment*
>
> *• tracing and surveillance*
>
> *• population reduction*
>
> *• restrictions on hunters. "*

(Animal Health Australia 2012)

The above is well written but can be criticised as just being a plan to make a plan. Both from interviews and the analysis provided above the likely action (possibly with one exception — below) would be to either:

- Take no action
  or
- Test wildlife as part of the **proof of freedom** program

Embarking on any action to reduce or eradicate the population does have significant risks.

An exotic disease exercise in Australia demonstrated that with feral pig poisoning programs a certain proportion of individuals may either not eat the bait or will eat bait and not die.

Similarly, some individuals will not enter traps. Consequently, even with the combination of helicopter shooting, trapping and poisoning there will still be a small residual population. During the exercise, most marked pigs shot were close to the sites of their initial capture, except for one pig that was shot 55 km south of its initial site of capture. An additional risk is spreading wild animals over a larger range during an attempted control program.

The study concluded eradication of feral pigs during an outbreak of exotic disease may be an unrealistic goal, and it may be more efficient to aim to eradicate the disease within the animal population (Saunders and Bryant 1988).

Surveying and declaring disease freedom in wildlife is difficult because information on population size and spatial distribution will often be inadequate.

A need is to examine procedures for instituting a program aimed at proof of freedom and not at necessarily reduction of feral animal numbers. Part of this gap is to look at laboratory specimens required, tests to be undertaken and potential false positive results that could be expected. [Note — as stated elsewhere in this document laboratory samples may not be required.]

The exception to this approach could be an incursion into Australia involving wild buffalo. This possibility appears to have received little consideration. Although not difficult, the current situation with buffalo needs further study, including numbers of wild buffalo, location, and contact with livestock, ecology and potential for containment or local eradication subsequent to an incursion of FMD. Further research into the role of water buffalo as carriers and the ongoing risk they present to domestic cattle should be undertaken in South East Asia. Such research would benefit both Australia in better understanding the risk from its feral water buffalo population during an outbreak as well as informing an important aspect of the epidemiology relating to endemic FMD in South East Asia. Such research to build on the work by Blesilda Verin (2011) could be managed under the Australian supported by the South East Asia and China FMD programme (SEACFMD).

AUSVETPLAN needs to include establishing PROOF OF FREEDOM with wildlife as an initial objective. Establishing a lack of wildlife may only require use of historical information and the use of maps, followed if necessary by selective sampling

Training

A large exercise was undertaken in Queensland several years ago (the author was involved) with a major aim to test the appropriate AUSVETPLAN manual. Regrettably the manual was swept aside by the Controller ("We will just eradicate the feral pigs!").

Future training (where appropriate) needs to include wildlife as part of the general training— even when wildlife is considered to be a minor consideration. Such training needs to include wildlife biologists and rangers, with them being part of the decision making process.

Village outbreaks in Southeast Asia, especially with pigs

Opportunities may arise in southeast Asia where Australian government officers (or similar) could investigate and report on FMD occurrences. Of use would be documentation of disease origin and how the disease spread or failed to spread, especially taking into account the involvement of 'free range' pigs or buffalo in villages. Particularly important would be any indications of infection arising from potential water buffalo carriers. Climatic conditions in Asia reflect, to some extent, the situation in parts of Australia.

Priority Areas for Future research

- We lack knowledge about:
    - *Transmission within wild species.*
    - *Differences with the behaviour of different viruses in wild species.*
    - *Semi- rural feral pig populations.*
    - *The significance of buffalo in Australia potentially becoming virus carriers.*

- *Contact rates among wild animals. The species of concern in Australia are pigs, buffalo and goats.*
- *The social side – how people think, especially about pigs.* Farmers and the public are influenced by comments such as listed in the section *"Some current views".* Fact sheets (commonwealth, states/ territories) should be reviewed and more accurately reflect the real risk.

- There is a need to consider opportunistic surveillance with especially the collection and processing of laboratory testing. For example, blood samples could be collected from feral pigs being destroyed for other reasons. Samples could be tested for false positive results.

In summary the next steps

Consider:

1) a change of policy highlighting proof of freedom is a key step;
2) the potential emerging role of feral buffalo in Australia;
3) intra and inter specific contact rates, and;
4) influencing viewpoints that exaggerate the risk.

Appendix 1: Project Background and Terms of Reference

As part of Australia's continuing vigilance in FMD preparedness a report, '*A review of Australia's preparedness for the threat of foot-and-mouth disease*' (October 2011), was commissioned and an FMD Taskforce formed within DAFF to provide national leadership for necessary activities, including a review and assessment of FMD risks relating to wildlife. The risk assessment was to consider the potential role of wildlife in or around those areas identified by the Animal Health Committee (AHC) General Surveillance Epidemiology Working Group as at "higher-risk" of an FMD incursion." This report addresses the first step in the process: to identify gap areas that need to be addressed to help inform a risk assessment for wildlife in Australia.

Aims

The potential consequences of FMD being found in wildlife in Australia has led to considerable work much of which has been supported by the Australian government through various programs including the Australian Government Department of Agriculture, Fisheries and Forestry's (DAFF) Wildlife Exotic Disease Preparedness Program (WEDPP). The project aims to stocktake past and current work; consider priorities for further work, including research needed, and provide a report with a draft plan of gaps, research and activities required to inform the abovementioned risk assessment for FMD and wildlife.

The project utilizes literature review, drawing heavily on experience overseas and through WEDPP funded local FMD projects, and expert elicitation. The intention was not to perform an exhaustive review, but to identify gap areas to guide future research.

Appendix 2: Key Resource Organisations

- The Wildlife Exotic Disease Preparedness Program, (WEDPP) is a joint program involving the Australian Government and state and territory governments that commenced in 1984-85. WEDPP's mission is to improve Australia's emergency animal disease preparedness through the development of strategies to monitor, prevent, control or eradicate emergency diseases in wildlife and feral animals that threaten Australia's livestock industries.

- The Invasive Animals Cooperative Research Centre (CRC) provides Australia’s largest integrated invasive animal research program. It creates new technologies and integrated strategies to reduce the impact of invasive animals on Australia’s economy, environment, and people. The CRC in cooperation with other organisations have developed a comprehensive, interactive and a website on pest animals. The site website http://www.feral.org.au provides information about past and current research related to invasive animal control in a readily accessible format (Lapidge, Braysher et al. 2004-2013).

- State government departments with special reference to the vertebrate pest research unit within the NSW Agriculture department (http://www.dpi.nsw.gov.au/research/areas/biosecurity/vertebrate-pest-research).

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