AUSVET

Lumpy skin disease vector management guide

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Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

Contents

Tables

Boxes

Figures

Abbreviations and acronyms

Abbreviation	Definition
ABS	Australian Bureau of Statistics
AHA	Animal Health Australia
AUSVETPLAN	Australian Veterinary Emergency Plan
AW-IPM	Area-wide integrated pest management
BTV	Bluetongue virus
DAFF	Department of Agriculture, Fisheries and Forestry
EFSA	European Food Safety Authority
EPF	Entomopathogenic fungi
EPN	Entomopathogenic nematodes
ESI	Export slaughter interval
FAO	Food and Agriculture Organisation of the United Nations
IGR	Insect growth regulator
IPM	Integrated pest management
IIT	Incompatible insect technique
JEV	Japanese encephalitis virus
LSD	Lumpy skin disease
LSDV	Lump skin disease virus
ML	Macrocyclic lactone
MLA	Meat and Livestock Australia
NAMP	Northern Arbovirus Monitoring Program
NAQS	Northern Australia Quarantine Strategy
NVMAG	National Vector Management Advisory Group
SIT	Sterile insect technique
SP	Synthetic pyrethroids
WHP	Withholding period
WOAH	World Organisation for Animal Health

1 Executive summary

1.1 Background

Lumpy skin disease (LSD) is a threat to livestock industries in Australia, particularly with its recent expansion across Asia, including incursion into Indonesia. Preparedness for an LSD outbreak in Australia is critically important, as a response involves several concurrent strategies as outlined in the AUSVETPLAN response strategy for LSD (including vector management). Several control measures are essential to contain an outbreak, such as vaccination, movement restrictions and stamping out. Vector control should be considered as an adjunct measure, as the effect of vector management in an LSD outbreak is currently unknown.

1.2 Purpose of this manual

This manual provides technical information to inform the development of operational plans for managing vector (insect) populations capable of transmitting lumpy skin disease virus (LSDV). It is designed to be used as an evidence-based reference to assist Australian governments to develop tailored operational plans for vector management once the extent and nature of an outbreak is understood. For example, an outbreak that is limited to a single extensive northern cattle property will require a different approach to an outbreak affecting several southern beef properties. In summary, the manual will ensure governments:

- in collaboration with industry, can rapidly develop effective and safe vector management plans at a property and regional level using the guide.
- will have a consolidated list of available registered chemicals for use against vectors that could spread disease between cattle.
- can identify any availability and use issues that need addressing, including emergency use permits.

As more knowledge is gained on how LSD virus would behave in the Australian context, this guidance can be revised.

1.3 Using this manual

To develop operational vector management plans, policymakers can refer to vector control options for the relevant premises types or circumstance (see Table 1) while keeping in mind the general principles of vector management, including uncertainties and research gaps.

Table 1. Premises type index.

Premises type	Page
Extensive northern cattle systems	77
Southern beef cattle systems	79
Feedlots	81
Dairies	83
Saleyards	85
Abattoirs (including lairage)	87
Ports	89
Milk processing facilities	91
High value stock (e.g. breeding stock)	92
Movement of cattle and cattle products	94
Movement of non-susceptible animals	96
High-risk premises	97

1.4 General principles of vector management

Vector control measures either kill vectors, eliminate suitable habitats, or reduce vector contact with the host. Approaches to vector control are grouped into environmental, biological, and chemical controls.

Environmental controls typically involve landscape modification or changes to human, animal, or vector behaviour such as removing decaying manure or implementing rotational grazing of livestock.

Biological controls involve the introduction of natural enemies of a target vector or pest, such as parasitic wasps. Although several have been developed for horticulture and crop production, there are very few commercially available options for livestock-specific vectors.

Chemical control involves the use of insecticides. Chemical control has been heavily relied on historically in Australia and globally. This overuse has resulted in resistance and ecological harm. Excessively focusing on chemical control during an outbreak of LSD is likely to result in further resistance and ecological harm.

Integrated pest management (IPM) combines environmental, biological, and chemical methods to control pests.

To ensure efficacy and avoid unnecessary harm, when developing vector management policies:

- Prioritise methods that present the least risk to the environment and human and animal health.
- Intervene only when a predetermined threshold is reached (action threshold).
- Identify pests and monitor their populations.

- Implement area-wide approaches when appropriate.
- Tailor environmental controls to the biology and seasonality of target insects.
- Avoid environmental spraying or use only as a last resort.
- Remember that vector control is a small part of a wider disease response that includes more effective disease control strategies such as movement controls and vaccination.

1.5 Vector control on different premises types

Extensive northern cattle systems

The vastness of properties, low density of cattle, seasonality, and variability in vector breeding sites in Northern Australia will render most vector control measures too costly to implement, and those that can be implemented may have limited efficacy. The response to an LSD outbreak in Northern Australia will rely heavily on other disease control strategies.

Southern beef cattle systems

Integrated pest management strategies are more likely to be effective in southern cattle systems. Environmental controls like habitat reduction and sanitation could be effectively implemented across neighbouring farms, enabling an area-wide integrated pest management (AW-IPM) approach to vector control.

Feedlots and dairies

Many vector species are attracted to feedlots and dairies, due to the density of cattle and the presence of manure, feed, and water. IPM strategies can be very effective in intensive animal settings like these, depending on vector species and environmental conditions. The focus here should be on environmental controls.

Saleyards

Saleyards are in diverse geographic locations throughout Australia. Vector control should take this into account. Cattle being transported to saleyards may arrive with vectors on them or in the vehicles they arrive in, and saleyards themselves will have their own populations of vectors, particularly nuisance flies. These vector populations should be considered when designing vector management plans and the focus should be on environmental controls.

Abattoirs

In the context of an LSD outbreak, additional vector control strategies at abattoirs are probably unnecessary, as these facilities must undertake daily pest control measures already. However, vector control strategies should be audited throughout any LSD response. This is especially so for trucks and waste vehicles leaving from the site, as exposed vectors may inadvertently be transported to new locations. Limiting lairage is also important in reducing the probability of disease spread prior to slaughter.

Ports

There are robust vector monitoring and mitigation measures already in place at Australian ports. For example, empty live export vessels returning to Australia are required to undergo thorough cleaning, disinfection with soda ash, and two insecticide treatments before docking. In the event of a LSD outbreak, the vector monitoring and risk mitigation activities already in place at ports may be intensified but the overall approach should not change.

Milk processing facilities

There is limited evidence of contaminated milk being a route of direct transmission of LSDV and dairy manufacturers are already legally required to control pests. It is not necessary to implement additional vector control at milk processing facilities during an LSD outbreak.

1.6 Vector control in specific circumstances

High value stock (e.g. breeding stock)

Vector contact should be minimised for high-value cattle. On-host chemical repellents and insecticides can reduce host-vector contact; however, their effectiveness may be short-lived and resistance levels to some active ingredients can be high. Consider screens, barriers and keeping animals indoors.

Movement of cattle and cattle products

Movement of susceptible animals from 'restricted' and 'control' areas during an LSD response will be prohibited except under Special Permit (SpP), this includes movements to slaughter. However, cattle movements between outside areas will not be subject to restriction. Consider appropriate on-host vector control for cattle being transported in outside areas. Avoid transport during peak hours of vector activity where possible. Clean, disinfect, disinsect and inspect vehicles involved in the transport of cattle, cattle products or associated activities (e.g. feed delivery, waste removal) before leaving a premises.

The AUSVETPLAN Response Strategy for Lumpy Skin Disease outlines requirements for vehicle movements in the event of a LSD outbreak, including requirements for disinsection.

Movement of non-susceptible animals

Trucks carrying cattle are the primary concern for LSD spread because they are most likely to be carrying vectors that preferentially feed on cattle and the animals being transported may be infected with LSD. However, stable flies (that are likely to carry LSDV) also feed on horses, sheep and goats. Therefore, trucks carrying non-susceptible livestock such as horses, sheep and goats should also be cleaned, decontaminated and disinsected. This is particularly important for trucks entering properties where both horses and cattle are present, along with the vectors of interest.

High risk premises

During an LSD outbreak, an AW-IPM approach should be implemented, tailored to local conditions and considering vector, geography, climate, and host characteristics in the transmission area. The focus should be on environmental and biological controls, complemented by targeted chemical controls when necessary.

1.7 Uncertainties

There are three major areas of uncertainty that should be considered when developing vector management plans.

1. **The specific vector species capable of transmitting LSDV in Australia in field conditions are not fully understood.** However, given the rapid spread of LSD through Eastern Europe and Asia, there are almost certainly vectors capable of transmitting LSDV in all regions of Australia. Haematophagous arthropods (such as midges, ticks, mosquitoes and flies) that favour feeding on cattle, are most likely to play a role in the transmission of LSD Therefore, midges, ticks, mosquitoes and flies should the targets of any vector management program.

2. The efficacy of IPM in controlling LSD remains uncertain. It is widely understood that LSD is spread by vectors. It is also clear that the overuse of chemical controls is associated with resistance and negative impacts on human, animal, and environmental health. Therefore, it is logical to use IPM to inform any vector management plan. However, it should not be assumed that IPM will be effective in controlling LSD. Vector management should be used in combination with other nationally agreed control strategies such as movement restrictions, eradication, and vaccination.

3. It is unclear how many vectors are needed to transmit LSDV. It is assumed that a swarm of vectors is required. If this assumption is correct, it is not necessary to eliminate vectors from an environment reduce transmission. Further research is required to confirm the number of vectors required to transmit LSDV.

2 Background

Lumpy skin disease (LSD) is a highly contagious viral infection affecting cattle and water buffalo caused by the *capripoxvirus* LSDV. Biting flies, mosquitos, ticks, and possibly midges are thought to be responsible for local transmission of LSDV (WOAH 2022; Paslaru et al. 2022). Vectors are mechanical only; the virus does not replicate within the vector, unlike some other vector-borne diseases, such as Bluetongue virus (BTV) and Japanese encephalitis virus (JEV). The virus can also spread via secretions, saliva, semen and fomites such as feed and water, although these are less important pathways (WOAH 2022; Sprygin et al. 2019). Recent studies suggest that new recombinant strains of LSDV can spread in the absence of vectors via indirect contact (e.g. cattle co-habitation without direct contact or shared resources) (Aleksandr et al. 2020; Nesterov et al. 2022). Long-distance spread mainly occurs through movement of infected animals, however wind dispersal of vectors has been implicated as a theoretically possible route of introduction into new areas (WOAH 2022; Klausner et al. 2017; Magori-Cohen et al. 2012; Yeruham et al. 1995).

Lumpy skin disease virus (LSDV) was first reported in Zambia in 1929 and has since spread to other African countries. The first confirmed case of LSD in the Middle East occurred in Egypt in 1988, and by 1989 the virus had spread to Israel and then throughout the Middle East (WOAH 2024). The disease emerged in Eastern Europe (Balkan countries) and the Russian Federation in 2015. Since 2019, LSDV has spread across Asia, with outbreaks reported in China, Hong Kong (Special Administrative Region, People's Republic of China), India, Pakistan, Bhutan, Myanmar, Nepal, Bangladesh, Thailand, Laos, Cambodia, Vietnam, Singapore, Malaysia, South Korea and Indonesia (EFSA Panel on Animal Health and Welfare (AHAW) et al. 2022; Sprygin et al. 2019; Bianchini et al. 2023).

Lumpy skin disease (LSD) poses a significant economic threat to the Australian cattle industry and rural and regional communities. The importation of live animals is mostly limited to zoo animals and occasional reproductive products (e.g. germplasm). Importation is tightly regulated and considered of negligible risk. Vector movements from LSD-endemic countries could pose a very low (although highly uncertain) incursion risk either from wind-dispersion or as hitchhikers on shipping vessels or aircraft (Hall et al. 2023). Recent modelling of LSD introduction risk via vectors carried by wind from South East Asian countries or as hitchhiker pests on ships found a low to negligible probability of incursion, although with extremely high uncertainty (Hall et al. 2023). According to the authors, the median incursion rate was estimated at one every 403 years (or 0.02 per year, 95% CI, $6x10^{-6}$, 0.15) based on the assumption that a small batch of three to five infectious insects biting a single animal is necessary to transmit infection. The incursion risk becomes negligible, with an estimated entry once every 20,706 years, if bites from many more insects (i.e. a 'large batch' of 30–50 insects) are necessary (Hall et al. 2023).

Virus incursions through wind dispersal of vectors have been observed, such as the introduction of JEV by windblown *Culex* spp. (Ritchie and Rochester 2001) and BTV serotypes carried by exotic *Culicoides* spp. (Eagles et al. 2014). However, unlike for JEV and BTV, the vectors implicated in LSDV transmission are mechanical rather than biological. Surra (*Trypanosoma evansi*) is another example of a mechanically transmitted disease vectored by biting flies. With this disease, the probability of survival of *T. evansi* on the mouthparts of tabanid flies (the primary vector) decreases rapidly with time and between successive feeds (AHA 2021). Importantly, Australia has not experienced an incursion of Surra from infected vectors arriving from neighbouring countries despite the longstanding presence of the disease in the region. In contrast to the short survival time of *T. evansi* on insect mouthparts, experimental studies have demonstrated significantly longer survival times of LSD virus, lasting several days or longer depending on the vector species (Gubbins 2019; Sanz-Bernardo et al. 2021; Bianchini et al. 2023).

Successful eradication of LSD relies on early detection combined with mass vaccination, movement restrictions and some stamping out activities, as demonstrated by successful responses to outbreaks in some countries the Balkans and Israel (Tuppurainen et al. 2021; EFSA Panel on Animal Health and Welfare (AHAW) et al. 2022). While vector control has been part of the overall strategy to disrupt local transmission, there is limited evidence demonstrating its effectiveness in reducing LSDV transmission (WOAH 2022). Two recent case studies exploring risk factors in LSD transmission in Indonesia and Thailand reported a positive association between LSD cases and a 'lack of vector control measures', suggesting that farms that did not implement vector control had greater odds of an LSD outbreak than farms that did (Susanti et al. 2023; Arjkumpa et al. 2024). However, these studies should be interpreted with some caution, as vector control measures were not explicitly defined and similar management factor on LSD-positive and case farms suggests some degree of bias in the results.

The uncertainty regarding the effectiveness of vector control may be attributed to several factors. One factor is the limited understanding of the predominant vectors contributing to local spread, impeding the implementation of effective targeted measures. Another factor is that even the most rigorous vector control measures in outdoor settings may struggle to reduce vector numbers enough to significantly reduce transmission. Further, few chemical products used on cattle act as repellents to deter contact, with most relying on insects biting and ingesting the chemical before perishing. Consequently, these chemicals only take effect after the vector has made contact with the host, potentially limiting their effectiveness in preventing disease transmission. Lastly, the effectiveness of chemical control (or lack of) in preventing LSDV spread is likely to be difficult to measure appropriately in field settings. Despite knowledge gaps regarding the effectiveness of vector control, these measures will likely remain part of the multi-modal approach to control and eradicate LSD.

3 Vector species that carry lumpy skin disease

3.1 Vectors implicated in lumpy skin disease virus transmission

Flies, mosquitoes, ticks and potentially midges are implicated in the transmission of LSDV. Specifically, stable flies (*Stomoxys calcitrans*), yellow fever mosquitoes (*Aedes aegypti*) and several tick species (*Rhipicephalus appendiculatus, R. decoloratus and Amblyomma hebraeum*) have demonstrated the capability of transmitting LSDV to cattle.

While other fly, tick, mosquito and biting midge species can carry infectious virus or viral DNA, evidence of transmission to cattle is lacking (Table 2). Identifying viral DNA on vectors indicates the presence of LSDV genetic material, but this finding on its own does not imply infectivity. Detecting infectious virus on vectors is more concerning, as this demonstrates a capability to cause infection when transmitted to a host.

In principle, any biting insect species that prefers cattle, moves between hosts and is abundant could mechanically transmit LSD (Berg et al. 2015; Horigan et al. 2018; Tuppurainen et al. 2017; Sohier et al. 2019; Sprygin et al. 2019; Kahana-Sutin et al. 2017; Wang et al. 2021). Current knowledge of potential vectors is incomplete, and there are likely other vectors capable of transmitting LSDV. Peer-reviewed literature demonstrating transmission of LSDV is also dominated by species that are easily bred and managed in laboratory environments such as *Ae. aegypti.* While a species like this easy to work with, in field conditions it preferentially bites humans, so the relevance of some of these studies to the situation in the field is questionable (Stephenson et al. 2019).

Table 2. Vectors implicated in LSDV transmission.

Vector type	Species	Distribution	Importance to Australia*	Evidence	References
Flies (Diptera)	Stable fly (*Stomoxys calcitrans, S. sitiens, S. indica)*	*S. calcitrans* – Global *S. sitiens* – Africa and Asia *S. indica* –India, SE Asia	High	LSDV virus has been isolated from field collected *S. calcitrans* specimens. *S. sitiens and S. indica*. *S. calcitrans*, the stable fly, has been implicated in many outbreaks, including in Israel. Recent experimental evidence demonstrated stable flies transmitted LSDV to cattle. Of all vectors, the stable fly is the most implicated vector species for LSD.	(Gubbins 2019; Sohier et al. 2019; Issimov et al. 2020; Weiss 1968; Tuppurainen et al. 2011; Lubinga et al. 2015; EFSA Panel on Animal Health and Welfare (AHAW) et al. 2022; Chihota et al. 2003; Kahana-Sutin et al. 2017; Duvallet and Hogsette 2023)
	Tabanids – *Haematopota* spp. Horse/March fly (*Tabanus*)	*Tabanus latipes* – World-wide, except Australia *Haemotobia irritans* – Global	High	LSDV DNA has been found in *Tabanid* species and successful transmission of LSDV to cattle has been demonstrated experimentally. One field study isolated LSDV in 14% of horse flies sampled during an outbreak but could not confirm if they played a role in transmission. It has been hypothesised that tabanids may be more competent hosts than stable flies, given they have larger mouthparts and have aggressive interrupted feeding behaviour.	(Alexandrov, 2016; Sohier et al. 2019; Kahana-Sutin et al. 2017; Issimov et al. 2020; Orynbayev et al. 2021)
	House fly *(Musca domestica)*	Global	Low	It is hypothesised that non-biting flies could act as vectors by feeding on the carcasses of LSDV-infected cattle. During an LSD outbreak in Russia in 2017, *M. domestica* tested positive for the presence of LSDV genomic DNA, but no evidence was found linking it to transmission to cattle hosts. Similarly, an outbreak in China in 2019 found viral DNA in *M. domestica.* It was hypothesised that non-biting flies were the dominant insects involved in this outbreak, but no direct evidence was found.	(Sprygin et al. 2020; Wang et al. 2021)

Vector type	Species	Distribution	Importance to Australia*	Evidence	References
	False stable fly *(Musca stabulans)*	Global	Low	An outbreak in China in 2019 found LSDV in *M. stabulans.* It was hypothesised that non-biting flies were the dominant insects involved in this outbreak, but no direct evidence of transmission was found.	(Wang et al. 2021)
Mosquitoes (*Culicidae)*	Dengue mosquito (*Aedes aegyptii*)	Global, limited distribution in Australia (central and northern Queensland)	Very low	LSDV has been isolated from *Ae. aegypti*. It has been shown to have the longest retention period of LSDV for any vector tested. In one study, after feeding on LSDV-rich skin lesions, *Ae. aegypti* mosquitoes were shown to transmit the virus to susceptible cattle over two to six days. The strong preference of this species for human hosts reduces its potential importance as a vector for livestock diseases.	(Gubbins 2019; C. M. Chihota et al. 2001; Bianchini et al. 2023; Paslaru et al. 2022; Sanz-Bernardo et al. 2021; Trewin et al. 2017; Stephenson et al. 2019; Scott et al. 2000)
	Asian malaria mosquito *(Anopheles stephensi)*	Africa, Southern Asia, Arabian Peninsula	Low	To date, experimental transmission of LSDV to cattle has been unsuccessful. *A. stephensi* is currently considered to be an inefficient vector.	(Gubbins 2019; Chihota et al. 2001; Bianchini et al. 2023; Paslaru et al. 2022; Sanz-Bernardo et al. 2021)
	Southern House Mosquito (*Culex quinquefasciatus)*	Global	Low	To date, experimental transmission of LSDV to cattle has been unsuccessful. *C. quinquefasciatus* is currently considered to be an inefficient vector.	(Gubbins 2019; Chihota et al. 2001; Bianchini et al. 2023; Paslaru et al. 2022; Sanz-Bernardo et al. 2021)
	Common house mosquito (*Culex pipiens*)	Americas, the Middle East, Asia, Africa, and Europe	n/a	In an experimental study, viral DNA retention was found for 7 days post-feeding on virus-spiked blood for *C. pipiens.* However, onwards transmission to cattle has not been proven.	(Paslaru et al. 2022; Bianchini et al. 2023)

Vector type	Species	Distribution	Importance to Australia*	Evidence	References
	Asian bush mosquito (*Aedes japonicus*)	Europe, North America, China, Taiwan, Korea, Japan, New Zealand	n/a	In an experimental study, viral DNA retention was found for 10 days post-feeding on virus-spiked blood for *A. japonicus.* Transmission to cattle has not been proven.	(Paslaru et al. 2022; Bianchini et al. 2023)
Hard ticks (*Ixodidae*)	Brown ear tick (*Rhipicephalus appendiculatus*)	Sub-Saharan Africa	n/a	Found capable of LSDV transmission between cattle in several experimental studies. Transstadial transmission has been demonstrated. They are likely to be reservoirs rather than be involved in an outbreak.	(Tuppurainen et al. 2011, 2013; Lubinga, Clift, et al. 2014; Lubinga, Tuppurainen, et al. 2014; Lubinga et al. 2015; EFSA Panel on Animal Health and Welfare (AHAW) et al. 2022)
	South African Bont tick (*Amblyomma hebraeum*)	Africa	n/a	In one study, *A. hebraeum* female ticks that fed on infected cattle were positive for LSD virus, but cattle exposed to these ticks did not develop clinical signs or seroconvert.	(Lubinga et al. 2013; Lubinga, Clift, et al. 2014; Kahana-Sutin et al. 2017)
	Blue tick (*Rhipicephalus decoloratus*)	Africa	n/a	Studies have demonstrated that experimentally infected *R. decoloratus* was able to transmit LSDV to cattle. Transstadial and transovarian transmission of LSDV has been demonstrated. They are likely to be reservoirs rather than be involved in an outbreak.	(Lubinga et al. 2013, 2015; Tuppurainen et al. 2011, 2013)
	Cattle tick (*Rhipicephalus annulatus)*	Global	Medium	Transovarian transmission of LSDV to tick larvae has been demonstrated in one study. They are likely to be reservoirs rather than be involved in an outbreak.	(Rouby et al. 2017)

Vector type	Species	Distribution	Importance to Australia*	Evidence	References
Biting Midges (*Culicoides Diptera: Ceratopogonidae)*	*European biting midge* *(Culicoides nubeculosus)*	Eurasia	n/a	To date, experimental transmission of LSDV to cattle has been unsuccessful. In one experimental study, there was no persistence of viral DNA observed in field-collected midges. During their gonotrophic cycle, midges do not refeed for four days, so infectious virus would need to persist in high enough amounts for this length of time, unlike Stomoxys which can re-feed rapidly. *Culicoides* biting midges have been considered as putative vectors in the Balkans LSD outbreaks, but no evidence has been found to confirm their role. Recent work from the Pirbright Institute was not able to find evidence of LSDV transmission from *Culicoides* under laboratory conditions. Several other studies have also concluded that biting midges are not competent mechanical vectors of LSDV.	(Gubbins 2019; Chihota et al. 2003; Paslaru et al. 2022; Sanz-Bernardo et al. 2021)
	Culicoides punctatus	Eurasia	n/a	A single study reporting on the 2014–2015 LSD outbreak in Türkiye found that field-collected *C. punctus* harboured LSDV DNA and hypothesised that this species could have played a role in transmission. Recent work from the Pirbright Institute was not able to find evidence of LSDV transmission from *Culicoides* under laboratory conditions. Several other studies have concluded that biting midges are not competent mechanical vectors of LSDV	(Şevik and Doğan 2017; Chihota et al. 2003; Paslaru et al. 2022; Sanz-Bernardo et al. 2021)

* Importance to Australia, refers to whether the vector species is present in Australia and the relative importance of its potential role in transmission. High importance relates to vectors where published evidence demonstrates transmission or supports likely transmission, and the vector species is abundant where cattle are raised. Medium importance relates to instances where evidence of transmission is high, but transmission spread is low (e.g. cattle tick). Low importance relates to vectors where the evidence of transmission is limited (e.g. non-biting flies). Very-low importance relates to vectors who are proven transmitters of LSDV, but their distribution is extremely limited (e.g. *Ae. Aegypti*). n/a – not applicable: applies to vectors that are not present in Australia.

3.2 Vector transmission

3.2.1 Mode of transmission

Mechanical transmission by arthropods is considered the primary mode of local LSD spread, at least for classical LSDV strains. Long-distance spread is attributed to the movement of infected animals (Tuppurainen and Oura, 2012; Namazi and Tafti, 2021; Sprygin et al., 2019 Bianchini 2023). Biological transmission, involving infection and replication of the virus in Diptera vectors has not been established (Sanz-Bernardo et al. 2021; Paslaru et al. 2022). Transstadial and transovarial transmission in hard ticks has been demonstrated in several studies (Lubinga et al. 2013; Tuppurainen et al. 2011; Lubinga, Tuppurainen, et al. 2014; Tuppurainen et al. 2013). Important transmission considerations for LSD are detailed in Box 1.

Understanding the biology, feeding preferences, biting behaviour and habits of vector species is essential in controlling LSD incursions. Interrupted feeders are prime candidates for LSD transmission, with the probability of transmission positively correlated to the abundance of vectors and hosts (Gubbins 2019; Berg et al. 2015). While the precise number of vectors required to initiate infection in a single animal is unknown, experimental studies (laboratory or field) have demonstrated successful transmission with large (range: 50 – 400) and small batches of insects (e.g. 20) after feeding on viremic cattle (Issimov et al. 2020; Sohier et al. 2019; C. M. Chihota et al. 2001; Haegeman 2023).

3.2.2 Vector contamination

Vectors are contaminated when the proboscis pierces skin lesions and scabs on infected cattle, with the virus persisting in nodules of infected animals for up to 35 days (Namazi and Tafti 2021). Vectors may also be contaminated from contact with nasal secretions, saliva, semen and milk from infected animals. Virus uptake by vectors is more efficient from clinically affected cattle than in asymptomatic ones (Sanz-Bernardo et al. 2021). Lumpy skin disease virus (LSDV) transmission efficiency is influenced by virus survival time in vectors. Most experimental studies suggest that the virus DNA has been detected for 2–6 days in insect vectors, extending to over 8 days in mosquitoes (Bianchini et al. 2023). The potential for longer-term survival cannot be ruled out (Gubbins 2019). For ticks, experimental studies have shown that the virus can remain viable for up to 35 days (Tuppurainen et al. 2015).

3.2.3 Environmental influences

The environment significantly influences the abundance and distribution of vectors, both spatially and temporally. Seasonal conditions such as high temperatures and rainfall are correlated with increased vector activity and may increase the risk of LSD outbreaks (Issimov et al. 2020; Molla et al. 2017; Selim et al. 2021; Bianchini et al. 2023; EFSA 2018; Kahana-Sutin et al. 2017; Namazi and Tafti 2021). Wind has also been shown to contribute to the dispersal of vectors. In general, vector-borne transmission tends to be limited to short distances due to the restricted flight capabilities of insects (Sprygin et al., 2020). For example, most blood-sucking insects fly between 100 and 200 metres without wind assistance (Russell et al. 2005). However, some flies and biting midges can travel much further, with reports that stable flies carrying LSDV have been observed travelling up to 28 km in 24 hours (Gubbins 2019; Issimov et al. 2020).

Wind-aided dispersal of vectors has been implicated in the spread of LSDV over longer distances (Rouby and Aboulsoud 2016; Chihota et al. 2001; Chihota et al. 2003), with this mechanism proposed as a factor in two LSD outbreaks in Israel in 1989 and 2006 (Klausner et al. 2017; Magori-Cohen et al. 2012; Yeruham et al. 1995).

Box 1. Vector transmission considerations.

Vector considerations

- Vector life cycle and gonotrophic cycle
- Feeding habits, e.g. blood meal frequency, host range preference
- Feeding behaviour, e.g. interrupted feeders (mosquitos, stable flies, horse flies), stationary feeders (ticks)
- Biting behaviour, e.g. siphon feeding (mosquitoes, ticks) pool feeding (horse flies, stable flies, midges)
- Vector competence, e.g. the ability to acquire, retain and transmit LSD to the host.
- Host seeking behaviour
- Vector abundance, e.g. high density, low density

Environmental considerations

- Seasonal conditions, e.g. temperature, humidity, rainfall
- Wind conditions, e.g. direction and strength
- Habitat, e.g. vegetation, surface water, topography
- Immature habitat used by vectors

Virus considerations

- Virus survival time on vector
- Viral load on the proboscis or body or vector
- Virus transfer efficiency from vector to host

Host considerations

- Host density
- Host susceptibility, e.g. *Bos taurus*, *Bos indicus*, *Bubalus bubalis*, *Bos javanicus*. Particularly the proportion of infected hosts with clinical symptoms
- Host movements, e.g. movement over long distance
- Land use patterns, e.g. feedlot, extensive grazing, dairy
- Host wounds.

3.3 Potential vectors in Australia

Vectors known or suspected of transmitting LSDV are present in Australia (Table 3). It is probable that Australia has other additional vectors capable of transmitting the virus. Possible vectors of LSD in Australia include:

- Stable fly (*S. calcitrans*)
- Horse flies (*Tabanus* species)
- Buffalo flies (*Haematobia irritans exigua*)
- Common house fly (*M. domestica*)
- Bush fly (*M. vetustissima*)
- Dengue mosquito (*Ae. aegypti)*
- House mosquito (*Culex quinquefasciatus)*
- Common banded mosquito *(Culex annulirostris)*
- Biting midge *(Culicoides* species)
- Cattle tick *(Rhipicephalus australis)*
- Australian paralysis tick (*Ixodes holocyus)*
- Bush tick (*Haemaphysalis longicornis*)

Biological information on vectors potentially associated with LSD transmission in Australia can be found in Appendix 1 (flies), Appendix 2 (mosquitoes and midges), and Appendix 3 (ticks). Figure 1 presents the estimated relative monthly activity of 12 potential LSD vectors in Australia.

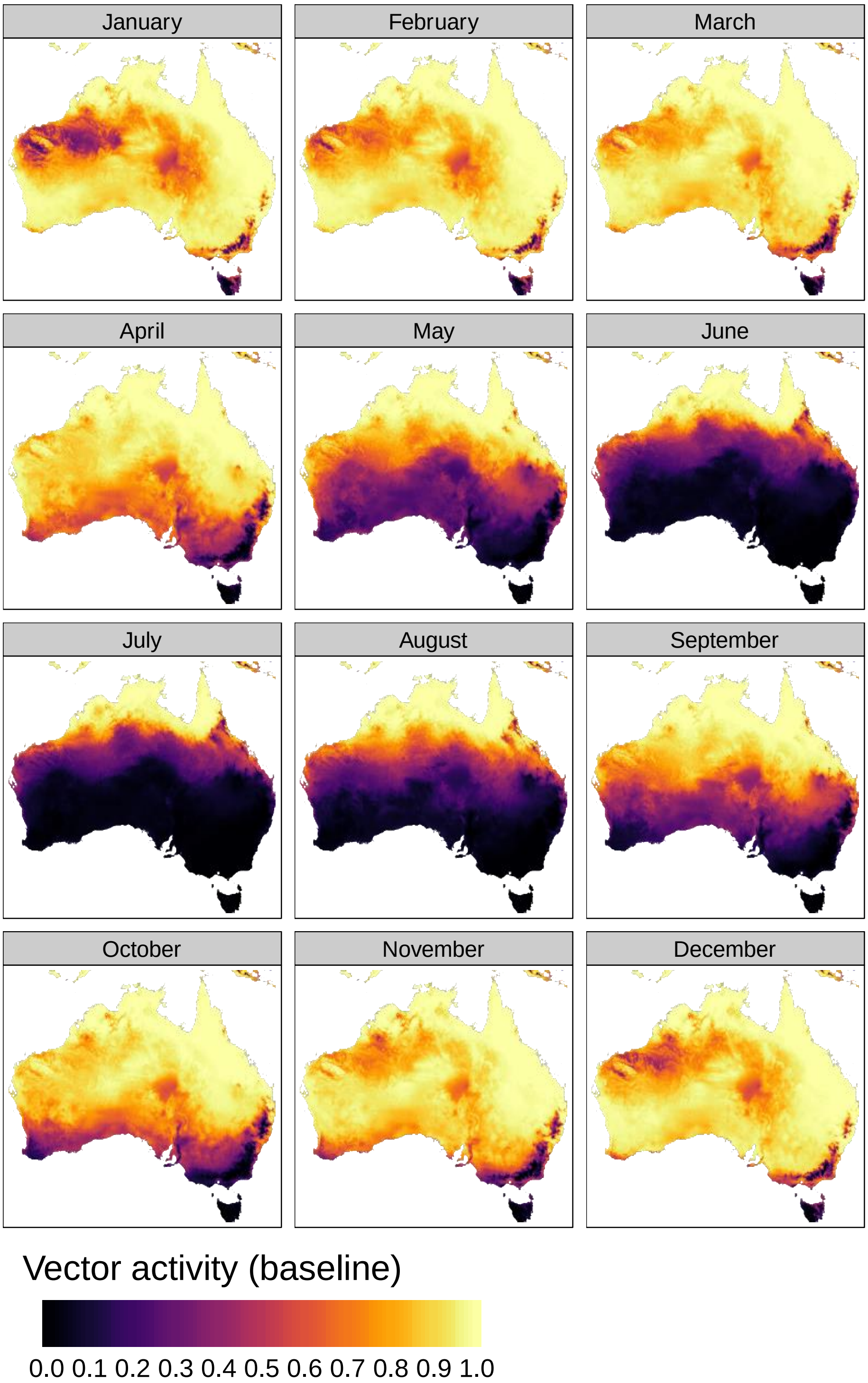
Importantly, LSDV has spread from Southern to Northern Africa and throughout Eastern Europe and Asia. This suggests that there are always vectors capable of transmission, regardless of the climatic or geographic zone (FAO 2023). Therefore, unlike other vector-borne viruses such as dengue fever, the absence of a particular vector is unlikely to stop the spread of LSDV. Determining which exact vectors present in Australia that may carry LSDV could be considered a largely academic exercise.

Table 3. Vectors specific to Australia implicated in LSDV transmission.

Vector type	Species	Distribution in Australia
Flies (Diptera)	Stable fly (*Stomoxys calcitrans, S. sitiens, S. indica)*	Stable fly occurs throughout Australia, particularly in areas close to human settlement and livestock (Atlas of living Australia 2022). They are typical in Queensland, NSW and Tasmania seasonally in association with cattle feedlots. However, in parts of WA stable flies can be a year-round problem and are declared pests (Cook 2017).
	Tabanids – *Haematopota* spp. Horse/March fly (*Tabanus*)	Horse flies, also known as March flies, are present year-round across most of Australia (Atlas of living Australia 2022). Their populations fluctuate seasonally, with higher abundance during the wet season in northern Australia, and in coastal and subcoastal regions of Australia (FlyBoss 2024). In the dry season, their numbers decrease and they tend to be focally distributed around permanent water and swamps (AHA 2021).
	House fly (Musca domestica)	House flies are found across Australia, with numbers peaking from spring to autumn, and especially after summer rain (Atlas of living Australia 2022). Increasing temperature and humidity increases numbers (FlyBoss 2024).
	Bush fly (*Musca vetustissima)*	Bush flies are distributed across Australia (Atlas of living Australia 2022). In northern Australia, bushflies occur year-round and are active over winter/ dry season. In southern areas of Australia, bush flies die out over the winter and flies from northern parts of Australia immigrate and reinvade during spring and summer.
	Buffalo fly (Haematobia irritans exigua)	Buffalo flies are mostly located in the northern parts of Australia, spanning from north-eastern NSW to northern Western Australia (MLA 2022). Their range is expanding southwards and buffalo fly have been found as far south as Maitland in eastern NSW and as far west as Narromine, Dubbo and Bourke during the wet years of 2010–11 (FlyBoss 2024).
Mosquitoes (*Culicidae)*	Dengue mosquito (*Aedes aegyptii*)	Dengue mosquito is primarily limited to central and northern Queensland, but has been present in NSW historically (Atlas of Living Australia 2022).
	Common banded mosquito *(Culex annulirostris)*	Found distributed across Australia, especially within Victoria and along coastal regions of the country (Atlas of Living Australia 2022).

Vector type	Species	Distribution in Australia
	Southern House Mosquito (*Culex quinquefasciatus)*	Current occurrence reports demonstrate the distribution of southern house mosquitos to be primarily widespread in Victoria and NSW, and sporadically distributed in southern WA and on the east coast of southern QLD (Atlas of Living Australia 2022).
Midges *(Ceratopogonidae)*	Biting midges *(Culicoides* species*)*	Midges are widely distributed across Australia, but especially prolific tropical and subtropical coastal areas (MLA 2017). In southern Australia, there is limited midge activity in winter as it is too cold for egg development.
Hard ticks (*Ixodidae*)	Cattle tick (*Rhipicephalus annulatus)*	Cattle tick is endemic in regions of QLD, NT and WA, with sporadic infestations occurring outside of endemic regions.
	Australian paralysis tick (*Ixodes holocyus)*	The paralysis tick is found in coastal regions on the eastern seaboard along VIC, NSW and QLD (Stewart 2021).
	Bush tick (*Haemaphysalis longicornis*)	The bush tick is mostly found in sub-tropical regions and some temperate areas with summer rainfall. The main endemic zone is a relatively narrow coastal strip extending from Gympie, Queensland, in the north to the north coast of NSW though the ticks may occur up to 100 km inland (Stewart 2021). It also occurs sporadically in Victoria and WA.

Figure 1. Monthly national maps of estimated relative activity of potential LSD-vectors. Maps show modelled infectious pressure of LSD via vectors on domestic grazing cattle where black areas represent lower vector pressure and yellow areas represent higher vector pressure (courtesy of DAFF under the National LSD Action Plan, 2024).



The maps presented in Figure 1 were prepared by the Department of Agriculture, Fisheries and Forestry as part of a project modelling LSD spread and control in Australia under the National LSD Action Plan (report in preparation, 2024). They were prepared using data for 12 exemplar species that are closely associated with cattle in Australia: blood feeding flies (Buffalo fly and Stable fly), non-biting flies (Bush fly, Common House fly), midges (*C. brevitarsis*, *C. wadai*, *C. actoni*, *C. brevipalpis*) and mosquitoes (*Cx. annulirostris*, *Ae.camptorhynchus*, *Ae. vigilax*, *An. annulipes*). It is expected that the distribution and activity of these exemplar species is likely to encompass that of other potential vector species. Each species' geographic distribution was approximated using long-term climate suitability modelling, and temporal dynamics in relative activity were approximated according to literature-derived estimates of vector's optimal, minimum, and maximum tolerable temperatures. Species' maps were combined, accounting for the estimated relative importance of each vector group (blood-feeding flies, non-biting flies, midges, mosquitoes) in LSD transmission in Australian grazing domestic cattle. The modelled outputs represent the monthly relative infectious pressure of LSD on grazing cattle via vectors.

Stable flies

Stable flies are biting insects primarily targeting cattle and horses. They feed several times a day, typically in the morning or late afternoon. They are irritating, persistent biters that are frequently disrupted and so feed at several sites and on different hosts. Females require a blood meal before laying eggs, which are deposited in old manure or decaying organic matter. They prefer to bite cattle on the limbs and underbelly.

The fly occurs throughout Australia, particularly in areas close to human settlement and livestock (Figure 2). Stable flies are typically a seasonal problem in Queensland, NSW and Tasmania in association with cattle feedlots. However, in parts of WA stable flies can be a year-round problem and are declared pests (Cook 2017). Many feedlot and dairy operations experience large stable fly populations. In two studies examining fly populations in Queensland and NSW feedlots, stable flies accounted for approximately 12% of the total pest fly population (Godwin et al. 2017; Hogsette et al. 2012).

Figure 2. Occurrence reports of *Stomoxys calcitrans* in Australia (Atlas of living Australia 2022).

Tabanids

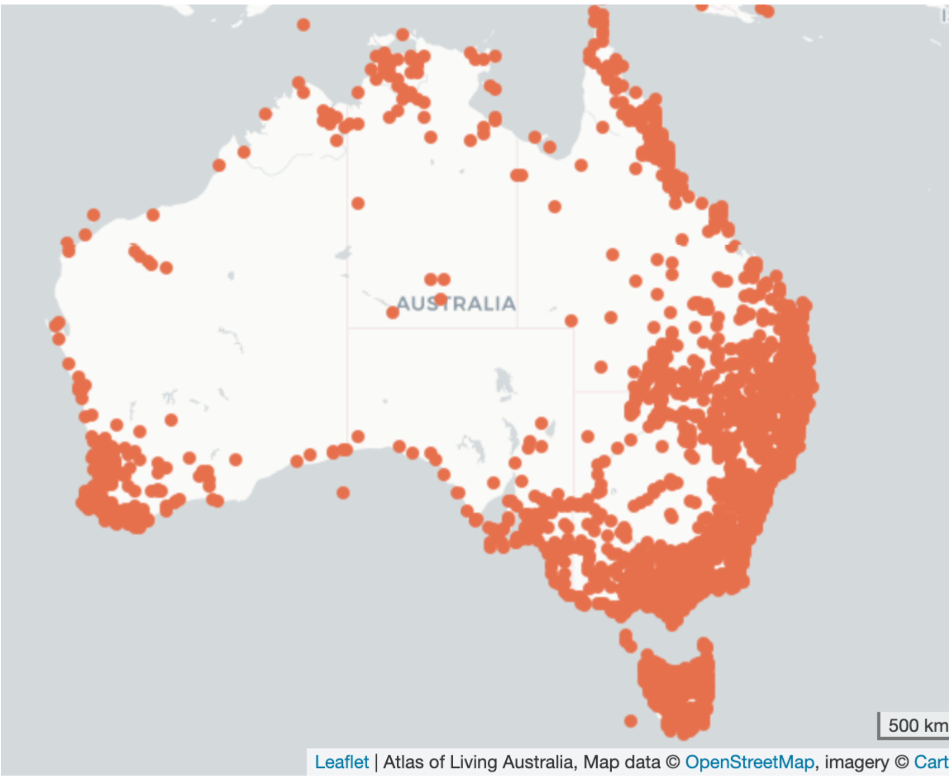
There are over 230 species of tabanids in Australia (Daniels 2016) each adapted to various ecological niches and not all species feed on blood. The species attacking cattle is not well studied although Mackerras (1971) reported specimens of *Tabanus pallipennis*, *T. innotabilis* and *T. dorsobimaculatus* collected from cattle and Muzari et al. (2010) detected cattle blood in specimens of *Tabanus strangmannii, T. concolor T. dorsobimaculatus T. pallipennis, Pseudotabanus silvester* and *Lilaea fuliginosa.*

Horse flies, also known as March flies, are present year-round across most of Australia (Figure 3). Their populations undergo seasonal fluctuations, with higher abundance during the wet season in northern Australia, and in coastal and subcoastal regions of Australia (FlyBoss 2024). In the dry season, their numbers decrease and they tend to be focally distributed around permanent water and swamps (AHA 2021). Little is known about the breeding habitats of tabanids, but it is thought that they prefer to breed in or near water, with the larvae living in mud or in the sediment of dams, swamps and creeks (AHA 2021).

Horse flies are not host specific, mostly preferring to feed on wildlife, so they do not often cause severe problems for cattle. However, the female flies are aggressive daytime biters and cause considerable pain and irritation. Their painful bite can trigger host grooming that disturbs the fly mid-meal and can lead to interrupted feeding where partially fed flies feed on multiple hosts in quick succession. This interrupted feeding behaviour is a major contributor to the transmission of viruses between animals. Tabanids are vectors for several important livestock diseases exotic to Australia, such as Equine Infectious Anaemia and Surra.

Because horse flies are not host-specific, they are difficult to control. Given their preference for woodlands and waterways, contact between horse flies and cattle can be minimised by grazing animals in open pastures during peak fly activity (FlyBoss 2024). Tabanids will not enter buildings looking for hosts (AHA 2021).

Figure 3. Occurrence reports of *Tabanidae* species in Australia (Atlas of living Australia 2022).



Australian bush fly and common house fly

The common housefly (*M. domestica*) and Australian bush fly (*M. vetustissima)* do not bite, instead they feed on secretions from the skin, eyes, mouth, nose and wounds of cattle. Their feeding behaviour causes irritation to cattle and spreads diseases such as pink eye. Bushflies breed in older manure pats in pastures (not feedlots) and other animal dung. Both fly species are found across Australia (Figure 4 and Figure 5). They are attracted to feedlots in large numbers to feed on cattle. Two studies looking at fly populations in feedlots in Queensland and NSW reported that house flies and bush flies accounted for approximately 67% and 21%, respectively of the total pest fly population (Godwin et al. 2017; Hogsette et al. 2012). Bush flies are at their highest abundance in late spring and early summer. In northern Australia, bushflies occur year-round and are active over winter/ dry season. In southern areas of Australia, bush flies die out over the winter and flies from northern parts of Australia immigrate and reinvade during spring and summer. House fly numbers peak from spring to autumn, and especially after summer rain. Increasing temperature and humidity increases numbers (FlyBoss 2024).

Figure 4. Occurrence reports of *Musca vetustissima* in Australia (Atlas of Living Australia 2022).

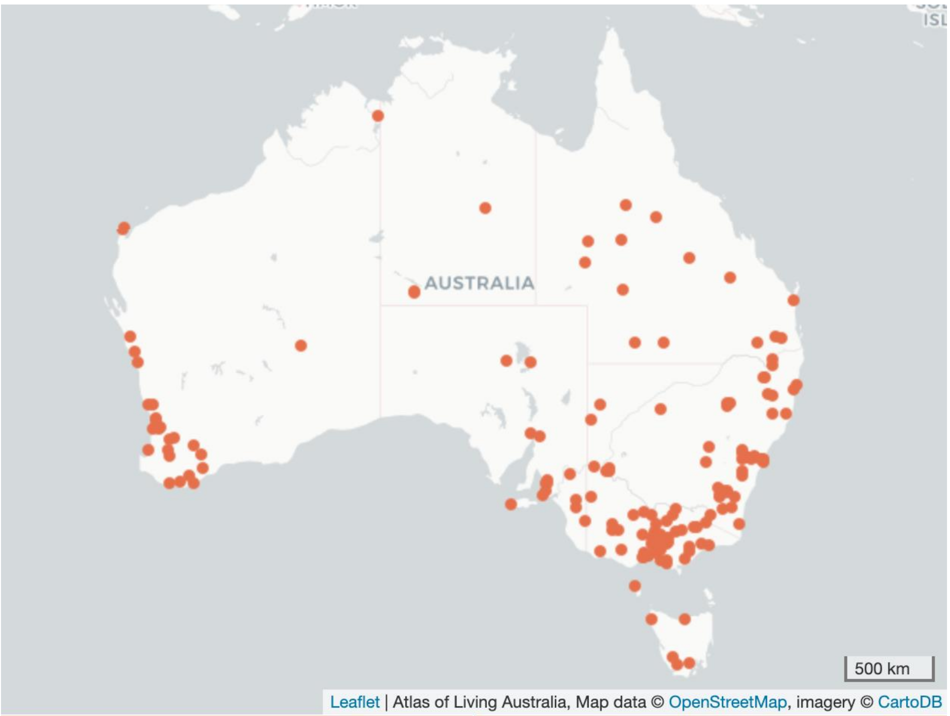
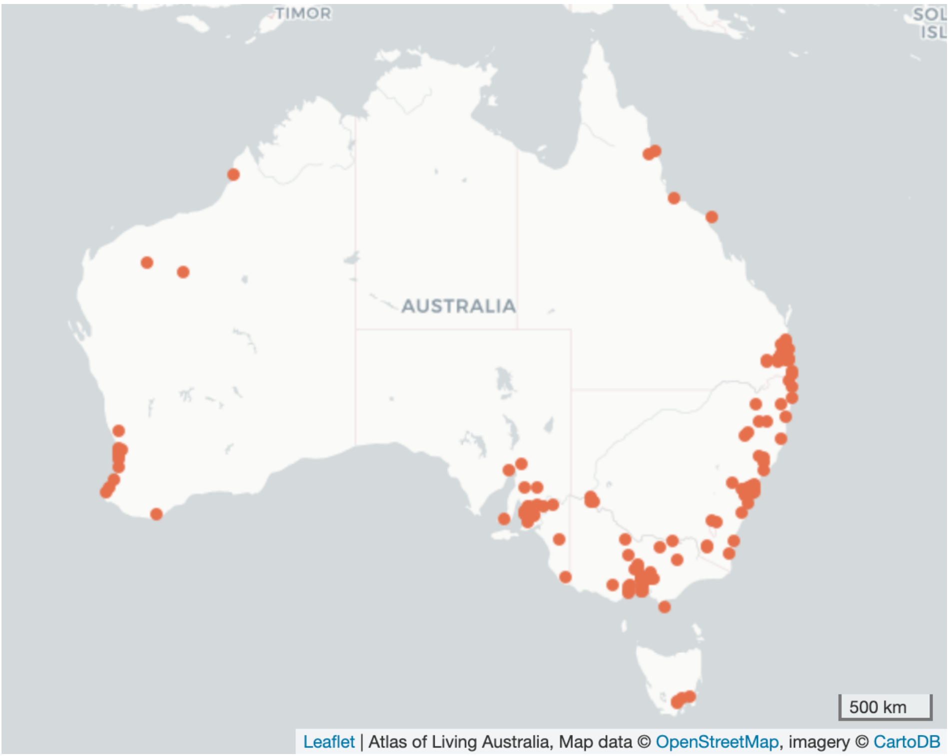


Figure 5. Occurrence reports of *Musca domestica* in Australia (Atlas of Living Australia 2022).



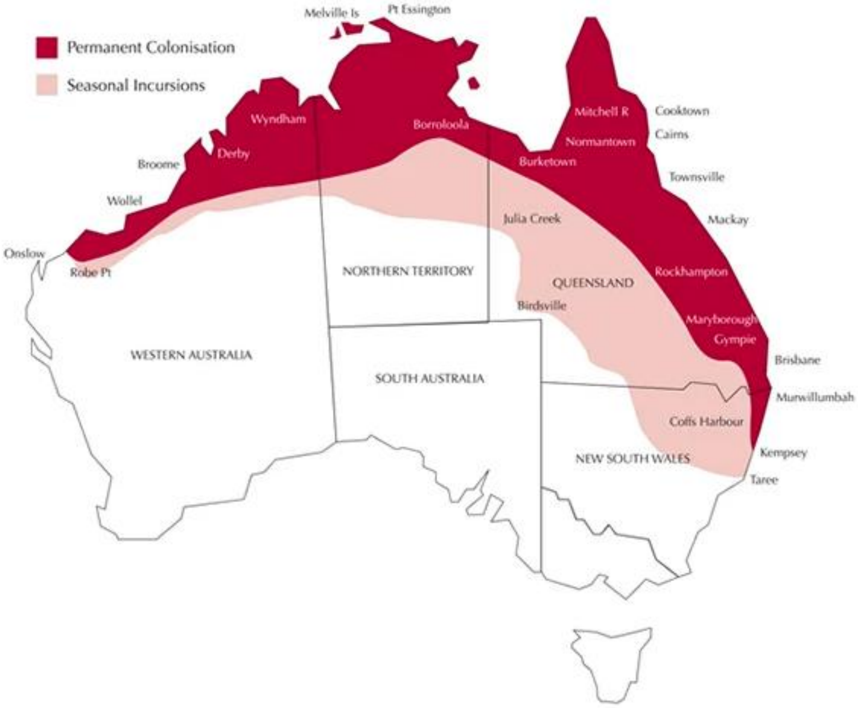
Buffalo flies

The buffalo fly, *Haematobia irritans exigua*, is closely related to the horn fly (*Haematobia irritans irritans)*, which has been suggested as a possible vector of LSDV, although not yet studied (Kahana-Sutin et al. 2017). They are a major cattle pest in northern Australia. Buffalo flies spend most of their time resting or feeding on cattle. They only leave when disturbed or when cattle defecate. Buffalo flies feed 20–40 times a day, with females leaving the host to lay eggs in fresh manure (Madhav et al., 2020). They are usually found on the head and back of cattle, but in the daytime will congregate in the shade of the belly and flanks. Their persistent feeding causes severe irritation to cattle, leading to significant economic losses through reducing milk and meat production, as well as damaged hides (FlyBoss 2024).

Buffalo flies are mostly located in the northern parts of Australia, spanning from north-eastern NSW to northern Western Australia (Figure 6). Their range is expanding southwards and buffalo fly have been found as far south as Maitland in eastern NSW and as far west as Narromine, Dubbo and Bourke during the wet years of 2010–11 (FlyBoss 2024).

The main buffalo fly season is from November to April in northern Australia. They are at their highest numbers in high rainfall coastal areas of Queensland and spread westward into northern WA following heavy summer rainfall. Lower numbers are seen in winter months as they do not like cold weather and dry conditions. The fly season is shorter in southern areas for the same reasons. They tend to overwinter in low numbers on cattle that are sheltered and in areas where there is less likely to be frost (FlyBoss 2024).

Figure 4. Distribution of buffalo fly in Australia (MLA 2022).



Mosquitoes

Australia has over 200 mosquito species capable of transmitting pathogens to animals, with *Aedes*, *Culex*, and *Anopheles* the most prevalent genera (Ong et al. 2021). Most mosquito species exhibit specific preferences for habitats, hosts and feeding behaviour, although this is dependent on host availability and abundance. For example, *Culex annulirostris* typically feeds on cattle in rural areas, but has also been shown to feed on birds, rodents and rabbits in urban areas such as Sydney (Ong et al. 2021; Gyawali et al. 2019). Most mosquito species feed at night, around dusk and predawn, although some species can continuously feed during the day (FlyBoss 2024).

Of particular interest as LSDV vectors in Australia are three mosquito species: *Ae. aegypti* for its confirmed transmission of LSDV, *Cx. quinquefasciatus* for being shown to carry LSD DNA and *Cx. annulirostris*, which is known for transmitting several viruses including Bovine ephemeral fever virus, Murray Valley encephalitis virus, Kunjin virus and Japanese encephalitis virus. However, numerous mosquito species feed on cattle (Stephenson et al. 2019), potentially serving as mechanical vectors of LSDV. Therefore, all species should also be considered when undertaking vector control activities.

In Australia, the distribution of *Ae. aegypti* is limited to central and northern Queensland (Figure 7**Error! Reference source not found.**). Notably, although *Ae. aegypiti* has been shown to be a competent vector of LSDV, it predominantly feeds on humans, suggesting that its potential role in LSDV transmission is likely to be limited (Stephenson et al. 2019; Gubbins 2019). The distribution of *Cx. quinquefasciatus* and *Cx. annulirostris* can be seen in Figure 8 and Figure 9, respectively.

Figure 5. Historic occurrence records of *Aedes aegypti* in Australia. The pink box represents the current distribution of *Ae. aegypti* in Australia (Atlas of Living Australia 2022).

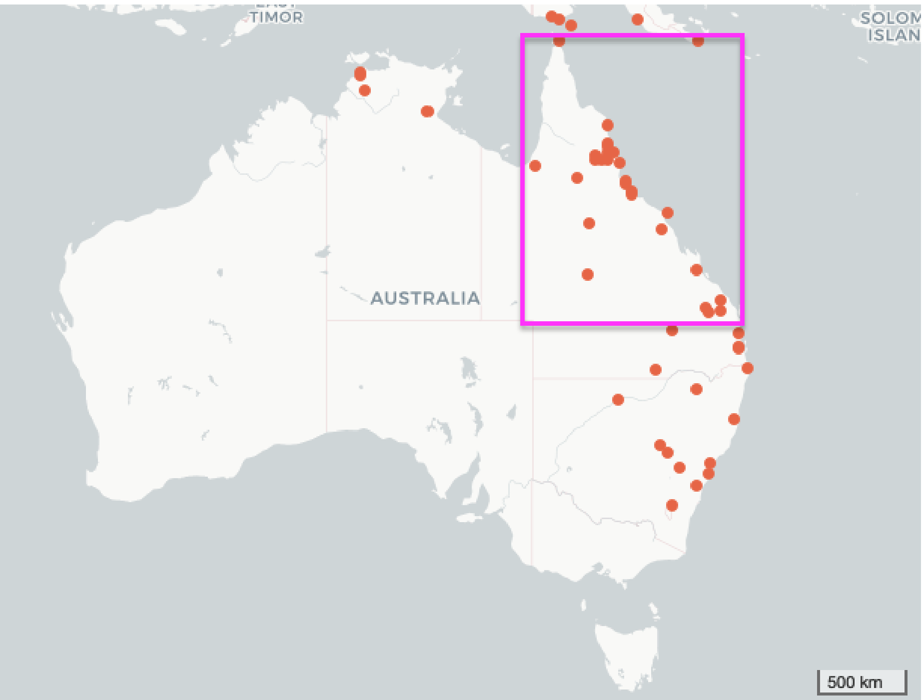


Figure 6. Occurrence reports of *Culex quinquefasciatus* in Australia. (Atlas of Living Australia 2022).

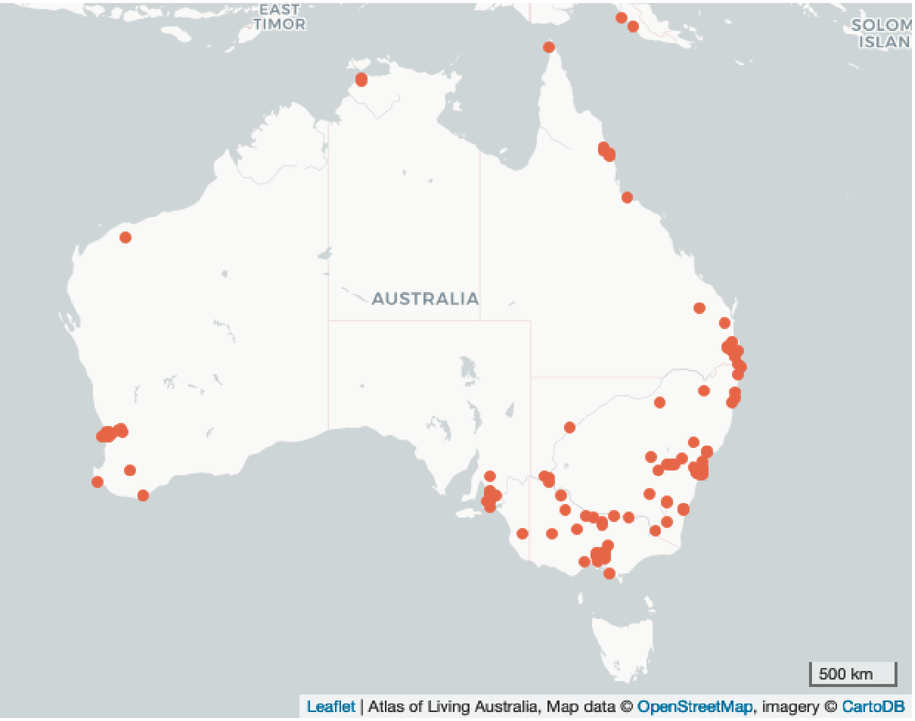
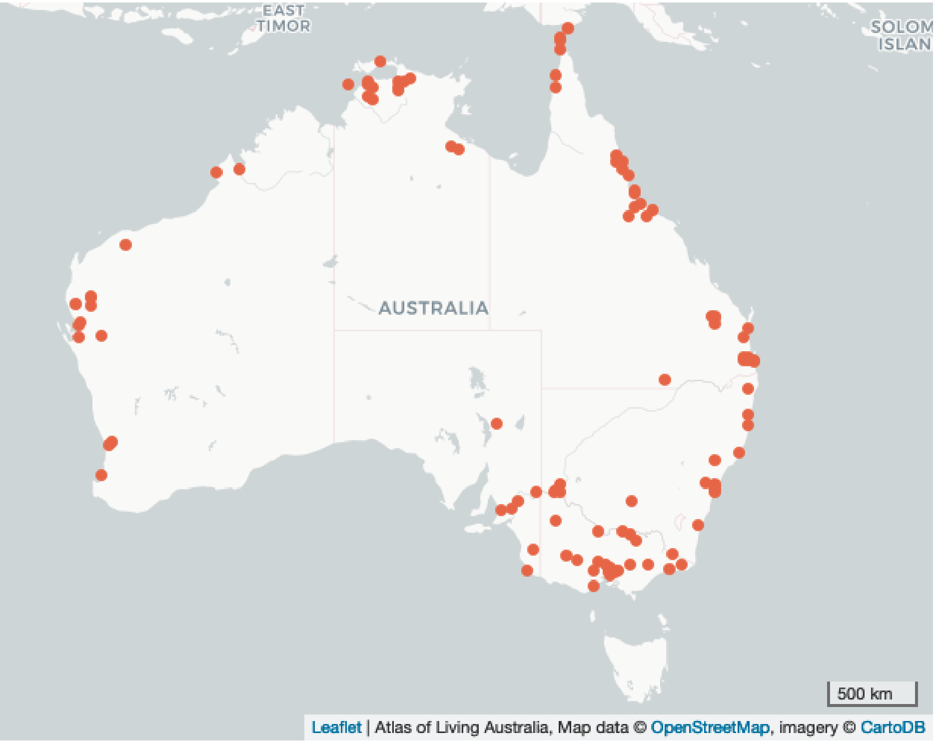


Figure 7. Occurrence reports of *Culex annulirostris* in Australia. (Atlas of Living Australia 2022).

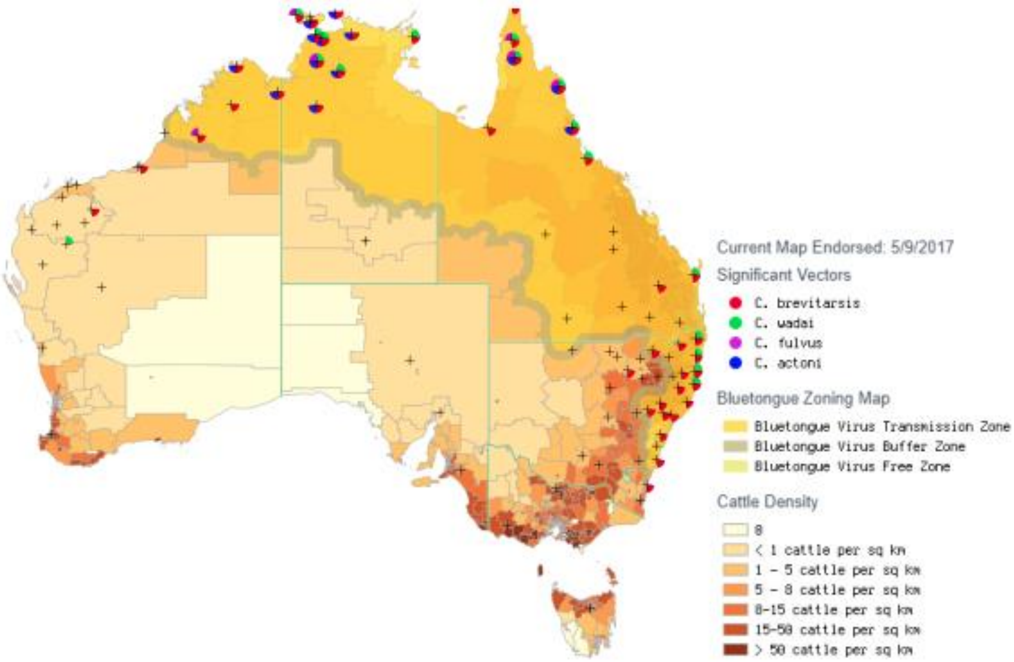


Biting midges

Culicoides midges have been implicated in LSDV transmission, although transmission of LSDV from *Culicoides* to bovines has never been demonstrated experimentally (Chihota et al. 2003a; Eagles et al. 2014; Sanz-Bernardo et al. 2021; Şevik and Doğan 2017). *Culicoides* species are small dark insects measuring 1–5mm, with females requiring a blood meal for the maturation of fertilised eggs. Males feed on plant nectar only. Australia has more than 140 species (Dyce et al. 2007) but the hosts of most of these are not known. Several species feed on livestock (Muller and Murray 1977; Muller et al. 1981).

It is believed that midges undergo three or four generations (reproductive cycles) per year, with adult midges living for one to two weeks. Biting midges are most active under calm conditions and are prevalent around dawn and dusk but may continue to bite through the night. In southern Australia, there is limited midge activity in winter as it is too cold for egg development. Midges are widely distributed across Australia, but the important pest species are mostly tropical and subtropical (Figure 10). They are especially prolific in tropical and subtropical coastal areas. Because of their small size they are considered highly suited to wind-assisted dispersal over long distances. Some midge species are important vectors for BTV and are routinely monitored by the National Arbovirus Monitoring Program (NAMP) to detect incursions of exotic strains of BTV and vectors.

Figure 8. Culicoides trapping results from September 2016–August 2017 with cattle density (MLA 2017).



Australian *Ixodid* ticks

Rhipicephalus is a genus of hard ticks in the *Ixodidae* family. The Australian cattle tick, *R. australis* (previously known as *R. microplus*), is the most economically important tick affecting cattle in Australia, with European breeds of cattle being the most susceptible. *R. australis* is closely related to *R. decoloratus, R. appendiculatus* and *R. annulatus* which have all been shown to transmit LSDV. *R. australis* is endemic in northern Queensland, the Northern Territory and Western Australia (the 'tick zone') and a quarantine zone is in place on the border between Queensland and NSW and in Western Australia (Figure 11). In Australia, regulatory treatment requirements are imposed by jurisdictions when cattle ticks are found outside of the 'tick zone'.

Cattle ticks (*R. australis*) have a 1-host life cycle and, while they prefer cattle, will also feed on buffalo, deer and other livestock. Cattle ticks remain viable year-round, although in colder areas they may slow down reproduction.

Other hard ticks affecting cattle include the bush tick (*Haemaphysalis longicornis*) and the wallaby tick (*Haemaphysalis bancrofti*). Cattle are the preferred host for the bush tick, but it does infest other livestock and mammals. They have a 3-host life cycle, which is usually completed in around 12 months but may range between 4 to 18 months. The bush tick is mostly found in sub-tropical regions and some temperate areas with summer rainfall. The main endemic zone is a relatively narrow coastal strip extending from Gympie, Queensland, in the north to the north coast of NSW though the ticks may occur up to 100 km inland. It occurs sporadically as far south as Gippsland in Victoria, and inland as far as Albury-Wodonga. In Western Australia a small area of infestation has established in the Walpole-Denmark district on the far south coast (Figure 12). Adult numbers peak in spring and early summer. Seasonality is more pronounced in temperate climates with only a few weeks for adult tick development in summer.

The paralysis tick (*Ixodes holocyus*) is capable of inflicting severe disease. It is found in coastal regions on the eastern seaboard (Figure 12). It has a 3-host cycle, and prefers wildlife (bandicoots, bettongs bats, etc) but also feeds on livestock. Adult females, larval and nymph stages feed on animals, while adult males parasitise females for blood meals. They have a complicated life cycle that is usually completed in around 12 months, but this may range from 4 to 18 months depending on the weather (faster in warm, humid conditions). Adult numbers peak in late spring and summer.

Figure 9. Distribution of *Rhipicephalus australis* in Australia, also showing the cattle tick zone (TickBoss 2022).

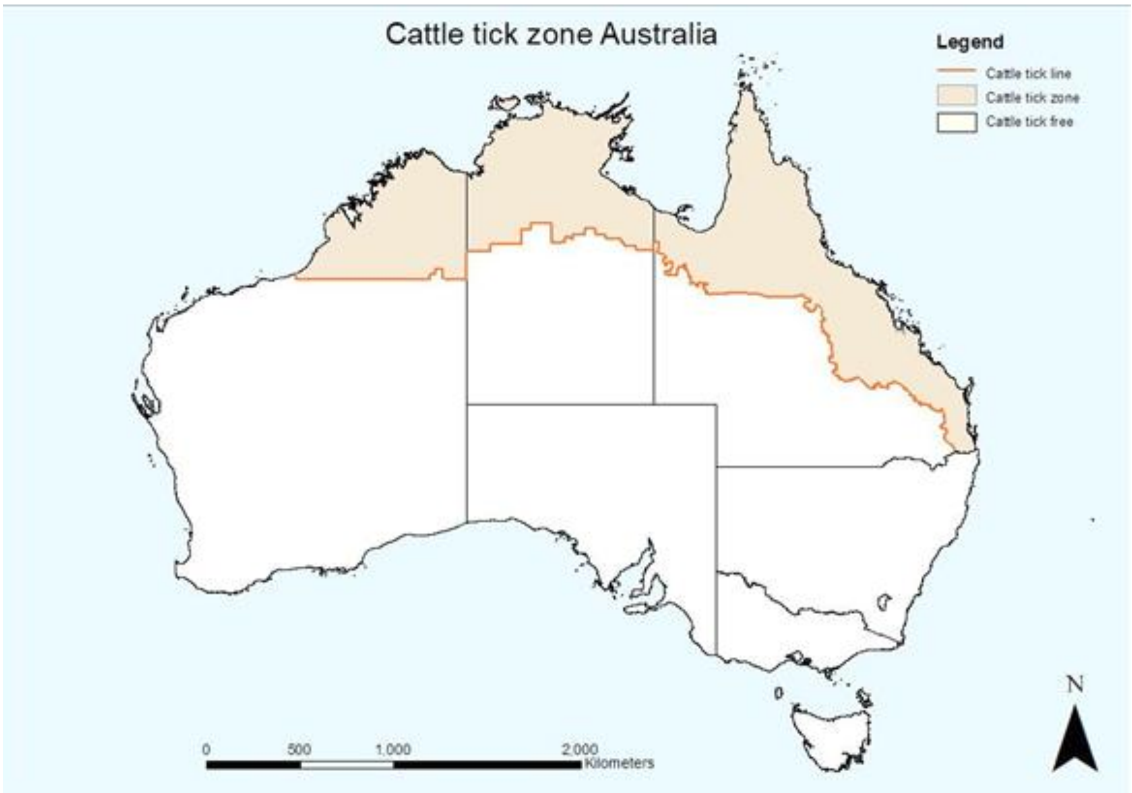
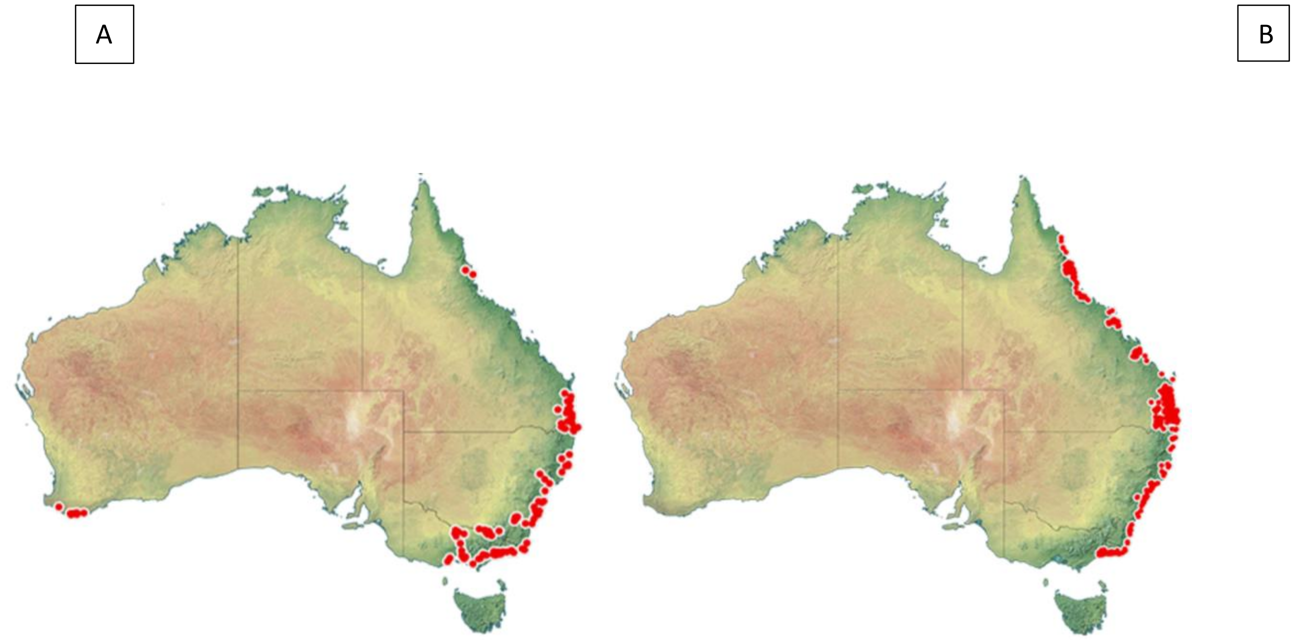


Figure 10. Occurrence reports of ixodid ticks in Australia. (A) *Haemaphysalis longicornis* (Australian bush tick), (B) *Ixodes holocyus* (Australian paralysis tick) in Australia (Stewart 2021).



4 Host types

Lumpy skin disease virus (LSDV) can infect both cattle and water buffalo (*Bubalus bubalis*). There is evidence of antibodies to LSDV in several wild African ruminant species including African buffalo, blue wildebeest, eland, giraffe, impala and great kudu but clinical disease has only been observed in captive oryx and experimentally infected giraffe and impala (Barnard 1997; Fagbo et al. 2014; Greta et al. 1992; Young et al. 1970). Lumpy skin disease virus (LSDV) may persist in susceptible African wildlife, making it plausible to consider wild species as a source of recurrence or reservoir after seemingly successful eradication from domestic animals (Calistri et al. 2018; Gortazar et al. 2021). There is no evidence of clinical disease or seropositivity in wildlife outside the African continent, but there are also no studies that indicate work in this area.

While all ages of cattle are susceptible, young cattle and those at the peak of their lactation appear to be most vulnerable although this is not a consistent finding in all LSD risk analysis studies (Tuppurainen et al. 2011; Bianchini et al. 2023). Thin-skinned and high-producing *Bos taurus* breeds are highly susceptible to LSD, whereas *Bos indicus* and zebu-breeds indigenous to Africa may have some natural resistance to the virus (Gari et al. 2011; Şevik and Doğan 2017; Klement 2018; Tageldin et al. 2014; Bianchini et al. 2023). Banteng cattle (*Bos javanicus*) have been infected with LSD in Asia, but whether they are more or less susceptible than other breeds is unknown (OIE 2022). Most LSD transmission studies have used *Bos taurus*, whereas in northern Australia, the more resistant *Bos indicus* and buffalo breeds are prevalent (Hall et al. 2023).

4.1 Australian cattle population

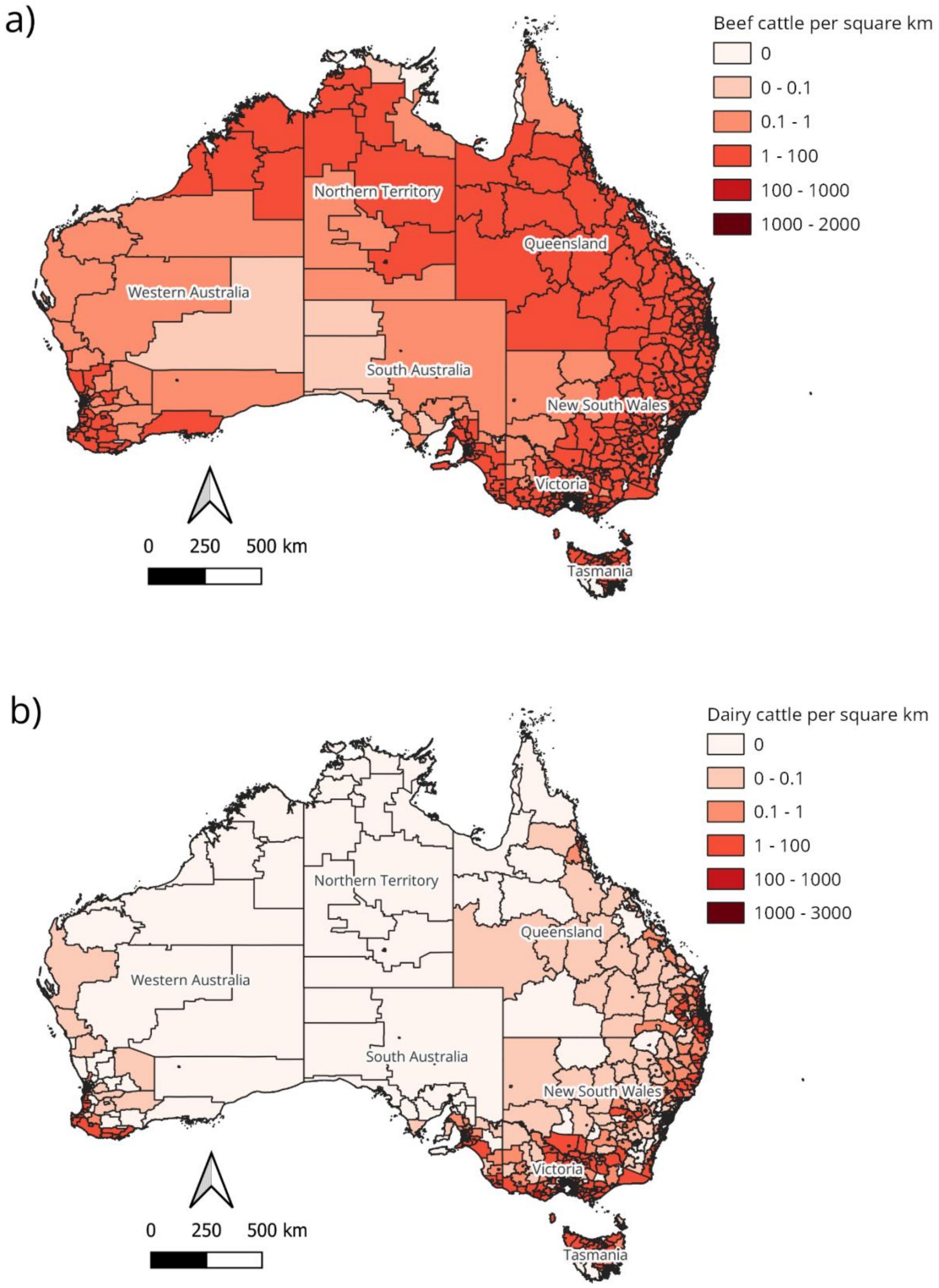
In 2021, the total domestic cattle herd in Australia was 24.4 million head, comprising 22.2 million head of beef cattle and 2.2 million dairy cattle (ABS 2022). Most beef cattle are in Queensland (45%), followed by NSW (19%), Victoria (14%), Western Australia (8%), the Northern Territory (7%), South Australia (4%) and Tasmania (3%) (Figure 13). Dairy operations mostly occur in south-eastern Australia and across temperate and some subtropical regions (DAFF 2023a).

The Australian buffalo industry consists of the Northern Territory herd and the dairy buffalo industry (DAFF 2023a). The Northern Territory industry relies on water buffalo, found either in uncontrolled herds in areas such as Arnhem Land and other Aboriginal lands, or managed within large paddocks on extensive commercial stations primarily located close to Darwin (MacDonald et al. 2021). In 2020, the uncontrolled herd was estimated to exceed 180,000, while approximately 10,000 head were managed on commercial stations (MacDonald et al. 2021). The buffalo dairy industry, as of 2020, consisted of 12 dairies with approximately 3,000 head, operating in most states.

Three species of bovines are feral in Australia: feral domestic cattle (including *Bos Taurus* and *Bos indicus* species), *Bos javanicus* (banteng cattle, also known as Bali cattle) and water buffalo (DAFF 2023a). Feral cattle are present around most pastoral areas, albeit at much lower densities than domestic cattle (Reid et al. 2020; Woolnough et al. 2005). A small population of feral banteng cattle inhabit the Cobourg Peninsula in the Northern Territory. While contact rates between banteng cattle and domestic cattle are unknown, the domestic cattle density in this region is low (0–0.1 per square km) (DAFF 2023a).

The population of feral water buffalo is increasing, yet the level of contact between buffalo and domestic cattle is unknown (DAFF 2023a). Given the numbers and widespread distribution across the Northern Territory, it is probable that contact occurs between buffalo and domestic cattle around watering points, especially during the dry season (DAFF 2023a). Observations suggest that when domestic cattle and buffalo share a paddock, they tend to not interact (Lemcke 2017).

Figure 11. Cattle density in Australia. (a) commercial beef cattle, (b) dairy cattle (DAFF 2023a).



4.2 Host density and vector transmission

Modelling studies have shown that high cattle density is a risk factor for LSD occurrence (EFSA 2018; Şevik and Doğan 2017; Allepuz et al. 2019). Allepuz et al. (2019) used logistic regression modelling and data from the Balkans, Caucasus and the Middle East outbreaks to identify increased odds of LSD associated with high cattle densities, cropland, grassland or shrubland, higher annual mean temperature and higher diurnal temperature.

For LSDV introduction to occur in Australia, infectious vectors must locate a suitable host on arrival, which depends on the density of bovines near the arrival site and the physiological condition of the arriving vector (Hall et al. 2023). Bovine density in northern Australia where infectious vectors could arrive via wind dispersion from northern neighbours would is much lower compared to southern areas, reducing the risk of windborne introduction considerably, based on cattle distribution alone (Figure 13).

5 Options for vector control

Understanding vector life cycles aids in the design of successful integrated management and control programs, as targeting a single life stage is unlikely to be effective in sustainably reducing vector populations. Methods that are effective for one vector species may not apply to another. Arthropods are best targeted for control when they are concentrated, immobile and accessible during the egg and larval stages. Control is challenging in areas with abundant vectors and hosts, and if the vector is capable of long-distance movement, as reinfestation is likely.

Currently, there is no evidence regarding the effectiveness of vector control in preventing LSD (WOAH 2022; CFSPH 2017; Gottlieb 2018). Nonetheless, instances of vector control using chemical methods have been reported during LSD outbreaks (European Food Safety 2017). Effective insect control on cattle and in the environment may reduce the rate of mechanical transmission of LSD, particularly if cattle are housed or penned (e.g. feedlots) (Gottlieb 2018; Susanti et al. 2023; Arjkumpa et al. 2024). Achieving a successful reduction in vector populations is much more challenging when cattle are free-roaming (Tuppurainen et al. 2017).

The decision to implement vector control measures should be carefully considered. The concurrent use of multiple vector control methods (i.e. integrated control) may help reduce vector populations and interrupt virus transmission cycles, however there is currently no evidence supporting the efficacy of vector control in preventing or controlling LSD outbreaks (WOAH 2022; CFSPH 2017). Data on how much reduction to the vector population is required to interrupt transmission is needed to provide a goal for any vector reduction strategy (Mullens et al. 2015). If vector control is included in a response to an LSD outbreak it should be regarded solely as a supplementary measure alongside other strategies, such as vaccination and movement restrictions. The cost and potentially negative impacts of vector control on human, animal and environmental health should be considered. However, integrated vector control strategies are an integral component of general farm biosecurity and can yield broader production benefits when effectively implemented, irrespective of their effectiveness (or lack of) in reducing LSD transmission.

This section reviews the principles of IPM and evaluates the environmental, biological and chemical control options for potential LSDV vectors in Australia. Appendices 1, 2 and 3 details the biology of vectors considered to be of potential importance to LSDV transmission in Australia.

5.1 Important concepts of vector life cycles

Abundance and seasonality

Before initiating vector control, abundance and seasonality should be considered. Abundance refers the number of vectors in an area, usually expressed as a metric based on monitoring and surveys. Abundance is associated with seasonality, which is related to the fluctuations in the vector population that occur throughout the year (ECDC and EFSA 2018). In subtropical and temperate climates, vector populations are reduced or absent over winter months, and more numerous in other months, with peaks in summer. Vectors in tropical and sub-tropical regions may not experience population reductions as rainfall, temperature and humidity remains high over the year. Variations in vector populations are often related to environmental factors and the timing of these cycles of abundance can be used to advantage when implementing controls. Abundance and seasonality vary between regions, and understanding these two factors in regions is beneficial for implementation of control measures.

Overwintering

During periods of shorter day length and cooler water temperatures where some vectors breed, many species of insects and ticks enter diapause (a spontaneous state of dormancy) or seek sheltered areas until conditions improve. Depending on the species, diapause may occur in adults or in immature stages, leading to substantially reduced activity and populations. The overwintering behaviour of vector species can be used to advantage when implementing population control measures as interventions are most effective when populations are low. Targeted measures should be implemented in locations where vectors overwinter or seek shelter. Timing interventions shortly before or during emergence from overwintering is also more effective at reducing populations than responding during peak season. In tropical areas, such as northern Australia, overwintering is unlikely to occur, although some Diptera populations may decline during the dry season. Implementing complementary control measures such as vaccination during winter periods is also more likely to result in effective disease because vector numbers are lower. This was seen in the 2015-2017 campaign that saw LSD brought under control in the Balkan region (Tuppurainen et al. 2020).

5.2 Integrated pest management

Integrated pest management (IPM) combines environmental, biological and chemical methods to control pests (Smith et al. 2022) (Box 2). It involves developing a plan to regulate pest populations in a safe way, which reduces reliance on chemicals and seeks to minimise harm to the environment and non-target species. One of the key premises behind IPM is to intervene only when pest numbers reach a threshold where they are causing a problem. Once the threshold has been crossed, intervention is necessary, and the type of intervention is dictated by costs, environmental impacts and efficacy.

If pest numbers are low then local predators and parasites are likely to keep the population under control, and no intervention is required. In this manual, we present interventions for when interventions are required. However, we acknowledge that intervention thresholds for LSDV control are not known. For dairies or feedlots where vectors have access to abundant food sources and can therefore reproduce rapidly, thresholds may be lower because interventions must be implemented before adult insect populations become too large, or they risk being completely ineffective. Ideally, ongoing monitoring and evaluation should be undertaken to determine when interventions are necessary, especially in environments with high insect pressure, to maintain populations below disease-causing or production thresholds and to implement appropriate responses when exceeded (Figure 14).

Box 2. Pest management control definitions

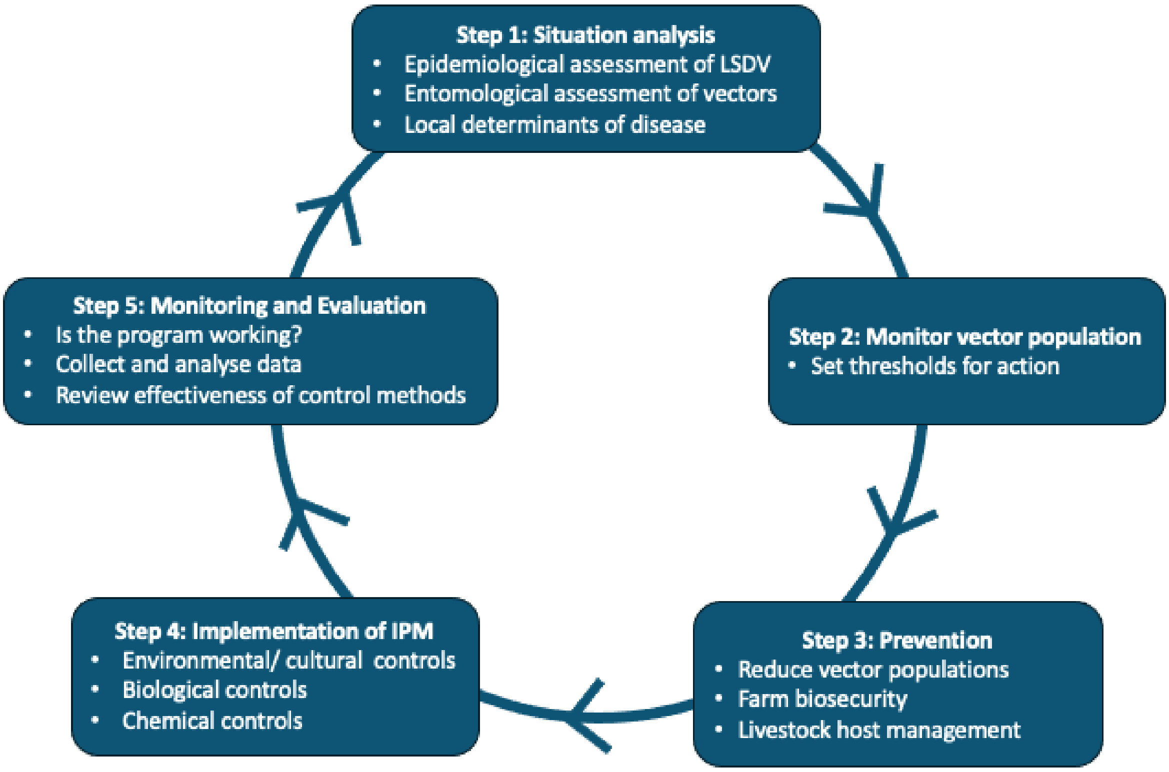
Environment controls (sometimes referred to as cultural control) include physical or cultural activities that make the environment less favourable for pests. This may include source reduction (e.g. manipulating breeding sites), habitat manipulation, and waste management e.g. removal of manure, rotting feed.

Biological controls use predators, parasites or microbial pathogens of insects to suppress populations. E.g. parasitic wasps and entomopathogenic fungi.

Chemical controls use substances that kill or repel pests. E.g., pour-ons, sprays and dips.

Action threshold is the point at which the pest population or disease situation indicates action must be taken to prevent the pest from becoming an economic threat.

Figure 12: Integrated pest management model for vector control. Adapted from (Farm Biosecurity 2024).



When developing IPM programs, important factors to consider include:

- **Pest identification:** Understand the pest population lifecycle and preferred breeding habitats to identify the most appropriate combination of control measures. This should include a local survey of vectors to understand abundance and seasonal dynamics.
- **Forward planning:** Implement an IPM once the predetermined threshold is reached.
- **Regular monitoring:** Pest populations (adult and larval) need to be regularly monitored to ensure IPM strategies are working and to identify if pest populations are increasing due to a failure in IPM strategies or if climate and environmental conditions have become favourable.
- **Timely decision-making:** Pest populations can increase rapidly if conditions are favourable. Issues must be identified early, and action taken promptly if pest populations change.

5.2.1 Area-Wide Integrated Pest Management

Area-wide integrated pest management (AW-IPM) is an approach that targets the entire pest population in a geographic area. This approach aims to prevent or minimise the risk of re-infestation once the vector is eliminated from an area and requires coordinated efforts among numerous stakeholders, centralised management and broad community support to prevent re-infestation (Hendrichs et al. 2021). This approach increasingly successfully applied to global vector control programs for vector-borne diseases of public health importance, such as malaria, dengue fever, and trypanosomiasis (Culbert et al. 2018; Gómez et al. 2023; FAO and WHO 2022). Successful implementation of AW-IPM forms the basis of the global effort to eliminate human African trypanosomiasis in Africa (See Appendix 4).

Area-wide integrated pest management (AW-IPM) programs have been used to manage the spread of bovine babesiosis, and it is currently being evaluated as an option to manage *Theileria orientalis* in Australia. In this program, new strategies are being developed that embrace the principles of AW-IPM by looking beyond existing chemical strategies to incorporating non-chemical methods such as vaccination, genetic manipulation and environmental manipulation (Emery 2021) (See Box 3).

Of potential vectors implicated in LSD transmission, the stable fly appears the most well-suited for an AW-IPM approach. This is because their life cycle, feeding behaviour and ability to disperse over large distances challenges traditional farm-level control measures (Taylor 2021). Stable flies can fly several kilometres from their breeding sites, which complicates on-farm efforts to target larval development sites before adult emergence. An AW-IPM strategy capable of addressing larval development and eliminating breeding substrates across a large area, in conjunction with a range of complimentary control measures, potentially offers a more effective strategy for stable fly management (Taylor 2021).

Buffalo flies may also be well-suited to a AW-IPM approach given their ability to disperse over long distances (James et al. 2021). Current control strategies, primarily relying on herd-level chemical treatments and movement controls, have proven largely ineffective in stopping the southward spread of buffalo flies (James et al. 2021). To address this, research is exploring the implementation of an AW-IPM approach. This involves transinfecting buffalo flies with the *Wolbachia* bacteria and targeting the overwintering phase when the population is at its lowest (James et al. 2021). Researchers are currently establishing transinfected buffalo fly lines and characterising the effects of *Wolbachia* infection on buffalo fly populations in laboratory settings as a preliminary step. By using biological agents, such as *Wolbachia,* vector control shifts the focus from individual cattle treatments to the whole pest population in a region and will reduce reliance on chemical treatments for management (James et al. 2021).

Box 3. Case study: Integrated pest management options for controlling *Theileria orientalis* in cattle in Australia.

Theileria orientalis affects cattle in coastal Victoria, NSW, southern Queensland, and southern parts of Western Australia. The 3-host ixodid tick, *Haemaphysalis longicornis*, is the major vector for *T. orientalis* in Australia. Infected cattle become carriers, contributing to the circulation of the pathogen in ticks within endemic regions and facilitating spread to new areas through movement of infected cattle. Current control measures focus on restricting the movement of naïve cattle into infected areas and managing tick infestations. However, new strategies incorporating the principles of IPM are being explored. Vector control options underway include:

- Environmental controls such as rotational grazing, situating calving paddocks away from bushland to avoid exposure to *H. longicornis* carried by wildlife, and changing calving times to avoid the emergence of adult ticks in spring.
- Deliberate pre-infection of cattle before movement into an endemic area to induce a 'carrier status' protective against further clinical disease. Further research is needed as this approach carries some risks.
- Vaccination against *H. longicornis*: Research into vaccine development is ongoing.
- Breeding tick resistant cattle.
- Acaricides targeting *H. longicornis* on cattle: Flumethrin pour-ons have shown efficiency in reducing *H. longicornis* populations and theilerial infections in Korea. However, macrocyclic lactones have demonstrated only a partial reduction in tick numbers on cattle and have negative impacts on beneficial insects (e.g. dung beetles). Controlling 3-host ticks like *H. longicornis* is challenging due to their short feeding times (5–7 days), and some acaricides may require longer exposure to kill ticks.

Summarised from Emery (2021).

The strengths and limitations of IPM for vector-borne diseases are detailed in Box .

Box 4. Strengths and limitations of integrated pest management for vector-borne control

Strengths of IPM

- Environmentally sustainable and protective
- Reduces reliance on single tactics to control vectors
- Cost-effective by reducing unnecessary use of chemicals and lowering the disease burden on hosts
- Targeted control – minimise impact on non-target species (e.g., beneficial insects)
- Reduces reliance on chemicals (should be the last resort option)
- Minimises or slows resistance to chemicals
- Reduces potential residues in the environment and livestock
- Flexible and adaptable to changing environments and pests
- Greater social acceptance of methods.

Limitations of IPM

- Time intensive and long-term
- Technical knowledge required of biology and transmission methods (evidence may not be available or robust)
- Separate plan required for each pest, farm or location
- Close monitoring is required
- Some non-chemical methods may not be available for specific pests e.g., SIT
- Risk of being ineffective if poorly planned or monitored
- Potentially costly.

5.3 General measures used for vector control

Vector control measures employ strategies that either kill (e.g. larvicides, adulticides, predator species), eliminate suitable habitats (e.g. habitat modification) or reduce vector contact with the host (e.g. repellents, barriers) (Wilson et al. 2020). When implementing measures to control vectors, methods that present the least risk to the environment and human health should be prioritised. The effectiveness of a control method depends on factors such as the species, their transmission competency, breeding habitat and susceptibility to insecticides (Global Vector Hub 2024). Increased resistance to insecticides and their potentially hazardous impact on the ecosystem strengthens the need for effective non-chemical control strategies for LSD vectors (Sprygin et al. 2019). Combining several methods has been found to be the most efficient method of controlling vector populations (Global Vector Hub 2024; Oliveira et al. 2018).

5.4 Environmental controls

Vector control using environmental (or cultural) tools should be tailored to the biology and seasonality of the target insects, considering factors such as habitat, vector density and host activities. Environmental controls typically involve landscape modification and behaviour manipulation. Landscape modifications aim to eliminate breeding grounds for vectors, while behavioural manipulation targets humans, animals or the vectors themselves. Table 4 summarises environmental control measures suitable for the main vector types implicated in LSD transmission.

Table 4. A summary of environmental control measures suitable for flies, mosquitoes, midges and ticks.

Environmental control method	Action	Life stage targeted	Muscids	Tabanids	Mosquitoes	Midges	Ticks
Sanitation measures e.g. removing manure, decaying vegetation, stagnant water, spoiled feed.	Habitat reduction; Reduce vector population	Eggs, Larvae	✓	✓	✓	✓	✗
Housing modification, e.g. screens, fans, nets.	Reduce vector-host contact	Adults	✓	✓	✓	✓	✗
Pasture management, e.g. rotation grazing, patch burning.	Habitat reduction; Reduce vector population	Eggs, Larvae	✓	✓	✗	✗	✓
Animal management e.g., paddock sweeper program.	Reduce vector-host contact	Adults	✗	✓	✗	✗	✓
Traps and baits.	Reduce vector-host contact; Reduce vector population	Adults	✓	✓	✓	✓	✗

5.4.1 Environmental controls for flies

Environmental control measures primarily focus on eliminating potential egg-laying habitats. Flies require moisture to prevent their eggs, larvae and pupae from desiccating, so reducing moisture in their egg laying habitats will disrupt development (CFSPH 2021a). Exclusion activities aim to limit vector-host contact, such as installing screens on buildings to prevent adult flies from entering areas where livestock are housed. Environmental control methods are summarised in Tables 5—10.

Table 5. Environmental control methods for flies: Sanitation practices

Method detail	Description	References
Action	• Remove manure and organic debris (e.g. spilled feed, rotten vegetation) away from cattle yards, feedlot pens, dairy to reduce available breeding sites. Particularly focus on areas that are inaccessible to cattle, such as under fence lines and water troughs. • Spread manure and organic matter thinly on pasture (<5mm deep), harrow into soil, or compost. • Disturb or break up manure and organic debris weekly to prevent insect eggs from hatching. Do this by dragging over pasture, scraping to physically break apart dung piles. • Promote drying by circulating air and draining wet areas. Fix any leaks promptly. Improve drainage. • Periodically move round bale hay placement sites in paddocks (these can be a significant source of stable fly larvae development). • Keep silage dry, off the ground, and cover silage pits. • Incorporating wet crop residues into the soil at 15 cm deep as quickly as possible following harvest and stopping irrigation can help prevent fly development in crop residues. • Compacting the soil where the crop residue has been buried with a land roller has been reported to have reduced stable fly populations in Western Australia. • Manage feed and water to reduce moisture.	(CFSPH 2021a; Rochon et al. 2021; Taylor 2021; DPIRD 2022)
Target flies	All species, especially stable flies, house flies, bush flies, buffalo flies. Less effective for tabanids.	
Effectiveness	• These actions can be very effective at reducing local populations of stable flies, buffalo flies, bush flies, and house flies. • Much higher abundance of fly populations can be expected without the implementation of these actions.	(Baldacchino et al. 2018, 2013; Rochon et al. 2021)
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported.	

Method detail	Description	References
Limitations	• Once an adult population reaches the action threshold it may be too late to initiate sanitation methods during that fly season. Therefore, sanitation methods should be implemented pre-emptively to prevent build up in adult populations. Or use thresholds on larval numbers. • Stable flies are strong fliers and can migrate over long distances so local sanitation measures may be ineffective. An AW-IPM approach is required for these species. • Tabanid species often breed in pasture and bushland, which may be away from where cattle are kept. So, sanitation methods may not be effective for these species.	(Baldacchino et al. 2014; Floate et al. 2013; Rochon et al. 2021)

Table 6. Environmental control methods for flies: Housing modifications

Method detail	Description	References
Action	• Use of basic shelters as some fly species, such as tabanids, do not like entering facilities, therefore tabanid biting is reduced. • Door and window screens (particularly insecticide-impregnated nettings) prevent flies entering livestock production facilities. • High powered fans indoors can inhibit flight activity and decrease the number of flies disturbing cattle. • Physical barriers such as solid fencing or net barriers in outside environments can reduce the number of flies reaching cattle. Nets are typically treated with SP chemicals or a repellent (e.g. DEET). Barriers should be around 1.2m high.	(Baldacchino et al. 2018)
Target flies	Any, specifically tabanids, stable flies, buffalo flies	
Effectiveness	• Effective if cattle are housed or there is infrastructure that can be protected (e.g. milk shed, abattoir). • Fly species such as tabanids and stable flies do not tend to fly over barriers, instead they try to fly around them. • Fly net barriers surrounding pens or yards have been shown to successfully protect livestock from stable flies and tsetse flies in Africa. • In a study conducted in Thailand, focusing on insecticide-impregnated screens and hematophagous flies (tabanids and stable flies), researchers reported that the insecticidal activity of screen prototypes lasted approximately 3-4 months under laboratory testing. However, in field conditions, significant	(Baldacchino et al. 2018, 2018; Bauer et al. 2011; Desquesnes et al. 2019)

Method detail	Description	References
	reductions in fly densities were observed in all test farms for up to 7 months after screen deployment.	
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported. But nets may impact on non-target species.	
Limitations	• Screens and fans only work for certain infrastructure e.g., indoor housed animals or relatively small livestock facilities (e.g. milk processing facilities, slaughterhouses, covered saleyards, etc.). • Outside pens can have net barriers erected, but this can be a costly exercise. Also, there are concerns about sustainability and safe disposal of used netting. • Any damage to netting will impar effectiveness.	

Table 7. Environmental control methods for flies: Traps and targets

Method detail	Description	References
Action	• Traps and targets are designed to attract biting flies using sensory cues such as colour, movement, heat and light intensity or polarisation. Relative efficiency varies for different species (Figure 15). • Traps and targets are species-specific. • Place traps as close to hosts as possible to maximise capture of the greatest number of flies. • Trap height above ground can impact trapping success. Ideally, for most fly species, they should be approximately 1 meter to 1.5 metres above the ground. • Walk-through traps can be used for any fly species, although they have been shown to be most effective for buffalo flies. The traps can be equipped with a vacuum system to increase fly catches, and hence, can collect large numbers of flies. • The buffalo fly trap tunnel catches flies as cattle walk through the tunnel. Changes in light intensity cause the flies to fly upwards, where they are trapped and die from dehydration. • Another version of this is the curtain trap, which brushes the flies off the animal as they walk through. The curtain can be impregnated with insecticide. • Tabanids are strongly attracted to horizontally polarised light (e.g. as reflected from surface water). Large open-style traps with shiny black spherical targets are commonly	(Baldacchino et al. 2014, 2018; Horváth et al. 2014; Egri et al. 2013; Taylor and Berkebile 2006; Denning et al. 2014; Rochon et al. 2021)

Method detail	Description	References
	used (e.g. the malaise, canopy, box, greenhead, Manitoba, H and Epps traps). • Adhesive-coated traps control house flies and stable flies. These include the Alsynite trap, the Williams trap, the Broce trap and the EZ trap. Cloth traps with a funnel collection mechanism may also be used for stable flies. Stable flies are attracted to white panel sticky traps at 2.5 times the effectiveness compared to Alsynite traps. Young stable flies prefer white, whereas gravid females prefer blue, and more males are reported to be captured than females, at a 2:1 ratio. • The Williams fly trap can be used for stable flies. It is a simple trap that uses a white Alsynite panel painted with a non-drying glue to catch flies. The traps are specific to stable flies and will not trap other species. Smaller commercial versions of the Williams fly trap available for order overseas include Olsen Sticky Traps, Farnam Bite Free Stable Fly Trap, Starbar Bite Free Stable Fly Trap and EZ Sticky Fly Trap. • Odour-baited blowfly traps are ineffective for other species such as stable flies.	
Target flies	Buffalo flies, tabanids, stable flies, non-biting flies	
Effectiveness	• Provide good control for adult fly populations, especially on feedlots and dairies provided users understand seasonal fly patterns. • Large sticky traps were reported to be effective in controlling house flies and stable flies in dairy calf greenhouse facilities in New York, USA. • The Bruce walk through trap has been found to reduce horn fly numbers on pastured cattle from 73% to 54%. A modified version of the Bruce trap for use in dairy systems reportedly reduces horn flies between 82 – 88%. • One study observed a decrease in stable fly populations using permethrin-treated targets made of white Coroplast® panels in Canadian dairy farms. • Buffalo fly trap tunnels can reduce buffalo fly burden by up to 60%.	(Baldacchino et al. 2018; Kaufman et al. 2010; Zhu et al. 2016; Hall and Doisy 1989; Beresford and Sutcliffe 2010; Rochon et al. 2021; Brewer et al. 2021; Miraballes et al. 2017)
Applicable to Australia	• Yes. Traps are commonly used to control fly populations in cattle. They are also used to protect high value animals e.g., horses and zoo animals.	(FlyBoss 2024; DPIRD 2015)

Method detail	Description	References
Impact on animals, humans, environment	• Sticky traps may capture non-target insects, which vary by location and season. • Insectivorous birds and reptiles may come into contact with the glue on the traps when feeding on dead insects, but there are no reports of long-term impacts on wildlife.	(Rochon et al. 2021)
Limitations	• High vegetation around the trap can reduce effectiveness. • Success is dependent on proper placement of traps, the number of traps per unit area, and routine servicing. • Traps are expensive and labour-intensive. • Control on a large scale, especially for tabanids, may not be practical. But targeted applications may be possible for farms/ livestock facilities with smaller host populations.	(Rochon et al. 2021; Baldacchino et al. 2018)

Figure 13: Examples of trapping devices for tabanids, stable flies and tsetse flies: (A) Broce trap, (B) malaise trap, (C) canopy trap, (D) blue target, (E) Vavoua trap, (F) Nzi trap, (G) Manitoba trap, (H) H trap and (I) horizontally polarising liquid trap.

Table 8. Environmental/chemical control method: Attractants and insecticide baits for flies

Method detail	Description	References
Action	• Attract flies to bait where they are killed or repelled. • The attractiveness of traps or toxic baits is enhanced by using odour attractants such as pheromones (e.g. (Z)-9-tricosene for *M. domestica*) or kairomones (e.g. carbon dioxide, animal urines, octenol, phenols). • House fly taps are regularly used in indoor livestock units. • Pheromone, (Z)-9-tricosene, is added as attractant alone or in combination with sugar to many commercial house fly insecticide baits.	(Baldacchino et al. 2018, 2014; Brugman et al. 2018; Butler et al. 2007)

Method detail	Description	References
	• Several chemical compounds found in excretory products, glandular secretions and exudations have been identified as attractants for biting flies such as octenol (1-octen-3-ol) and several phenolic compounds.	
Target flies	Any, especially non-biting flies.	
Effectiveness	• The efficacy of baits depends on the target size and pheromone concentration. • The attractiveness of a compound depends on the dose, the combination with other compounds and the species. • Attractive toxic sugar baits, commonly used for house flies, have also been tested successfully against mosquitoes as this method exploits the diet used by insects to sustain their daily activities. • Stable flies are attracted by octenol, m- and p-cresol in olfactometer assays in the laboratory, as are many other biting insects. • In the field, a recent study found that 2–3 times more stable flies were caught by sticky white panels baited with phenol, m- or p-cresol than non-baited panels. • Phenols are more consistently attractive for tabanids, but with variation among species. Carbon dioxide is also very attractive for tabanids.	(Brugman et al. 2018; Baldacchino et al. 2018; Zhu et al. 2016; Tangtrakulwanich et al. 2015; Müller et al. 2010; Oyarzún et al. 2009)
Applicable to Australia	Yes	
Impact on animals, humans, environment	• Baits impregnated with pesticides should not be placed in areas where animals can access them or where they can contaminate feed, water or milk. • Some baits are not species selective and may impact on beneficial insect populations.	(CFSPH 2021a)
Limitations	Baits are often ineffective in outdoor situations because of the short-range attractiveness and the weathering of actives.	

Table 9. Environmental control methods for flies: Pasture management

Method detail	Description	References
Action	• Choice of pasture type can affect biology and larval survival for buffalo flies and tabanids, which lay eggs in dung in pasture. • Rotational grazing allows for better management of manure. By rotating pastures, the concentration of manure	(Brewer et al. 2021; Scasta et al. 2012)

Method detail	Description	References
	in any given area is reduced, which decreases the available breeding sites for flies and reduces larval survival. • Maintaining shorter grass can help reduce fly populations as it provides fewer places for adult flies to rest and lay eggs. • Patch burning is where discrete patches of a pasture are burnt using prescribed fire. Plant regrowth attracts livestock to preferentially graze there, resting other pasture areas where cattle graze. This improves biodiversity and reduces fly populations by combusting manure and fly pupae. It also acts by reducing vegetation used as resting places for some fly species.	
Target flies	Buffalo flies, tabanids, non-biting flies	
Effectiveness	• Season and location specific. • Tall fescue pastures have been shown to reduce larval and adult survival of horn flies. It is thought this is due to alkaloids in endophyte-infested tall fescue plants. One study reported approximately 30% larval mortality in dung piles and decreased adult horn fly abundance on cattle grazing tall fescue compared to cattle grazing on endophyte-free fescue. • A study from Iowa and Oklahoma (USA) using patch burn grazing showed a 41% reduction in horn fly numbers on cattle compared to traditional management of pastures without fire.	(Parra et al. 2016) (Scasta et al. 2012, 2015)
Applicable to Australia	Yes. Rotational grazing is a common practice in Australia. Patch burning is routinely practiced by First Nations people to reseed native grasses and control wild bush fires.	(FutureBeef 2022)
Impact on animals, humans, environment	None reported.	
Limitations	• Dependent on ability to choose the right pastures or manage pastures. May not be possible for all farm types. • Patch burning is limited to outside of the fire ban season.	

Table 10. Environmental control methods for flies: Animal grazing management

Method detail	Description	References
Action	• Where possible, avoid grazing animals where there are high fly populations.	(Baldacchino et al. 2018)

	• Selective grazing relative to tabanid seasonal activity can limit contact – graze in large open areas well away from bush or forest.	
Target flies	Tabanids, and possibly other fly species	
Effectiveness	• Dependent on the fly species – some species prefer pasture-forest, while other species like open pasture. For example, tabanids are most active at the edge of pasture-bush ecotones. Tabanid activity decreases the further away from the bush that animals are grazed. • Animals tend to select areas to graze where there is low tabanid activity if they are free to roam (e.g., dense thickets, hilltops, etc).	(Baldacchino et al. 2014)
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported.	
Limitations	Effects are location specific as landscape and altitude can be determining factors for their distribution. For example, farms in low-lying lands with scrub and/or marshes may not see much improvement in fly populations with this method.	Baldacchino et al. 2018)

5.4.1 Environmental controls for mosquitoes

Environmental control of mosquitoes with measures such as improved sanitation, barrier proofing (e.g. bed nets and screens) and personal protection have been shown to assist in control of human vector-borne diseases (Wong et al. 2023). Source reduction and exclusion methods can also be used to reduce mosquito populations in cattle-rearing areas. For mosquitos, source reduction involves eliminating breeding areas and habitats, particularly water sources, as most mosquitoes require water for development. For control of oviposition sites, the most effective approach is to prevent eggs being laid in stagnant water. For larvae, disrupting water sources is effective. Housing modification to prevent vector contact with cattle is also necessary for effective control, however, this is not always feasible in Australia. Environmental controls for mosquitoes are summarised in Tables 11—13.

Table 11. Environmental control methods for mosquitos: Sanitation practices

Method detail	Description	References
Action	• Remove stagnant water sources around areas where cattle graze or are yarded (Figure 16). • Circulate or change water in stock tanks weekly. Consider using aerators to reduce larvae numbers (larvae can complete development to adulthood if water is undisturbed for more than 8 days). • Cover water storage such as tanks or other large containers. If coverage is not possible use a 1mm mesh screen. • Remove organic material from structures that may trap water e.g. gutters, downpipes, old tires. • Reduce vegetation that may shelter adult mosquitoes. • Add drainage holes to containers that may trap water. • Drain silage covers if they have captured water. • Fill potholes, ruts etc with sand.	(CFPSH 2021; Farm Biosecurity 2022)
Target mosquitoes	All species	
Effectiveness	These are critical actions that reduce the development of immature populations and interrupt the life cycle.	
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported.	
Limitations	Sanitation methods directed towards immature stages should be implemented prophylactically, to prevent build up in adult populations.	

Figure 14: Examples of water sources where mosquitoes breed. From (Farm Biosecurity 2022).

Table 12. Environmental control methods for mosquitoes: Housing modifications

Method detail	Description	References
Action	• Door and window screens prevent mosquitos from entering livestock production facilities. • High powered fans inhibit flight activity and decrease the number of mosquitos disturbing animals.	(CFPSH 2021; Farm Biosecurity 2022)
Target mosquitoes	All species	
Effectiveness	• Good effectiveness if cattle are housed or there is infrastructure that can be protected (e.g., milk shed, abattoir).	
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported.	
Limitations	Only works for infrastructure that can be protected with screens or fans e.g., indoor housed animals or livestock facilities (e.g. milk processing facilities, slaughterhouses, covered saleyards, etc.).	

Table 13. Environmental control methods for mosquitoes: Traps and targets

Method detail	Description	References
Action	• Traps and targets are designed to attract mosquitos using sensory cues such as odour. Chemical attractants usually include carbon dioxide, ammonia, lactic acid or octenol to attract adult female mosquitoes. • Common traps include attractive targeted baits (attract and kill e.g., ATSB bait station), peridomestic combined repel and lure devices (repel and lure), lure and kill traps (e.g. AGO trap, TNK trap, ALO, In2Care). • Eave tubes traps are a form of "lure and kill" device which are placed under the eaves of buildings. They contain insecticide-treated netting. • Attractant sugar baits kill male and female adult mosquitoes by treating the sugar bait with an insecticide. These baits are effect against *Aedes* species. • Place traps as close to hosts as possible – this will maximise capture of the greatest number of mosquitoes.	(Onen et al. 2023; WHO 2020a)
Target mosquitoes	Any species	
Effectiveness	• Traps and targets are species-specific. • UV-light traps are generally not effective for mosquito control. • There is limited research demonstrating trap effectiveness against populations feeding on cattle. However, traps have been shown to be effective in urban or residential areas when used in an AW-IPM program. • For eave tube traps, if coverage of the traps is high enough, they are reported to reduce mosquito populations or change life stage structures.	(Onen et al. 2023; WHO 2020a)
Applicable to Australia	• There are a range of commercial outdoor mosquito traps that could be used on-farm, but there do not appear to be any products specifically available for use in agriculture settings in Australia.	
Impact on animals, humans, environment	None reported.	
Limitations	• Traps are expensive and labour-intensive. • Control on a large scale may not be practical. But targeted applications may be possible for smaller host populations.	

5.4.2 Environmental controls for biting midges

Localised control efforts, such as larval habitat removal and pesticide application are not particularly effective for midge management (Miranda 2018; Shults et al. 2021). They are generally untargeted and ineffective, primarily because the ecological and behavioural traits of *Culicoides* species differ and are poorly understood. Furthermore, midges can travel long-distances from breeding habitats and are easily dispersed by the wind, leading to re-infestation in previously controlled areas (Miranda 2018; Lawson and McDermott 2023).

It is largely unknown if habitat modification and source reduction strategies are effective on midge populations either (Lawson and McDermott 2023; WOAH 2021). One study found no significant impact on biting midge populations when wastewater ponds were removed from dairies (Mayo et al. 2014). Other approaches, such as improving sanitation and stabling animals, have been suggested but their effectiveness may vary depending on the midge species present on farms (Carpenter et al. 2008; Miranda 2018). The removal, disturbance or treatment of dung pats should theoretically help to reduce populations of dung breeding midges such as *C. brevitarsis* (*G. Bellis, pers. comms*). However, Bishop et al. (2005) concluded that dung beetles were ineffective in controlling *C. brevitarsis.* While stabling with or without screens has been shown to reduce vector-host contact, this method is impractical on farms with large numbers of cattle and no infrastructure to stable them (Doherty et al. 2004; Miranda 2018; Lawson and McDermott 2023). Screens would need to be very fine to keep midges out and this may cause problems with air circulation (*G. Bellis, pers. comms*). Use of traps (e.g., electrified ultraviolet lights) in outside areas to attract and catch midges is generally not recommended as they may attract more midges than they can kill (WOAH 2021).

Environmental control option tables are not included for midges as they are for mosquitoes and flies because there are no evidence-based strategies available to summarise. However, as the habitats of many midge species are similar to some fly and mosquito species, it is recommended the reader review sanitation activities related to habitat modification and disruption of breeding sites in Table 5 (flies) and Table 11 (mosquitoes).

5.4.3 Environmental controls for ixodid ticks

While environmental control of ticks is challenging, measures can be taken to increase desiccation, predation and hinder the host-seeking capacity of ticks (de Miranda Santos et al. 2018). Source reduction activities involving disrupting, reducing, or eliminating areas where ticks develop are the primary environmental control methods (de Miranda Santos et al. 2018). Environmental tick control methods are summarised in Tables 14—16.

Table 14. Environmental control methods for ticks: Pasture management

Method detail	Description	References
Action	• Tick control is important for extensively grazed cattle more so than intensively managed cattle. In feedlots, dropped ticks are often trampled underfoot. • Choice of pasture can affect the survival of eggs and larvae by manipulating shade and opportunities to reach a host. At any given time, around 90-95% of the tick population is in the environment, thus the population can be greatly influenced by choice of pasture. • Some Australian native pastures are thought to have 'anti-tick' properties (e.g. genus *Stylosanthes, Melinis minuitflora, Andropogon gaynus*) that can immobilise, repel or kill ticks. • Slash or mulch pastures to keep them short. • Avoid having a heavy layer of mulch or dried grass, as this is an ideal habitat for ticks. • Clear scrub from paddocks if possible. • Judicious use of burn-off techniques. • Spell paddocks free of cattle for 3 months over summer or 5 months over winter to reduce the number of seed ticks. • Pasture and crop rotation – but pasture must not be allowed to get too high. Paddocks that have been used for crops for two consecutive years have been found to have significantly fewer tick larvae.	(TickBoss 2022; CFSPH 2021b; de Miranda Santos et al. 2018, 2018; Fernandez-Ruvalcaba et al. 2004)
Target ticks	Any – location specific	
Effectiveness	• Season and location specific. • Choosing the right mix of pasture types can be effective. • Spelling paddocks can be combined with rotational grazing strategies, such as the paddock sweeper program (Table 15).	(TickBoss 2022)
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported.	
Limitations	• Dependent on ability to choose the right pastures or manage pastures. May not be possible for all farm types. • Spelling paddocks is not practical for all farms, e.g. if small farm size, or very large paddocks. • Not a lot of research has been done on 'anti-tick' pastures to see if they control ticks and meet the nutritional needs of stock.	

Table 15. Environmental control methods for ticks: Paddock 'sweeper' program

Method detail	Description	References
Action	• Place young cattle at a high stocking rate to collect ticks. • Treat the animals with an acaricide to prevent egg-laying and then relocate them to a fresh paddock. Cattle need to be kept in the original paddock for up to 5 days post treatment before being moved to allow the chemical to work and to prevent spreading ticks to the new paddock. • This lowers the tick burden in the original paddock so it can be used for cows and calves, thereby reducing the frequency of chemical treatments in vulnerable groups. • Can apply this method using older cows to sweep up ticks.	(TickBoss 2022)
Target ticks	Any – location specific	
Effectiveness	Effective but only at a small scale (paddock-to-paddock).	(TickBoss 2022)
Applicable to Australia	Yes	
Impact on animals, humans, environment	None reported.	
Limitations	• Relies on not having acaricide resistance in tick population.	(TickBoss 2022)

Table 16. Environmental control methods for ticks: animal management

Method detail	Description	References
Action	• Raising 'resistant' breeds e.g. *Bos indicus* that are more immune to ticks than *Bos taurus* breeds. Studies have shown that ticks feeding on *Bos indicus* cattle ingest less blood and produce smaller egg masses. • Calve earlier in the year so animals are older when exposed.	(TickBoss 2022; de Miranda Santos et al. 2018)
Target ticks	Any – location specific	
Effectiveness	Effective but only at a small scale (paddock-to-paddock).	
Applicable to Australia	Yes.	
Impact on animals, humans, environment	None reported.	
Limitations	Long-term control method. Therefore, it will likely have minimal impact on reducing tick populations during an LSDV response.	(AHA 2024; Namazi and Tafti 2021; Bianchini et al. 2023).

5.5 Biological controls

Biocontrol methods are increasingly favoured over chemical treatments because they are not associated with resistance and environmental impacts, and they are usually target-specific. However, biocontrol agents act more slowly than chemical controls, and hence thresholds for their use may be lower. They are most successful when integrated into AW-IPM programs rather than used as stand-alone strategies. Care must be taken if using chemicals in conjunction with biocontrol agents as beneficial insects can be vulnerable to chemicals. While biocontrol agents have been successfully developed for horticulture and crop production there are few commercially available options for livestock-specific vectors. Table 17 summarises the biological control measures suitable for the main vector types implicated in LSD transmission.

Table 17. A summary of biological control measures suitable for flies, mosquitoes, midges and ticks.

Biological control method	Action	Life stage targeted	Muscids	Tabanids	Mosquitoes	Midges	Ticks
Parasitoids e.g., parasitic wasps	Reduce vector population	Immatures*, Adults	✓	✗	✗	✗	✗
Entomopathogenic organisms e.g. fungi, bacteria, nematodes	Reduce vector population	Immatures	✓	✗	✓	✗	✓
Natural predators e.g. mites	Reduce vector population	Immatures, Adults	✓	✓	✓	UKN	✗
Genetic controls e.g. SIT	Reduce vector population	Adults	✗	✗	✓	✗	✗
Other e.g. dung beetles, vaccination	Reduce habitat (dung beetles), reduce vector-host contact (vaccination)	Immatures, adults	✓	✗	✗	✗	✓

Note: * Immatures include eggs, larvae, pupae.

UKN, unknown

5.5.1 Biological controls for flies

Biocontrol agents for managing fly populations are summarised in Table 18. Biocontrol agents that are not available in Australia can be found in Appendix 5.

Note, natural predators, such as macrochelid mites, staphylinid (rove) beetles are not discussed in this manual, as these biocontrol options currently rely on natural populations.

Table 18. Biocontrol methods for flies: Parasitic wasps (*Spalangia endius*)

Method detail	Description	References
Action	• The wasps attack the pupae and either feed on the contents or lay an egg that hatches inside the fly pupa. When hatched, the wasp larva feeds on the fly pupa, killing it. The wasp emerges from the fly pupal case after approximately 3 weeks. Adult wasps survive for 7–14 days. • The wasps can be naturally occurring or commercially bred. • Commercial wasps are purchased at pupae stage. They need to be placed in release stations at the facility. Wasps will emerge over several days after placement. Weekly releases of the wasps are recommended. • It is recommended that 50–200 wasps per animal per week are released, depending on the size of the intensive animal facility. The bigger the facility, the fewer wasps per animal (e.g., 100 wasps per animal per fortnight for large intensive facilities and 200 wasps per fortnight for smaller or less intensive facilities).	(FlyBoss 2024; Baldacchino et al. 2018)
Target flies	Stable flies, common house flies	(Baldacchino et al. 2018)
Effectiveness	• Parasitic wasps are most effective when present in large numbers. It is reported that up to 35% of developing flies in Australian feedlots are killed by parasitic wasps. • Wasps will not immediately reduce fly populations but will reduce the growth of fly populations over time. • Wasps are most active at the start of the fly season and will continue activity until fly numbers decrease due to changes in seasonal conditions. • Reported to be effective in dairy farms as well.	
Applicable to Australia	Yes. Well documented use in feedlots and dairies.	
Impact on animals, humans, environment	This parasite is not host specific and attacks a wide range of fly species, therefore it will likely impact some non-target flies.	
Limitations	• Do not produce immediate effects. • Care must be taken if using insecticides at the same time as these may negatively impact beneficial insect populations.	(FlyBoss 2024; Baldacchino et al. 2014; Machtinger

Method detail	Description	References
	• Can be costly if buying large quantities of *Spalangia endius* and doing weekly releases. • Effects may be limited depending on the number of pupae released and the distance between egg breeding habitat and release stations. The highest rates of parasitism of fly pupae occur within 5 metres of a release station. • Parasitic wasps do not have any effect on tabanids.	and Geden 2018; Baldacchino et al. 2018)

Table 19. Biocontrol methods for flies: Entomopathogenic fungi (EPF)

Method detail	Description	References
Action	• EPF stick to the exoskeleton of the adult fly. The fungi grow over the exoskeleton which kills the fly. Fungi produce spores that infect other flies. • Most effective against adult flies, but can affect eggs, larvae or pupae. • *Metarhizium anisopliae* and *Beauveria bassiana* appear to be the most pathogenic species. Both are present naturally in Australia and available as commercial formulations.	(FlyBoss 2024; Baldacchino et al. 2018; Weeks et al. 2018)
Target flies	House flies, stable flies, buffalo flies	
Effectiveness	• Pathogenic effects vary depending on the fly stage, fungal species, concentration, and formulation (powder or liquid). • Several studies have demonstrated the effectiveness of *M. anisopliae* at significantly reducing horn fly populations. • One study reported that application of fungi as a feed-through to kill eggs and developing larvae or pupae in manure pats showed a reduction in adult horn fly eclosion (emergence) from treated animals. • On-animal spray applications of strains of *M. anisopliae* and *I. fumosorosea* were shown to reduce horn fly infestations by 94–100% by day 13 post-treatment for animals in the dry tropics.	(Baldacchino et al. 2018; Cruz-Vazquez et al. 2015; Mochi et al. 2009; Brewer et al. 2021)
Applicable to Australia	Commercial formulations of *Metarhizium anisopliae* are available in Australia for tick control. However, fly-specific commercial formulations are not available in Australia.	
Impact on animals, humans, environment	Non-target insects may be impacted (e.g. dung beetles).	
Limitations	• Does not produce immediate effects. • EPF is not target specific. A newly identified local fungus species, *Beauveria australis,* infests and kills dung beetles. *B.*	(Caron et al. 2023)

Method detail	Description	References
	bassiana has also been reported in Australian soils and is known to decimate dung beetle populations.	

Table 20. Biocontrol methods for flies: Entomopathogenic bacteria

Method detail	Description	References
Action	• *Bacillus thuringiensis* sub-species, such as *Bt. israelensis* and *Lysinibacillus sphaericus*, are the most common species used to control dipteran insects. They are gram-positive, facultative anaerobic, spore-forming bacteria that produce protein crystals that are toxic to some fly species.	
Target flies	House flies, stable flies, buffalo flies	
Effectiveness	• *Bt* bacteria are reported to be fast acting, easy to manufacture at a relatively low cost, and can be applied using conventional equipment. They are applied as liquid sprays or powders (dust) in the environment, and work is underway to look at feed-through or bolus delivery in animals. • *Bt. israelensis* has been shown experimentally to be active against buffalo fly larvae, with some isolates causing up to 90% larval mortality. • Several *Bt* isolates have activity against stable fly larvae with one isolate, *Bt. thompsoni 4O1*, reporting high larval mortality in adult stable flies. • *Bt. israelensis* is widely used as a larvicide against mosquitoes – see below. Other *Bt* species are widely and successfully used to control horticulture and crop pests.	(Lacey et al. 2015; Lysyk et al. 2012; Madhav et al. 2020)
Applicable to Australia	Registered products are available for use in cattle in Australia (e.g. Zamigard-BL).	
Impact on animals, humans, environment	Bti is reported to be non-toxic and only affecting the target pest and closely related organisms. However, a metanalysis found that it can have negative impacts on non-target organisms in aquatic and terrestrial systems.	
Limitations	• This method will not produce immediate effects – should be done in combination with other fly control methods (especially sanitation). • No evidence these methods are active against tabanids.	

Table 21. Biological control methods for flies: Dung beetles

Method detail	Description	References
Action	• Dung beetles accelerate degradation of manure on pastures (Figure 17). This removes breeding areas for many fly species. • Dung beetles break up cow pats within 10–30 hours and remove most eggs from a manure pile.	(Floate et al. 2013; Brewer et al. 2021)
Target flies	Buffalo flies, non-biting flies	
Effectiveness	• In Australia, dung beetle species have been shown to compete successfully with bush flies for dung. • Researchers in WA have reported a reduction in bush fly numbers following establishment of dung beetle species in south-west WA. • Non-native dung beetle species are the most effective at breaking down livestock dung.	(DPIRD 2019)
Applicable to Australia	Dung beetles are widely distributed across Australia, although species vary by region. They can be purchased from various companies to introduce into pastures.	
Impact on animals, humans, environment	None reported.	
Limitations	• Dung beetles are vulnerable to pesticides, especially in their early breading season (MLs and SPs). This includes cattle treatments (injections, pour-ons, dips). Ear tags have least effect on dung beetle populations. Refer to the FlyBoss website for details on the chemicals that impact on dung beetle populations. • Fly populations are only reduced when dung beetles are at peak burial activity levels. • Non-native species of dung beetles are not well suited to the tropics. • It is thought that if dung beetles dominate in manure piles, other beetle populations that feed on larvae are reduced, which may reduce the overall impact on larval populations.	(Baldacchino et al. 2018; ParaBoss 2022; Brewer et al. 2021)

Figure 15: Dung beetles at peak summer activity shredding a manure pile. Photo courtesy of Department of Primary Industries and Regional Development, WA (DPIRD 2019).

5.5.2 Biological controls for mosquitos

Biocontrol agents play an important role in managing mosquito populations for human health, yet less attention has been given to developing commercial agents targeting disease-transmitting mosquitoes. Many potential biocontrol agents are still in the research or development phases and are unavailable for commercial use. For example, bacteria such as *Bacillus thuringiensis* offer some promise, but inconsistent efficacy has been reported by multiple studies (Wong et al. 2023). Similarly, manipulation of *Wolbachia* is showing much promise in controlling *Ae. aegypti* populations, but the technology is not yet available for other mosquito species that may be of interest for LSDV transmission. Other genetic techniques for controlling *Aedes, Anaopheles* and *Culex* populations, such as CRISPR gene editing, are in various stages of research or development (Wong et al. 2023; WHO 2020b). Discussion of newer genetic techniques for mosquito control is not included here, as they are not expected to be available for widespread use on mosquito vector populations of cattle in the foreseeable future. Current biocontrol agents for mosquitos are summarised in Table 22 and Table 23. Biocontrol agents that are not available in Australia can be found in Appendix 5.

Table 22. Biological control methods for mosquitoes: *Wolbachia* bacteria

Method detail	Description	References
Action	• Wolbachia species are found in ~28% of surveyed mosquito species. *Ae. aegypti* does not normally carry *Wolbachia*. • *Wolbachia* are used in several ways to reduce wild populations of mosquitoes, including: - IIT, is similar to SIT, although it is based on cytoplasmic incompatibility conferred by some strains of *Wolbachia* Hertig (Rickettsiales: Ehrlichiaceae) bacteria. With this technique, males with Wolbachia infect wild females, who become infertile. • The Pathogen Interference (PI) strategy occurs when the *Wolbachia* strain inhibits pathogen infection and replication in mosquito hosts.	
Target mosquitoes	*Ae. aegypti*	
Effectiveness	• *Wolbachia* has mostly been developed against *Aedes* mosquitoes and is being tested in pilot field trials. The focus for these techniques is on human vector-borne diseases that are biologically transmitted – dengue, zika, chikungunya and yellow fever. • *Wolbachia*-infected male *Cx. quinquefasciatus* was used to eradicate the wild-type population of this mosquito species from Myanmar in the 1960s. *Wolbachia* infected insects have also been successfully applied in pilot studies to reduce *Ae. aegypti* populations. • The pathogen interference (PI) strategy has been used successfully to modify local *Ae. aegypti* populations in pilot trials in Australia.	(Bouyer and Marois 2018; Onen et al. 2023; Hoffmann et al. 2011; World Mosquito Program 2022)
Applicable to Australia	*Wolbachia* control is used for *Ae. aegypti* populations in Qld as part of ongoing pilot programs.	(World Mosquito Program 2022)
Impact on animals, humans, environment	None reported.	
Limitations	• Not efficient if target mosquito populations are too high - can only happen when populations are low (e.g. over-wintering) • The cost may be prohibitive for an AW-IPM program. • Single mosquito species-specific. • Will have limited use for LSD vector control.	(Bouyer and Marois 2018; Onen et al. 2023)

Table 23. Biological control methods for mosquitoes: Predators

Method detail	Description	References
Action	• Includes other insects, reptiles, fish, crustaceans, arachnids. • Most predators feed on immatures but can feed on adults. • Predators can be native to the environment (preferred) but may be introduced as biocontrol predators.	(Vinogradov et al. 2022)
Target mosquitoes	Depends on predator preference	
Effectiveness	• Dragon flies are affected by water quality, therefore wide-scale application is limited. • Copepods and water bugs are affected by temperature, low oxygen and toxins in water. • Water beetles – there is limited research into their effectiveness. They tend to move to new locations and have many alternative prey preferences. • Frogs and toads – may be a threat to native fauna. • A study of three common predator fish (mosquitofish, dragonfly naiads, copepods) on the relative abundance of *An. stephensi* in the presence of other prey of these species found that effectiveness was related to larval size and abundance of alternative prey. Mosquito larval and instar consumption significantly decreased if alternative prey was present.	(Kumar et al. 2008; LGAQ 2014; Wong et al. 2023; Vinogradov et al. 2022)
Applicable to Australia	Yes, but limitations may impact on the effectiveness of this method on a large-scale.	
Impact on animals, humans, environment	• May be significant if the predator species is not native to the area. • Larvivourous fish, frogs, and toads can be a threat to native fauna.	
Limitations	• Jurisdictions have legislative restrictions on fish stocking and the introduction of non-indigenous fish may be illegal without a permit. A permit may not be needed if the fish are native to an area and are being stocked on private waters (e.g., dam). Enquiries should be directed to the relevant government department in a jurisdiction.	(LGAQ 2014; Wong et al. 2023)

5.5.3 Biological controls for biting midges

While biocontrol agents hold promise in complementing existing control methods for midges their availability is limited. Most options are still in research or development phases and not yet commercially available.

Genetic manipulation tools such as SIT, *Wolbachia* and CRISPR modification are promising control options, but these methods are in early research stages or not yet described (Shults et al. 2021). *Wolbachia* may reduce midge populations as it occurs naturally in some midge species, including some in Australia (Mee et al. 2015; Shults et al. 2021; Miranda 2018). However, a colony of midges with Wolbachia would need to be commercially bred up into the thousands for release, and to date, no Australian species of midge has ever been colonised (*G. Bellis, pers comm*.)

Many fungal entomopathogens have demonstrated efficiency in reducing midge populations experimentally, however, there are currently no commercially available formulations for midge control (Ansari et al. 2019; Miranda 2018; Carpenter et al. 2008; Nicholas and McCorkell 2014). An Australian study by Nicholas and McCorkell (2014) demonstrated the efficacy of four isolates of the EPF, *M. anisopliae*, in controlling the biting midge *C. brevitarsis*, by exposing adult midges to the fungus on paper substrate. Adult midges died within three to eight days after contract with the paper. When the fungus was applied to fresh cattle dung at various rates, the emergence of adult midges was significantly reduced by up to 98.5% compared to untreated dung (Nicholas and McCorkell 2014). In another Australian study, EPF were observed to cause 31% mortality in *Culicoides molestus* larvae (Wright and Easton 1996), while a separate Australian study found that a marine species of fungi could invade living and dead pupae of *Culicoides subimmaculatus* (Stephen and Kurtböke 2011). Other studies have also shown there is potential for EPF to control midges (Ansari et al. 2019; Miranda 2018).

Entomopathogenic bacteria are reported to be ineffective at killing midges, whereas nematodes from the *Mermithidae* family have shown some success experimentally. However, their potential is limited due to challenges in mass rearing for widespread use (Miranda 2018; Carpenter et al. 2008).

5.5.4 Biological controls for ixodid ticks

Few biocontrol agents demonstrate effectiveness against tick populations. Most predators of ticks are reported to have limited potential as biocontrol agents and many bacterial species found in ticks are non-pathogenic, with tick nymphs exhibiting bactericidal activity (Samish et al. 2004). Of all potential biocontrol agents, EPF and parasitic wasps show the highest promise. Anti-tick vaccines have also been developed as control option.

Biocontrol options for ticks are summaries in Table 24. Biocontrol agents that are not available in Australia can be found in Appendix 5.

Table 24. Biological control methods for ticks: Anti-tick vaccines

Method detail	Description	References
Action	• Tick vaccines target proteins that alter the on-host ecology by changing local and systemic reactions to tick bites. This has the potential to expel ticks attempting to feed or to reduce blood-feeding. There is a reduction in reproductive efficiency in some ticks. • Trivalent tick fever vaccine – live, whole organism, blood-based vaccine containing attenuated strains of *B. bovis, B. bigema,* and A. *centrale.* • Bm86 vaccines for *R. microplus* have been shown to limit tick feeding and reproductive performance by damaging the gut cells of ticks. The cattle immune system produced antibodies that attack the gut lining of the tick when it consumes the blood of vaccinated ticks. The antibodies prevent the tick from absorbing nutrients.	(TickBoss 2022; de Miranda Santos et al. 2018; Merino et al. 2013; Rodríguez-Mallon 2023; Arocho Rosario et al. 2022; USDA 2016)
Target ticks	Ixodid species	
Effectiveness	• Early studies on Bm86 vaccines found that cattle given three vaccines given 4 weeks apart has a 92% reduction in the number of larval progeny from ticks fed on vaccinated animals compare to control after being challenged with 1000 tick larvae per day for 3 weeks. • Vaccination against ticks using the tick gut protein Bm86 has been shown to be effective against acaricide-resistant ticks, with successful implementation in Puerto Rico for control of *R. microplus* on dairy and beef cattle. • There is a potential positive interaction between anti-tick vaccination when used in conjunction with systemic acaricide treatment using macrocyclic lactones which provided greater and longer efficacy than either treatment on their own. • Used for long-term control of tick fever in cattle but require multiple doses due to short duration of immunity. • International research is underway to develop cattle tick vaccines through CATVAC (cattle tick vaccine consortium), an initiative of the Bill and Melinda Gates Foundation.	(TickBoss 2022; Tabor 2021; Rodríguez-Mallon 2023; Arocho Rosario et al. 2022; Willasden et al. 1989; USDA 2016)
Applicable to Australia	• The tick fever vaccine is available in Australia. Either sold chilled, ready-to-use with a 4-day shelf life or as a frozen vaccine (Combavac 3in1; stored in liquid nitrogen). Combavac 3in1 is suitable for remote areas or for larger holdings. • The TICK-GARD^{PLUS} vaccine for *Rhipicephalus australis* was discontinued in 2010, primarily because it required 3–4	(TickBoss 2022; Tabor 2021)

Method detail	Description	References
	boosters per annum to maintain efficacy and producers were not utilising the product.	
Impact on animals, humans, environment	None reported.	
Limitations	• Limited to use for animals in cattle tick areas or entering cattle tick areas. • Clinical disease associated with use of the live vaccine is possible, but most animals show no visible reactions. • The selection on suitable antigens is a major constraint on vaccine development. • Very slow commercialisation of anti-tick vaccines for cattle tick.	(TickBoss 2022; Merino et al. 2013; Willasden et al. 1989)

5.6 Chemical controls

Most control programs for arthropods are centred on the use of insecticides. However, long-term use and overuse of insecticides has resulted in growing resistance and ecological harm. For effective long-term vector control, insecticides and other chemicals should be used judiciously and in combination with non-chemical methods such as source reduction. Bio-insecticides derived from natural sources, like the chrysanthemum plant or bioactive metabolites of *Streptomyces*, are considered safer alternatives to synthetic chemicals (Wong et al. 2023). Appendix 4 describes the different types of chemical approaches when controlling vectors (e.g. on-host, off-host, adulticides, larvicides).

The NVMAG has compiled a list of registered agriculture and veterinary (agvet) chemicals for LSD vector control (Table 25 and Table 26) which was current at time of publication. Regular review of the list before determining which chemicals to use is recommended as updates may occur. Search the Australian Pesticide and Veterinary Medicine Authority (APVMA) Chemical Registration Information System (PubCRIS) database to review the current registration status and label information of agriculture and veterinary chemicals.

In compiling this list, the NVMAG recommended the use of SP chemicals over other chemical classes due to their efficacy against multiple vector species, ease of application, and safer meat and milk residue withholding periods (WHPs). For detailed information on SPs, refer to Appendix 6. When considering on-host chemical treatments for cattle (Table 25), all pour products included in the NVMAG 'list of preferred chemicals' contains SPs. These include deltamethrin, as the active ingredient, or a combination of cypermethrin and chlorfenvinphos. These actives were chosen for their ability to provide protection against multiple LSD competent vectors, targeting both biting flies and midges or biting flies and ticks. They were also selected for their ease of application and relatively low toxicity to people. Ear tag products containing SPs are also included in the NVMAG list of preferred chemicals, primarily for controlling flies. Table 27 provides a summary of the registered insecticide classes and modes of action. Appendix 6 provides detailed information on each chemical class.

5.6.1 Regulatory considerations

Each Australian jurisdiction has its own laws governing the use of agriculture and veterinary chemicals. Generally, these laws require users to follow label directions, prohibit the use of unregistered products except under specific circumstances, and record treatments. Additional regulations pertain to off-label use of registered veterinary chemicals in livestock species. In each jurisdiction, livestock species are categorised as either ‘major’ or ‘minor’ species, with the highest level of chemical controls required for major species. Cattle (beef and dairy) are categorised as a major species in all jurisdictions. Chemical users are advised to consult with the relevant State and Territory authorities to ensure compliance, as penalties may apply for non-compliance.

Off-label use refers to the application of a registered chemical product in a manner not specified on the label (e.g. use in an unlisted species, unlisted condition, or different dosage). Off-label use should only be considered when no alternative product exists. For cattle, off-label use is restricted to under veterinary direction, with specific conditions. The APVMA may issue a minor use or emergency use permit if a chemical needs to be used in an off-label manner for a particular set of circumstances.

Unregistered chemicals are not registered by the APVMA. Their use is prohibited in cattle, except under exceptional circumstances according to laws in a jurisdiction. A veterinarian wishing to use unregistered chemicals in cattle must consult with the relevant authority before use. A permit from the APVMA may be sought for limited use under certain conditions if no alternative registered chemical is available.

The exception to off-label or unregistered use is if the product or active ingredient has been given ‘reserved status’ under the AgVet Code Regulations. Reserve chemicals consist of products or actives used for disinfection.

The APVMA may issue a permit for off-label or unregistered use of an agriculture or veterinary chemical under certain situations. The permit must be granted before recommending, supplying, or selling a chemical product. A permit may be either for minor use, emergency use or a small-scale trial.

Minor use permits authorise use in two circumstances: for limited use on a minor animal, crop or non-crop situation and when there is insufficient economic return in registering the product for that use, or for limited use in a major animal (e.g. cattle), crop or non-crop situation and it is for a proposed use.

Emergency use permits authorise the use of an agriculture or veterinary chemical or active ingredient for an emergency situation (e.g. exotic disease outbreak). These permits are issued for the duration of time needed to respond to the emergency. To find out more on the specific requirements for an emergency permit, visit the APVMA website.

For both minor and emergency permits, a separate ‘consent to import’ application is required if the agriculture or veterinary chemical or active ingredient is to be imported.

5.6.2 Responsible chemical use

Pesticides can be harmful to human health through ingestion, inhalation, or direct skin contact. Each jurisdiction has laws regulating safe pesticide use. Take precautions to minimise exposure, including:

- Reading the product label and Safety Data Sheet and following all directions.
- Wearing recommended personal protective equipment.
- Mixing pesticides in a well-ventilated area, free form obstructions.
- Cleaning up spills promptly by covering them with sand, sawdust, or other substance before sweeping up and disposing of properly.
- Avoiding spraying on windy days or where spray may drift onto oneself or others.
- Always washing hands and equipment thoroughly after use.
- Washing contaminated clothing separately.

When using veterinary chemicals:

- Understand your legal responsibilities regarding veterinary chemical use.
- Store chemicals responsibly – in a locked area, out of reach of children.
- Use only registered chemicals.
- Never use an agricultural chemical product to treat animals.
- Follow label directions, unless directed otherwise by a veterinarian.
- Identify treated cattle.
- Keep records of all veterinary chemical use, including the withholding period (WHP) and export slaughter interval (ESI).

When using agriculture chemicals:

- Understand your legal responsibilities.
- Store chemicals responsibly – in a locked area, out of reach of children.
- Restrict chemical use to areas required to be treated.
- Seek professional advice when unsure about chemical application directions.
- Consider using a licenced pest control operator.
- Keep records of pest control activities, including grazing WHPs.

Table 25. National Vector Management Advisory Group preferred list of veterinary chemicals for control of LSDV vectors (current at time of publication)

APVMA no.	Product name	Active ingredient	Application method	Pest	WHP (days)	ESI (days)
89229	Imperial pour-on fly and lice treatment for cattle and horses	Deltamethrin	Pour on	Biting midge, buffalo fly, house fly, stable fly,	0	21
88816	Pastoral ag deltafix pour-on for cattle	Deltamethrin	Pour on	Biting midge, buffalo fly, housefly, stable fly,	0	21
83884	Covine deltashield pour-on lice and fly treatment for cattle	Deltamethrin	Pour on	Biting midge, buffalo fly, house fly, stable fly	0	21
82675	Independents Own Incarcerate Easy-Dose Pour-On Cattle Lice and Fly Treatment	Deltamethrin	Pour on	Biting midge, buffalo fly, house fly, stable fly	0	21
65322	Deltamax quick-dose pour-on cattle lice and fly treatment	Deltamethrin	Pour on	Biting midge, buffalo fly, house fly, stable fly	0	21
2161413	Deltafly easy-dose pour-on cattle lice and fly treatment	Deltamethrin	Pour on	Buffalo fly, house fly, stable fly	0	21
54096	Coopers easy-dose pour-on cattle lice and fly treatment	Deltamethrin	Pour on	Biting midge, buffalo fly, housefly, stable fly	0	21
85568	Roust Cattle Dip and Spray	Chlorfenvinphos, cypermethrin	Dip and spray	Buffalo fly, cattle tick, Paralysis tick, bush tick, scrub tick	8	21
46815	Coopers blockade 's' cattle dip and spray	Chlorfenvinphos, cypermethrin	Dip and spray	Buffalo fly, bush tick, cattle tick, paralysis tick, scrub tick	8	21
45211	Barricade 's' cattle dip and spray	Chlorfenvinphos, cypermethrin	Dip and spray	Buffalo fly, cattle tick, paralysis tick, bush tick, scrub tick	8	21
60662	Co-ral plus insecticide cattle ear tag	Coumaphos, diazinon	Ear tag	Buffalo fly	0	0
60621	Cylence ultra insecticide cattle ear tag	Piperonyl butoxide, betacyfluthrin	Ear tag	Buffalo fly	0	0
57920	Y-tex python maxima insecticidal cattle ear tags	Piperonyl butoxide, zeta-cypermethrin	Ear tag	Buffalo fly, stable fly, house fly, bush fly	0	0

APVMA no.	Product name	Active ingredient	Application method	Pest	WHP (days)	ESI (days)
53910	Patriot insecticide ear tag for cattle	Diazinon*	Ear tag	Buffalo fly	0	0
51524	Y-tex warrior insecticidal cattle ear tags	Chlorpyrifos, diazinon	Ear tag	Buffalo fly	0	0
48148	Y-tex python insecticidal cattle ear tags	Piperonyl butoxide, zeta-cypermethrin	Ear tag	Buffalo fly, paralysis tick, scrub tick	0	0
46406	Y-tex optimizer insecticidal cattle ear tags	Diazinon*	Ear tag	Buffalo fly	0	0
48148	Y-tex python insecticidal cattle ear tags	Piperonyl butoxide, zeta-cypermethrin	Ear tag	Buffalo fly, paralysis tick, scrub tick	0	0

Note: * The registration status of diazinon is under review by the APVMA, as of June 2024. Refer to the APVMA website for further details.

Table 26. National Vector Management Advisory Group preferred list of agriculture chemicals for control of LSDV vectors.

APVMA no.	Product name	Active ingredient	Application method	Pest
88242	Vectorforce ulv & thermal fogging rtu insecticide	Cypermethrin	Fogging	Biting midge, fly, mosquito, adult mosquitoes
86487	David Grays Thermal Fogging and ULV Mosquito Adulticide Concentrate	Piperonyl butoxide, phenothrin	Fogging	Mosquito, adult mosquitoes
53738	Py-bo natural pyrethrum & piperonyl butoxide insecticidal concentrate	Piperonyl butoxide, pyrethrins	Fogging	Fly, midge, mosquito, adult mosquitoes,
32710	Py insecticide fog	Piperonyl butoxide, pyrethrins	Fogging	Fly, midge, mosquito, adult mosquitoes,
89714	Prolink liquid larvicide concentrate	(S)-methoprene	Aerial or ground	Mosquito
82315	Vectoprime FG Biological Larvicide Fine Granule	(S)-methoprene, *Bacillus thuringiensis* subsp. *israelensis*	Aerial or ground	Mosquito (larva), mosquito
70145	Gp mozx biological larvicide	*Bacillus thuringiensis* subsp. *israelensis*	Aerial or ground	Mosquito

APVMA no.	Product name	Active ingredient	Application method	Pest
62972	David grays graybate 50 sg mosquito larvicide granules	Temephos	Spray (aerial)	Mosquito (larva), nuisance midge (larvae), adult mosquito
62971	David grays graybate 10 sg mosquito larvicide granules	Temephos	Aerial or ground	Mosquito, nuisance midge, adult mosquito
62305	Barmac bti 1200 biological mosquito larvicide	*Bacillus thuringiensis* subsp. *israelensis* serotype h14	Aerial or ground	Mosquito
62304	Barmac bti 200 gr biological mosquito larvicide	*Bacillus thuringiensis* subsp. *israelensis* serotype h14	Aerial or ground	Mosquito (larva)
62020	Biopren 50 liquid mosquito larvicide	(S)-methoprene	Aerial or ground	Mosquito
62018	Biopren 4gr mosquito larvicide	(S)-methoprene	Aerial or ground	Mosquito
59560	Nomoz mosquito larvicide with prolink	(S)-methoprene	Placed into water to be treated	Mosquito
58063	Prolink liquid larvicide mosquito growth regulator	(S)-methoprene	Aerial or ground	Mosquito
56979	Teknar 1200 sc biological mosquito larvicide suspension concentrate	*Bacillus thuringiensis* subsp. *israelensis* serotype h14	Aerial or ground	Mosquito
55919	Vectolex wg biological larvicide water dispersible granule	*Bacillus sphaericus* strain 2362	Spray (aerial or ground)	Mosquito
53433	Vectobac 12as biological larvicide aqueous suspension	*Bacillus thuringiensis* subsp. *israelensis* serotype h14	Spray (aerial or ground)	Mosquito
52834	Vectobac g biological larvicide granule	*Bacillus thuringiensis* subsp. *israelensis* serotype h14	Aerial or ground	Mosquito (larva)
52642	Vectobac wg biological larvicide water dispersible granule	*Bacillus thuringiensis* subsp. *israelensis* serotype h14	Spray (aerial or ground)	Mosquito
62746	Hokoex fly larvicide	Cyromazine	Granules, spray or pour on (depending on manure consistency)	Bush fly, false stable fly, house fly, lesser housefly, stable fly

Table 27. Summary of registered insecticide classes and modes of action for the control of possible vectors of LSD in Australia. Adapted from Brewer et al. (2021)

Insecticide class	Mode of action	Target vectors	Life stage	Applications	Resistance
Synthetic pyrethroids	Sodium channel modulator	Flies (buffalo, house, stable), mosquitoes, midges, ticks (cattle, bush, paralysis)	Adult	• On host – pour-on, spray, dip, dust, ear-tags* • Off host – spray, fogging, treated materials baits	Widespread in all vectors
Organophosphates	Acetylcholinesterase inhibitors	Flies (buffalo), ticks (cattle, bush, paralysis), mosquitoes	Larva, adult	• On-host – spray, dip, back rubber*, ear tags* • Off-host –spray, fogging, baits	Widespread in all vectors
Carbamates	Acetylcholinesterase inhibitors	Flies	Larva, adult	• Off-host –spray, paint, granules, powder, baits	Not reported in Australia
Macrocyclic lactones –mectins	Chloride channel activator	Flies (buffalo), ticks (cattle)	Adult	• On-host – pour-on, injection, ear tags*	Not reported in Australia
Macrocyclic lactones – Spinosyns	Nicotinic acetylcholine receptors blockers	Flies (house, stable)	Adult	• Off host – surface spray for premises, bait	Not reported in Australia
Amidines	Alpha-2 adrenoreceptor agonists	Ticks (cattle, bush, paralysis),	Adult	• On-host – spray, dip	Widespread
Insect growth regulator – Methoprene, S-methoprene	Disrupt insect growth hormones	Mosquitoes, flies*, ticks*	Larva	• Off-host – spray, water soluble granules for premises	Not reported in Australia
Insect growth regulator – cryomazine	Moulting disrupter	Flies (bush, house, stable), ticks*, mosquitoes*	Larva	• Off-host – spray, water soluble granules for premises	Reported in sheep blowflies
Microbial bioinsecticide – *Bacillus thuringiensis* subsp. *Israelensis (*Bti)	Toxin which binds to larval gut receptors	Mosquitoes, flies*	Larva	• Off-host – surface spray, water soluble granules for premises	Not reported in Australia

Insecticide class	Mode of action	Target vectors	Life stage	Applications	Resistance
Other – DEET (N,N-diethyl-m-toluamid)	Repellent – odour causes insects to avoid host. Non-killing.	Not registered for vector control on cattle. (Flies Mosquitoes, midges, ticks)	Adult	• On-host – spray (handheld)	Not reported in Australia

Note: * Some applications are not registered for the treatment of cattle ticks

5.6.3 Application methods for insecticides

Chemical classes commonly used in insecticide formulations include SPs, OPs, carbamates, MLs, amidines, bioinsecticides and IGRs. Organochlorines are no longer registered in Australia due to concerns about worker safety and their significant environmental impacts. Table 28 provides a summary of insecticide control options for each vector type. For detailed Information on the common chemical classes used as insecticides, refer to Appendix 6. Mode of actions of important chemical classes

Insecticides can be applied to cattle as pour-ons, sprays, dips, powders, injections or impregnated ear tags. Pour-ons, sprays and dips require frequent re-application to maintain effectiveness. Ear tags are impregnated with either OPs, SPs or MLs. A benefit of using ear tags is that they can provide long-lasting protection of up to 16 weeks, however they must be removed when they lose efficacy or prior to slaughter, which can make them labour-intensive (FlyBoss 2024). Back rubbers, rubbing poles or fly curtains impregnated with OPs are commonly used to control buffalo fly populations. Animals self-treat by contacting these structures, although there is no dose control (Brewer et al. 2021; FlyBoss 2024). Feed additives and feed-throughs containing IGRs, which pass through the animal into the manure to act on fly larvae. These formulations have been reported to impact non-target insects and are unavailable in Australia (Brewer et al. 2021). Depending on the formulation and application method some products require frequent application (e.g. sprays), while others offer continuous action (e.g. impregnated ear tags) (Brewer et al. 2021).

Area or premises spraying should be considered as a last resort for outbreaks or when other control methods are ineffective (Taylor 2021; WOAH 2021; Roche et al. 2020). Environmental spraying in large areas has been found to be ineffective for some vectors species. For example, historical area-wide efforts to control buffalo fly incursions into southern Australia using insecticides for aerial spraying, intensive ground spraying and individual animal treatments have been largely unsuccessful (James 2020). If off-host chemical controls are required they should only be implemented after consideration of their environmental impact, identification of larval development and adult resting sites, and only after other control methods like source reduction and exclusion have been implemented (WOAH 2021). Furthermore, only chemicals registered by the APVMA for controlling flies, mosquitoes, midges or ticks in feedlots, animal facilities, farm buildings or agricultural buildings should be used.

Common methods for off-host vector control include spraying, painting, fogging or misting, granules, impregnated materials and baits. Residual sprays offer both immediate and long-term effects against flies and mosquitoes (FlyBoss 2024). However, several factors affect the residual efficacy of off-host insecticides such as UV light, rain, and resistance levels in the target insect population. If environmental sprays are used, chemical classes should be rotated to avoid the development of resistance. Most insecticides are toxic to aquatic life and beneficial insects like bees, so spraying in areas where these insects may be affected should be avoided. When using off-host spray applications it is important to ensure that cattle are not sprayed or located in areas where spray drift could occur and that they cannot ingest chemicals. Therefore, insecticides should not be sprayed onto water surfaces, feed or areas likely to come into contact with feed. Product labels should always be reviewed for grazing WHPs and ESIs.

Most baits are designed to be effective against adult house flies but can also capture other fly species with variable efficacy. Baits are typically used to reduce adult fly numbers around premises and are largely ineffective in outdoor areas such as cattle yards. Typically, baits consist of an attractant (e.g. sugar, pheromone) and an insecticide (e.g. OP). They may come in granular form or as a paint, which is applied to surfaces where adult flies rest or in bait stations.

Table 28. Description of chemical control types for vectors

Chemical control type	Description
On-host treatments	Applied directly to the animal's body. They work either by killing the insect through direct contact or via systemic absorption when the insect ingests blood. Most on-host treatments function as adulticides. They are particularly effective against pests that spend a significant portion of their life cycle on the host animal. In Australia, these treatments are usually formulated as topical sprays, pour-ons, dips, injections, and insecticide-impregnated ear tags.
Off-host treatments	Applied to the environment or the animal's surroundings. They mostly target the life stages when the insects are not on the host, such as eggs, larvae, or pupae, but can also target adults not on the host. These treatments act by killing immature insects, preventing adult development, or reducing the overall abundance in the environment. Off-host formulations include sprays, dusts, foggers and baits. However, fogging has been found to negatively affect pollinator and non-target invertebrate groups, especially those with limited chitinisation (Lee et al. 2020). Therefore, there should be a transition away from insecticide fogging to safer alternatives for vector control.
Insecticides	Designed to kill, lure, or repel insects. They are commonly formulated using synthetic chemicals, although some products may be derived from natural compounds. Insecticides can be broad-spectrum or targeted. They act on various stages of the life cycle and employ different mechanisms, such as disrupting the nervous system, affecting metabolism, or interfering with insect growth. Efficacy depends on the compound, formulation, application method, insect species, and resistance levels (Baldacchino et al. 2018). They are available in various formulations, such as sprays, dips, powders, and pour-on treatments, and can be applied on-host or off-host.
Larvicides	Designed to kill immature insects and prevent emergence of adults. Larvicides are often applied to breeding sites or areas where larvae develop. Larvicides tend to be more effective at controlling insect populations because chemical applications can be limited to specific habitats compared to trying to control the adult population, which is widely dispersed.
Adulticides	Work by killing adults either by direct contact or through ingestion. They provide an immediate but short-term reduction in the adult population and, therefore, should be used in conjunction with larvicides to control insects at all stages of insect development. Off-host adulticides tend to be used when

Chemical control type	Description
	there is a public health threat, such as from mosquito-borne diseases like Murray Valley encephalitis or Kunjin virus.
Repellents	Prevent insects from landing or biting the host animals. They work by either masking the host's scent (making it difficult to detect the hosts) or actively repelling insects through odour or taste. Repellents can be applied topically or spatially (e.g. netting) to create a barrier.
Attractants	Lure pests into traps or baits where they are captured and killed. Attractants mimic natural pheromones or food sources. Attractants are often used to monitor the abundance or presence of insects in an area.
Acaricides	Designed to kill arachnids such as ticks and mites. Acaricides disrupt the nervous system, interfere with metabolic processes, or halt the moulting cycle
Bioinsecticides	Derived from natural substances. They are typically a less harmful and more target-specific alternative to conventional chemical insecticides. Bioinsecticides may be derived from bacteria, fungi, viruses, or protozoa or from plant extracts or pheromones that either repel insects or interfere with their physiological processes, such as mating behaviours.
IGRs	Target different insect life stages and disrupt processes like moulting, metamorphosis, or reproduction. One type of IGR is synthetic juvenile hormone analogs that mimic the action of insect growth hormones and disrupt larval development (e.g. methoprene, and S-methoprene). Another IGR inhibits chitin development, which is a key component of the insect exoskeleton, preventing larvae from moulting and ultimately leading to death.
Combination formulations	Chemical product formulations may consist of a single active ingredient or a combination of two or more actives. **Combination formulations** are considered more effective, as they provide more than one way to kill and the chance of pests being resistant to all actives is low. Many combination products are active against more than one pest species or type. For example, combination products containing ivermectin (an ML) and fluazuron (an IGR), are active against buffalo flies, cattle ticks, mites and intestinal worms in cattle.

5.6.4 Chemical control for midges

Preventing midges from biting cattle is problematic. Currently in Australia, SPs are used for midge control on cattle. Achieving efficacy against midges requires whole-of animal application to ensure the insects receive a lethal dose when feeding (WOAH 2021). For some midge species, pour-on formulations are inadequate as midges bite cattle in areas distant from the application site (Carpenter et al. 2008). However, pour-ons can be efficacious against *C. brevitarsis* (*G. Bellis, pers. comms*). Repellent products containing DEET (N, N-Diethyl- meta-toluamide, or diethyltoluamide) are generally considered effective against *Culicoides*, especially for equids, to help prevent infection with African horse sickness virus (WOAH 2021). However, frequent reapplication of repellent products is required to provide the best protection against *Culicoides,* rendering them impractical in most cattle systems. Notably, in Australia, there is one APVMA-registered veterinary chemical product containing DEET for use on cattle as a topical spray, which can also be applied to surfaces where insects rest (*APVMA #62938, Saint Bernard Petcare Insect Repellent for Flies, Mosquitoes & Biting Insects*). Data regarding the efficacy of topical insecticides and repellents in halting disease transmission in midge populations, including in the spread of diseases such as BTV is scarce (Miranda 2018). Thus, the effectiveness of on-host chemicals in controlling midge populations during an LSD outbreak is also uncertain.

Environmental spraying to control larval midges is reported to be impractical and largely ineffective. Midge breeding habitats are diverse, and can be spread over large areas, and adult midge activities and resting places are not well understood so few pesticides are safe for application in their preferred habitats (e.g. wetlands, riverbanks, vegetation) (Carpenter et al. 2008; Peck et al. 2020; WOAH 2021; Miranda 2018). Treating only some larval habitat sites may not be effective given midges can travel several kilometres in a day, therefore re-infestation of an area is highly likely (Peck et al. 2020).

5.6.5 Resistance to insecticides and acaricides

Intensive insecticide and acaricide treatments, coupled with repeated use of the same product or chemical classes sharing similar modes of action, accelerate the development of resistance in arthropod populations (Baldacchino et al. 2018; Brewer et al. 2021). Australian producers have historically relied on these chemicals to control parasitic diseases, however, the increasing resistance to common chemical classes poses a significant threat to future control efforts on farms and in the broader context of responding to exotic vector-borne diseases. New chemical classes and biocontrol agents are slow to market, underscoring the many challenges of addressing chemical resistance in key vector species.

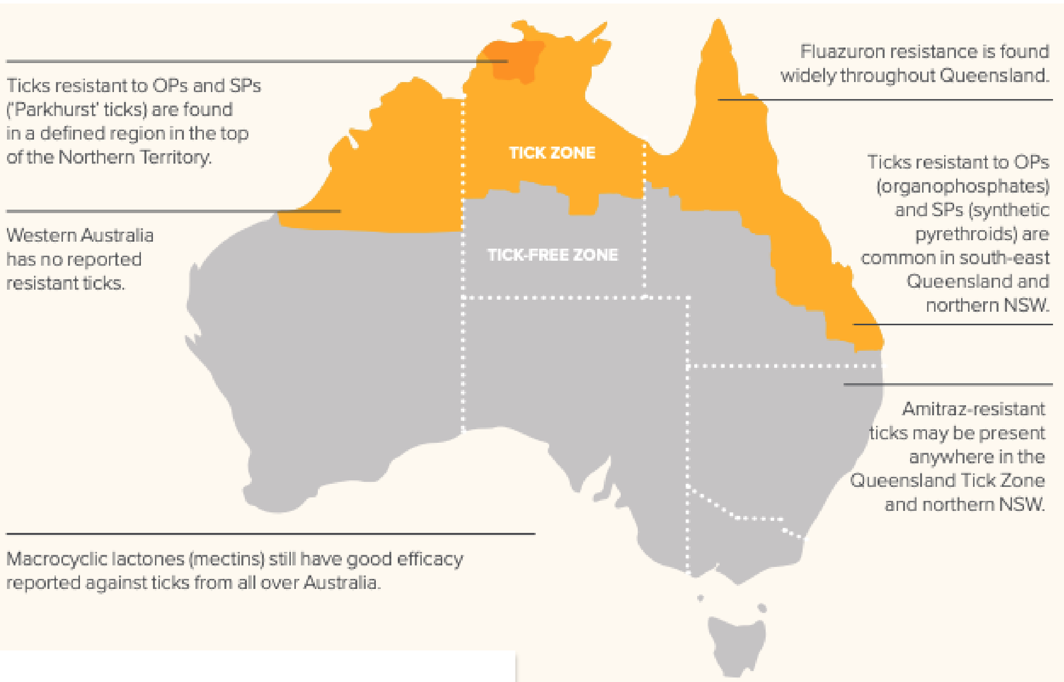
In Australia, resistance to SPs, OPs, amidines and carbamates has been documented in many fly and tick species (FlyBoss 2024; Meat and Livestock Australia 2021). For example, buffalo flies have exhibited resistance to SPs for many years, alongside reported emerging resistance to OPs (Rothwell et al. 2011; Kotze and Hunt 2023). Importantly, resistance to MLs has not been observed (FlyBoss 2024; Kotze and Hunt 2023). In the USA, OP resistance has been reported in the horn fly, a closely related species to the buffalo fly (Holderman et al. 2018). Some cattle tick strains in Queensland are multi-resistant to common chemical classes (Figure 18). While ML resistance has not been detected, there are anecdotal reports of reduced protection on some properties (Ball and Watt 2018). Overseas, resistance in ticks has been detected in all chemical classes, including spinosad, fipronil, and MLs (mectins), none of which are registered for use in cattle in Australia (Meat and Livestock Australia 2021; Rodriguez-Vivas et al. 2018).

In many malaria-endemic countries, mosquito resistance to all four major chemical groups has been reported, whereas mosquitoes in Australia currently remain susceptible to these chemicals (WHO 2022; Asgarian et al. 2023). Resistance to SPs and OPs has been documented in midge populations overseas, but not in Australia (Carpenter et al. 2008).

In Australia, resistance to the IGR, diflubenzuron, is so prevalent in sheep blowflies (*Lucilia cuprina*) that products can no longer claim efficacy against this fly species (Sales et al. 2020; FlyBoss 2024). However, IGR resistance has not been reported in other fly species in Australia. Resistance to fluazuron, another IGR targeting one-host cattle tick species, has not been reported in Australia but has been detected in Brazil (Kotze and Hunt 2023; Junquera et al. 2019).

The impact of resistance on the use of insecticides and acaricides depends on geographic location, usage patterns and the type of cattle enterprise. There is increasing urgency to move away from a reliance on chemical controls and to prioritise environmental and biocontrol strategies (Kotze and Hunt 2023). For this reason, this manual covers biological and environmental controls in detail. However, when chemical control agents are necessary choosing combinations or mixtures of insecticides alongside rotation strategies may help delay the rate and magnitude of resistance in vector populations (Brewer et al. 2021).

Figure 16: Chemical resistance trends in Rhipicephalus australis (cattle tick) across northern Australia (Meat and Livestock Australia 2021).



5.6.6 Chemicals available overseas

Active ingredients used in registered chemicals to control arthropod vectors in the environment or on cattle are compared across three jurisdictions - Australia, the European Union, and South Africa - in Table 29. While chemical registration data are readily available in Australia and the European Union, information is less accessible in South Africa, and for some chemicals information on their registration status could not be sourced. In the European Union not all active ingredients are available in registered products across all Member States. For example, several SPs and OP compounds are only registered for cattle in a single country (e.g. Bulgaria).

Some of the chemicals reviewed on the European Union and South African databases may be registered for use on other vector species or agricultural crops, although accessing this information is not straightforward. Literature regarding responses to the European LSD outbreak was reviewed looking for commentary on the chemicals used during vector control activities. However, limited details were provided on the chemicals used and the effectiveness of these strategies (FAO 2017a).

Table 29. Comparison of chemicals registered for vector control on cattle or in the environment in Australia, Europe and South Africa

Chemical class	Active ingredient	Target vector (Australia)	Australia[1]	European Union[2+]	South Africa[3]
Pyrethroids/ Synthetic pyrethroids	deltamethrin	Biting midge, buffalo fly, common housefly, stable fly	√	√	√
	cypermethrin	Buffalo fly, cattle tick, paralysis tick, Australian paralysis tick, bush tick, scrub tick	√	√	√
	betacyfluthrin	Buffalo fly	√	×	√
	zeta-cypermethrin	Buffalo fly, common housefly, stable fly	√	√	√
	alpha-cypermethrin	Not registered for cattle in Australia. Used for ticks, flies in Europe and South Africa.	×	√	√
	phenothrin	Mosquitoes	√	×	UKN
	flumethrin	Cattle tick, paralysis tick, Australian paralysis tick, bush tick, scrub tick	√	√	UKN
	cyfluthrin	Flies, mosquitoes	√	×	√
Organophosphates	chlorfenvinphos	Buffalo fly, cattle tick, paralysis tick, Australian paralysis tick, bush tick, scrub tick	√	×	√
	coumaphos	Buffalo fly	√	×	UKN
	diazinon	Buffalo fly, bush fly, common housefly, stable fly	√	×	√
	chlorpyrifos	Buffalo fly	√	×	×

Chemical class	Active ingredient	Target vector (Australia)	Australia[1]	European Union[2+]	South Africa[3]
	temephos	Mosquitoes	√	×	UKN
	azamethiphos	Flies	√	×	UKN
	malathion	Sand fly (biting midge), ticks	√	√	√
Carbamates	methomyl	House fly	√	×	√
Amidine	amitraz	Bush tick, cattle tick, paralysis tick, Australian paralysis tick, cattle tick, scrub tick	√	×	√
Macrocyclic lactones	Spinosad	House fly, stable fly	√	√	UKN
	abamectin	Buffalo fly	√	√	√
Neonicotinoids	imidacloprid		×	×	√
Bioinsecticide - microbial	*Bacillus thuringiensis subsp. Israelensis* (bti)	Mosquitoes	√	√	UKN
	Bacillus sphaericus strain 2362	Mosquitoes	√	√	UKN
Bioinsecticide - biochemical	thiamethoxam (z)-9 tricosene	Common house fly	√	×	UKN
IGRs	diflubenzuron	Mosquitoes	√	×	√
	methoprene	Mosquitoes	√	×	UKN
	(S)-methoprene	Mosquitoes	√	×	UKN
	cyromazine	Mosquitoes	√	×	UKN
Natural chemicals	Pyrethrin (pyrethrum)	Flies, mosquitoes	√	√	UKN
Other	diethyltoluamide (DEET)	Flies, mosquitoes	√	×	UKN

Note: UKN, unknown registration status.

Sources: [1.]Derived from the APVMA Pubcris database and the National Vector Management Advisory Group list of chemical for use on vectors implicated in transmission of LSD.

[2.]EU Pesticide database and Veterinary Medicines database

[3.]South African approved insecticides and veterinary medicines

[+] The registration of some chemicals is not always applicable to all European Counties. Some chemicals may only be registered in one country.

5.7 Coordination of vector control with other measures

Immunisation of cattle using a vaccine with demonstrated efficacy is the most effective option for controlling the spread of LSD (FAO 2023). Sufficient vaccination coverage (80 per cent or greater) with high quality and efficacious vaccines is the key for success in controlling LSD (FAO 2023). Detailed information on LSD vaccines and non-vector control strategies is out of scope for this manual but key details on LSD vaccines is summarised here.

Currently, vaccines against LSD are not available in Australia, although a regulatory review is underway to consider usage in an outbreak situation (AHA 2024). Readers are advised to refer to the latest version of the Animal Health Australia AUSVETPLAN Response Strategy for Lumpy Skin Disease for information on the vaccination strategy in case of an outbreak of LSD in Australia.

Aside from concerns regarding efficacy and safety, cost and availability of vaccines are significant factors when responding to an LSD outbreak. Tendering processes for large-scale vaccine purchases can cause delays in initiating vaccination campaigns (Tuppurainen et al. 2021). Additionally, delays may occur if a permit or authorisation for vaccine use is required. Currently in Australia, an import permit is required to bring in LSD vaccines, and an APVMA emergency permit will be required to supply and use the vaccine. National-level agreements and policies must be in place before a vaccination campaign can get underway. Additionally, international demand for vaccines during an outbreak could lead to manufacturers being unable to meet demands leading to further delays. Implementing systems to counter these potential delays will be crucial in the early stages of an LSD outbreak (Tuppurainen et al. 2021). Emergency vaccination strategies need to be defined before the occurrence of the disease considering resources for implementing vaccination, availability and accessibility of vaccines (FAO 2023). Therefore, other measures, including movement controls, stamping out, and possibly vector control will be important in the initial stages while waiting for sufficient vaccine supplies to initiate mass vaccination.

While mass vaccination is the critical strategy for eradicating LSD from a country, its effectiveness can be enhanced by combining it with other measures such as early detection, stamping out, movement restrictions and vector control (Tuppurainen et al. 2021; EFSA Panel on Animal Health and Welfare (AHAW) et al. 2022). However, implementing measures like stamping out in the absence of vaccination is unlikely to be sufficient to eradicate LSD, although it may help limit disease spread (WOAH 2022).

If implementing vector control in combination with other measures, it is important to understand the factors that precipitate LSD transmission by vectors, as well as regional variations in these factors. For example, the spread of LSD via vectors may in intensify when cattle are kept near watercourses (FAO 2017b). When considering large-scale vector control in the environment, exploiting the overwintering behaviour of some vector types can be effective. Targeting the diapause phase, when some vector species are at their lowest abundance and most vulnerable, can disrupt lifecycles and reduce populations. However, in northern Australia where an LSD incursion is more probable, vectors do not overwinter in the tropics. Therefore, targeting activities based on seasonality (temperature and humidity) may be more practical; however, the seasonality of vectors in northern Australia is poorly understood (*G. Bellis, pers. comms*). Additionally, controlling feral bovids is likely to be a significant consideration in implementing control measures for an LSD outbreak in northern Australia.

Although most countries have reported vector control on individual animals as adjunct measures to prevent transmission, large-scale vector control (e.g. aerial spraying) has not typically been employed (AHA 2024). Bulgaria is a noted exception. However, it is unclear if the aerial spraying program employed by Bulgaria was effective, or the severity and duration of adverse impacts on the environment (Casal et al. 2018).

6 Vector control on individual premises

6.1 Extensive northern cattle systems

Table 30 describes control options for vectors that may be involved in LSD transmission in extensive northern cattle systems. Northern Australia has a diverse geography, spanning from tropical coastal areas of Queensland through to the arid and wet tropics of Western Australia. Approximately 60% of Australia's beef herd is located in northern Australia (FutureBeef 2022). Most pastures are native grasslands, with only 35% improved pastures (Costa et al. 2012). Cattle are often dispersed and tend to congregate when accessing watering points. Some pastoral stations are moving towards small paddock practices to improve carrying capacity (FutureBeef 2022). There are very few feedlots in northern Australia (Condon 2022). Feral cattle and bovines can be a problem in some areas of northern Australia (see Section 4.1). Buffalo flies and cattle tick are major pests of cattle in northern Australia.

Table 30. Control options for vectors that may be involved in transmission of LSD on extensive northern cattle systems.

Category	Control Method	Comments	Buffalo flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes	Cattle tick	Other ixodids
Environmental	Sanitation measures	Difficult to implement in pastoral areas. Where possible, efforts should be made to reduce manure build up around watering areas and yards. Where feasible, the removal of stagnant water sources, and improvement of drainage may help to reduce mosquito and midge breeding habitats. Fix leaking water troughs and drains to reduce immature midge habitat around water sources.	√		√	√	√		
	Pasture management	Patch burning may have some effect at reducing dung pats in specific areas. Some native pastures are known to repel ticks. For most pastoral grazing systems, rotational grazing and spelling paddocks is not feasible. The 'paddock sweeper' programs are only		√				√	√

Category	Control Method	Comments	Buffalo flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes	Cattle tick	Other ixodids
		applicable for small paddocks which is not feasible for northern Australia.							
	Traps and baits	Traps are species specific. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re-infestation risk is high. If using, install around yards and watering areas. The buffalo fly trap tunnel has been reported to have some effect on populations. May not be very feasible in extensive northern areas except in limited areas. Baits are mostly only effective for non-biting flies.	√	√	√	√	√		
Biological	Parasitoids	Likely to be too expensive to release commercial wasps on the scale required to achieve a reduction in population. Impacted by chemical controls.			√				
	Entomopathogenic bacteria	Unlikely to be feasible on a large scale. Costly. May work for buffalo flies and non-biting flies.	√		√				
	Dung beetles	Useful for control of dung pats. Can buy commercial dung beetles (costly) or rely on natural populations. Impacted by chemical controls, especially SPs and MLs.	√		√				
	Vaccination	For cattle tick. Costly and requires multiple vaccinations over the lifetime of the animals.						√	
Chemical – on-host	Topical repellents – pour-ons, dips, sprays	Can be effective but high rates of resistance are reported to some chemicals. Often a short-term effect. Cost of ongoing treatments can be high.	√	√	√	√	√	√	√
	Ear tags	As above.	√					√	√

Category	Control Method	Comments	Buffalo flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes	Cattle tick	Other ixodids
	Environmental spraying	Not recommended. Feasibility of application over large areas is challenging. Effectiveness in dense vegetation may be limited. Very costly.	-	-	-	-	-	-	-

6.2 Southern beef cattle systems

Table 31 details control options for vectors that may be involved in LSD transmission on southern beef cattle systems. Southern Australian beef production extends from southern Queensland to Western Australia. It encompasses a diverse range of enterprises, including pasture-based cow-calf systems, backgrounding or grow-out periods on pasture, and feedlot or pasture finishing. Cattle numbers vary widely from small hobby farms to large scale enterprises (feedlots are dealt with in Table 32). Cattle farming in the southern regions is typically more intensive, with higher stocking rates and improved pastures, with *Bos taurus* breeds being preferred (Meat and Livestock Australia 2023). Southern Australia exhibits significant geographic diversity, with higher rainfalls along the coast and cold winters further south. Vectors vary in abundance and seasonality depending on the geographic region and local temperatures and rainfall. Before implementing controls, always be aware of regional characteristics.

Table 31. Control options for vectors that may be involved in transmission of LSD on southern cattle systems.

Category	Control Method	Comments	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
Environmental	Sanitation measures	It should be feasible to manage manure, decaying vegetation, spilled feed, stagnant water around yards and in small paddocks. It may be difficult to implement these measures in large paddocks. Efforts should	√	√	√	√	√	

Category	Control Method	Comments	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
		focus under water troughs and along fence lines. Requires ongoing effort.						
	Housing modification	Applicable if cattle have regular access to structures or yards where screens or netting can be erected. Can be costly.	√	√	√		√	
	Pasture management	Feasible. Rotational grazing and other pasture management methods (e.g. spelling paddocks) to reduce manure loads can be initiated on many southern farms. Activities are limited by property size. The ‘paddock sweeper’ program for ticks could be implemented in some locations.	√	√	√			√
	Animal management	Feasible depending on property size and location. Move cattle away from the bush-pasture ecotone to avoid horse flies. Consider changing calving season or use more ‘tick-resistant’ breeds.	√	√	√		√	√
	Traps and baits	Traps are species specific. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re infestation risk is high. The Williams fly trap has been reported to have positive effects on stable fly populations. The curtain fly trap can also be effective. The buffalo fly trap is reported to be effective at reducing populations. Baits are mostly only effective for non-biting flies.	√	√	√	√	√	
Biological	Parasitoids	May be feasible, depending on farm size and type. Dependent on number of wasps released, release stations, etc. Can be costly. Impacted by chemicals.	√		√			

Category	Control Method	Comments	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
	Entomopathogenic organisms	May be feasible, depending on farm size and type. Can be costly.			√			√
	Natural predators	Rely on natural populations only – limited commercial applications. Impacted by chemical controls.	√	√	√	?	√	
	Dung beetles	Useful for control of dung pats. Can buy commercial dung beetles (costly) or rely on natural populations. Impacted by chemical controls, especially SPs and MLs.	√		√			
Chemical – on-host	Topical repellents – pour-ons, dips, sprays	Can be effective but high rates of resistance are reported. Often a short-term effect. Cost of ongoing treatments can be high.	√	√	√	√	√	√
	Ear tags	As above.						√
Off-host	Environmental spraying	Not recommended.	-	-	-	-	-	-
	Residual surface sprays	Feasible in yards or other structures cattle access regularly. May increase resistance.	√		√			

6.3 Feedlots

Table 32 details control options for vectors that may be involved in LSD transmission on beef feedlots. There are around 400 accredited beef feedlots in Australia with capacities ranging from 500 to over 50,000 head (ALFA 2024). Of accredited feedlots, the majority are in regions that are close to cattle and grain supplies. 60% of feedlots are in Queensland, 30% in NSW, and 7% in Victoria. The remaining 3% are shared between SA and WA (FutureBeef 2024). Most feedlots are in southern Australia with only a few in northern Australia (Meat and Livestock Australia 2023). Many vector species are present in beef feedlots, attracted by large numbers of cattle, manure piles, spilled feed and stagnant water sources. Most feedlot operators report flies to be a major problem on site, with non-biting flies to be the most problematic followed by stable flies. November to February is the peak time for flies. In one study, 78%

of feedlot operators used some form of chemical treatment on cattle at induction, with 58% reporting chemical fly control, 43% used traps, 24% used sprays and 15% used baits (Urech et al. 2004). Ticks are not a problem in feedlots. Cattle are normally treated with an acaracide on induction (TickBoss 2022).

Table 32. Control options for vectors that may be involved in transmission of LSD in cattle feedlots.

Category	Control Method	Comments	Buffalo flies	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes
Environmental	Sanitation measures	It should be feasible to manage manure, decaying vegetation, spilled feed, stagnant water around yards and in small paddocks. It may be difficult to implement these measures in large paddocks. Efforts should focus under water troughs and along fence lines. Requires ongoing effort.	√	√	√	√	√	√
	Housing modification	Applicable if cattle have regular access to structures or yards where screens or netting can be erected. Can be costly.	√	√	√	√		√
	Traps and baits	Traps are species specific. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re infestation risk is high. The Williams fly trap has been reported to have positive effects on stable fly populations. The curtain fly trap can also be effective. If feedlots experience buffalo flies, the buffalo fly trap is reported to be effective at reducing populations. Baits are mostly only effective for non-biting flies.	√	√	√	√	√	√
Biological	Parasitoids	Routinely used. Effectiveness is dependent on number of wasps released, number of release stations, etc. Can be costly.	√	√		√		
	Entomopathogenic organisms	Potentially feasible, depending on farm size and type. Can be costly.	√			√		
	Natural predators	Rely on natural populations only – limited commercial applications.		√	√	√	?	√

Category	Control Method	Comments	Buffalo flies	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes
	Dung beetles	Limited use in feedlots. Dung beetles prefer pasture environments and undisturbed dung.	√	√		√		
Chemical – on-host	Topical repellents – pour-ons, dips, sprays	Effective for vector control but high rates of resistance to some chemicals reported. Often a short-term effect. Cost of ongoing treatments can be high.	√	√	√	√	√	√
	Ear tags	As above.	√					
Off-host	Baits	Similar considerations to traps. Mostly only effective for non-biting flies.				√		
	Environmental spraying	Not recommended.	-	-	-	-	-	-
	Residual surface sprays	Feasible in yards or other structures cattle may access regularly. May increase resistance.		√		√		

6.4 Dairies

Table 33 details control options for vectors that may be involved in LSD transmission on dairy farms. There are 5,700 dairies in Australia, and the national average herd size is 261 cows (Dairy Australia 2024). Dairies are located from sub-tropical Queensland across to the south-west of Western Australia. Victoria has the most dairy farms and accounts for approximately 65% of milk production, followed by NSW, Queensland, and Tasmania. South Australia and Western Australia have significantly smaller numbers of farms and herd sizes (Dairy Australia 2024). A large number of vectors are present in dairies, attracted by the large number of cattle, manure supply, spilled feed, and stagnant water sources. Nuisance flies can be a major problem, with non-biting flies the most problematic, followed by stable flies. Buffalo flies can be a problem in parts of Queensland and northern NSW. November to February is the peak time for flies. Ixodid ticks can also be a problem in some regions.

Table 33. Control options for vectors that may be involved in transmission of LSD on dairy farms.

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
Environmental	Sanitation measures	It should be feasible to manage manure, decaying vegetation, spilled feed, stagnant water around yards and in small paddocks. It may be difficult to implement these measures in large paddocks. Efforts should focus under water troughs and along fence lines. Requires ongoing effort.	√	√	√	√	√	√	
	Housing modification	Feasible around the milking shed and yards where screens or netting can be erected. Can be costly.	√	√	√	√		√	
	Pasture management	Feasible. Rotational grazing and other pasture management methods (e.g. spelling paddocks) to reduce manure in pasture can be initiated on many southern farms. Activities are limited by property size. The ‘paddock sweeper’ program for ticks could be implemented in some locations.	√	√		√			√

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
	Animal management	Feasible depending on property size and location.	√	√		√	?	√	√
	Traps and baits	Traps are species specific. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re infestation risk is high. The Williams fly trap has been reported to have positive effects on stable fly populations. The curtain fly trap can also be effective. Baits are mostly only effective for non-biting flies.	√	√	√	√	√	√	
Biological	Parasitoids	Feasible. Dependent on number of wasps released, number of release stations, etc. Can be costly.	√			√			
	Entomopathogenic organisms	May be feasible, depending on farm size and type. Can be costly.			√	√			√
	Natural predators	Relies on natural populations only – limited commercial applications.	√	√		√	?	√	
	Dung beetles	Useful for control of dung pats in paddocks. Can buy commercial dung beetles (costly) or rely on natural populations.	√			√			
Chemical – on-host	Topical repellents – pour ons, dips, sprays	Many on-host insecticide treatments have long milk withholding periods or are not registered for use in dairy cattle. Always read the label.	√	√	√	√	√	√	√
	Ear tags	As above.			√				√
Chemical Off-host	Environmental spraying	Not recommended.	-	-	-	-	-	-	-

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
	Residual surface sprays	Feasible in yards or other structures cattle may access regularly. May increase resistance	√			√			

6.5 Saleyards

Table 34 details control options for vectors that may be involved in LSD transmission at saleyards. There is an increasing trend for slaughter cattle to bypass saleyards, with a corresponding reduction in the number of saleyards, but those that remain are becoming larger (ACCC 2017). In general, small-scale producers rely on saleyards, particularly in southern Australia where saleyard auctions account for almost two-thirds of beef cattle sales (ACCC 2017). Saleyards may be publicly owned entities or owned privately. Saleyards are in diverse geographic locations throughout Australia; therefore, when planning vector control activities attention should be paid to the vectors present in these locations. Additionally, cattle being transported to saleyards may arrive with vectors on them or on the transport vehicles (e.g. buffalo flies, cattle tick). Note that long-distance movement of cattle (and their vectors) is the primary mode of spread of LSD into new areas. The saleyards are generally located on the outskirts of towns and in areas where livestock or other animals (e.g. horses) may be kept. The saleyards will have their own populations of vectors, particularly nuisance flies (stable flies, house flies and bush flies). Mosquito and midges may also be an issue for cattle kept overnight in locations where these species are present.

Table 34. Control options for vectors that may be involved in transmission of LSD in saleyards.

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
Environmental	Sanitation measures	It should be feasible to manage manure, decaying vegetation, spilled feed, stagnant water around yards and in small paddocks. Efforts should focus under water troughs and along fence lines. Requires ongoing effort.	√	√	√	√	√	√	
	Housing modification	Feasible around the yards where screens or netting can be erected. Can be costly.	√	√		√		√	
	Traps and baits	Traps are species specific. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re infestation risk is high. The Williams fly trap has been reported to have positive effects	√	√	√	√	√	√	

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
		on stable fly populations. The curtain fly trap can also be effective. Baits are mostly only effective for non-biting flies.							
Biological	Parasitoids	Feasible. Can be costly.	√			√			
	Entomopathogenic organisms	May be feasible, but costly.				√			√
Chemical – on-host	Topical repellents – pour ons, dips, sprays	Effective for vector control but high rates of resistance to some chemicals reported. Often a short-term effect. Cost of ongoing treatments can be high. May only be relevant in controlling an outbreak.	√	√	√	√	√	√	√
Chemical Off-host	Environmental spraying	Not recommended.	-	-		-	-	-	-
	Residual surface sprays	Feasible. May increase resistance	√		√	√			

6.6 Abattoirs (including lairage)

Table 35 details control options for vectors that may be involved in LSD transmission at abattoirs and lairage facilities. Australia has approximately 300 red meat processing facilities in Australia export and domestic abattoirs (MLA 2024). Abattoirs have abundant organic substrates, such as solid waste, effluent ponds, and sludge that are attractive breeding habitats for flies and mosquitoes.

Abattoirs are obliged to undertake certain pest control measures to minimise contamination according to federal or jurisdictional regulations related to food production (DAFF 2023b). The department has issued export-establishment guidelines outlining specific measures to manage fly and other insect populations, which are available here.

Lairage refers to holding pens where cattle rest before slaughter at an abattoir (George and George 2023). Most lairage facilities are attached to the abattoir, although some may be remote, requiring cattle to be trucked in. The duration of lairage typically ranges between 12–24 hours. Feedlot cattle are commonly transported the day prior to slaughter. Efforts to shorten lairage time to less than 12 hours are underway in some abattoirs (George and George 2023). Limiting lairage reduces the probability on disease spread prior to slaughter. Lairage is also a term used for transit yards where cattle are rested during long-distance transportation, or as they transit through saleyards or export yards. For information on vectors at saleyards see Table 34.

Vectors such as buffalo flies and ticks can accompany cattle to abattoirs and lairage yards, where they mingle with local populations of nuisance flies. Other vectors, such as mosquitoes and midges may also be present, depending on the region. Ticks are not considered important vectors at these sites as cattle are not transported further.

In the context of an LSD outbreak, additional vector control strategies at abattoirs and lairage facilities may seem unnecessary, as these facilities are required to already undertake daily pest control measures mandated by their licensing agreements. However, when considering the transportation of infected or suspected cattle to abattoirs it is important to maintain and audit vector control strategies throughout the response period. This is especially so for trucks and waste vehicles leaving from the site, as exposed vectors may inadvertently be transported to new locations.

Table 35. Control options for vectors that may be involved in transmission of LSD in abattoirs and lairage.

Category	Control Method	Comments	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes
Environmental	Sanitation measures	See the departments Export Meat Operational Guideline. 3.7 Pest control. Sanitation measures are required to maintain accreditation. Similar requirements exist for domestic abattoirs.	√	√	√	√	√
	Housing modification	Required. Screens, curtains or other barriers are required for internal structures.	√	√	√		√
	Traps and baits	Required. Sticky traps and non-chemical traps used around doorways and perimeters of the facility to prevent infestation of flies from neighbouring areas. Baits are mostly only effective for non-biting flies.	√	√	√	√	√
Chemical Off-host	Environmental spraying	May be required if there are heavy fly burdens in outside areas. Only spray in designated areas. Twice daily spraying may be required using a 'knock down' chemical. Continued use increase resistance rates in vector populations	-	-	√	-	-
	Residual surface sprays	Required. Will increase resistance rates in vector populations	√		√		

6.7 Ports

Table 36 details control options for vectors that may be involved in LSD transmission at ports. Hitchhiker arthropods on vessels and aircraft pose a potential pathway for the introduction of LSD (Oliveira et al. 2018). Recent quantitative risk assessment modelling by Hall et al (2023), considered midges, mosquitoes and heavy fliers (stable flies, tabanids and other brachyceran flies) as potential hitchhiker vectors on vessels. Hard ticks were excluded from the model as they are unlikely to be able to travel the distances required to carry LSDV into Australia in the absence of a host (Hall et al. 2023). These pests could travel on ships and aircraft, in shipping containers and cargo such as cars, tyres or machinery (Inspector-General of Biosecurity, 2018).

The Maritime Arrivals Reporting System (MARS) manages biosecurity risks on commercial vessels. MARS requires all commercial vessels to provide details of their biosecurity status and last port of call before arrival in Australia. A vessel compliance scheme is operated through MARS to facilitate risk-based, targeted inspections, with each ship being inspected unless exempt by the risk-based assessment (Inspector-General of Biosecurity 2018). Despite these biosecurity measures, commercial vessels are a potential area for overseas vector leakage (Hall et al. 2023).

Live export vessels returning to Australia are considered a high biosecurity risk and are managed separately to other commercial vessels. Before arrival, empty livestock ships must undergo thorough cleaning, disinfection with soda ash and two insecticide treatments, although the efficacy of these treatments may vary across decks (Hall et al. 2023). Insectocutors are used for screwworm fly (*Chrysomya bezziana*) surveillance and to attract hitchhiking flies once vessels are in Australian waters and during their time in port (Hall et al. 2023). All livestock vessels must undergo inspection on every visit to Australia. While these measures are considered effective against the entry of vectors, challenges in managing vectors are likely to increase due to rising global trade (Inspector-General of Biosecurity 2018).

Foreign fishing vessels and non-commercial yachts are assumed to arrive in insufficient volumes to pose a significant threat. Additionally, they spend extended periods of time at sea, which is not conducive to arthropod survival or retention of virus infectivity (Hall et al. 2023).

Table 36. Control options for vectors that may be involved in transmission of LSD at ports.

Category	Control Method	Comments	Stable flies	Horse flies	Non-biting flies	Biting midges	Mosquitoes
Environmental	Sanitation measures	Required on vessels arriving in Australian ports.	√	√	√	√	√
	Traps and baits	Required on vessels arriving in Australian ports.	√		√		√
Chemical Off-host	Environmental spraying	Required on vessels arriving in Australian ports.	-	-	√	-	-
	Residual surface sprays	Required on vessels arriving in Australian ports.	√		√		

6.8 Milk processing facilities

Table 37 details control options for vectors that may be involved in LSD transmission at milk processing facilities.

Other than one study reporting transmission of LSD from mother to calf via contaminated milk or skin lesions on the udder (Tuppurainen et al., 2017), subsequent studies investigating risk factors associated with transmission have not identified contaminated milk as a route of direct transmission (Horigan et al. 2018; A. Sprygin et al. 2019; Bianchini et al. 2023; Farra et al. 2022). Given this knowledge gap, further studies are needed to investigate the possibility of milk as a transmission route (Sprygin et al. 2019). However, potential risks associated with milk are mitigated by pasteurisation (FAO 2017a).

Dairy manufacturers are legally required to control pests, including flying insects. Like abattoirs, guidelines for controlling pests at milk processing facilities focus on sanitation measures to reduce potential breeding habitats and physical barriers, such as screens and non-chemical traps. Nuisance flies are of most concern in these settings. Given it is unlikely that milk is a transmission route, or if it is, it is likely to be low risk (FAO 2017a), initiating vector control during an outbreak, beyond existing control measures may be unnecessary. Control of conveyances where vectors may hitchhike to new locations is addressed in Table 39.

Table 37. Control options for vectors that may be involved in transmission of LSD at milk facilities.

Category	Control Method	Comments	Non-biting flies
Environmental	Sanitation measures	Required, according to legislation in each state or territory to control vectors on premises where food is prepared.	√
	Housing modification	Required. Screens, curtains or other barriers are required for internal structures.	√
	Traps and baits	Required. Sticky traps, electric traps, and other non-chemical traps.	√
Chemical Off-host	Environmental spraying	May be required if there are heavy fly burdens in outside areas.	√
	Residual surface sprays	Required in designated areas.	√

7 Vector control in specific circumstances

7.1 High value stock (e.g. breeding stock)

Table 38 outlines vector control options relevant for high value animals. High value bovine stock in Australia includes breeding stock (bulls, pregnant and lactating cows), animals of high genetic value and well-conditioned animals close to finishing (AHA 2023a).

Refer to Tables 30 to 37, for general control measures for any premises where cattle are kept. All vectors are included in Table 38 since high value animals can be found in diverse regions in Australia.

Vector contact should be minimised for high-value cattle using a combination of measures. Control measures may only be feasible in limited situations and largely impractical in extensive beef operations. On-host chemical repellents and insecticides can reduce host-vector contact; however, their effectiveness may be short-lived and resistance levels to some active ingredients can be high. For example, experience overseas with vector control for BTV indicates that there is no evidence to support the use of insecticides and repellents to prevent disease transmission from *Culicoide*s spp., however chemical control methods may reduce host-vector contact(EFSA 2017). The EFSA Panel on Animal Health and Welfare report into BTV control in Europe also highlighted that pour-on insecticides used alone provided lower protection against biting midges than using vector-proof establishments (EFSA 2017).

Erecting screens and barriers can lead to significant reductions in the number of vectors indoors, thereby reducing the likelihood that animals are bitten by potentially contaminated vectors. Although housing does not completely eliminate transmission risk, it can greatly reduce it (EFSA 2017). Several studies support the effectiveness of housing in reducing vector-borne disease transmission from midges. For example, research by Meiswinkel et al. (2000) demonstrated a 14-fold reduction in midge species inside stables in South Africa by using gauzed windows and closing doors. A study by Baylis et al. (2010) found that housing significantly reduced the risk of animals receiving bites from female midges. Lincoln et al. (2015) observed a significant reduction in blood-engorged female midges in stables with pesticide-impregnated nets (from 98% to 65% reduction). These findings highlight the importance of implementing physical barriers to protect high-value cattle where it is practical and cost-effective to do so. These measures may only be relevant in a small number of circumstances, and will not be feasible in extensive enterprises, especially those in northern Australia which are at most risk of vector incursion from overseas by windborne dispersal (Hall et al. 2023).

Table 38. Specific control options for vectors that may be involved in transmission of LSD and high value cattle*.

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
Environmental	Sanitation measures	In most circumstances it is feasible to manage manure, decaying vegetation, spilled feed, stagnant water, leaking water troughs, around yards and in small paddocks. It may be difficult to implement these measures in large paddocks. Efforts should focus under water troughs and along fence lines. Requires ongoing effort.	√	√	√	√	√	√	
	Housing modification	Recommended if possible. Screens and impregnated netting can reduce vector-host contact. Stable flies and tabanids do not tend to fly over barriers. Housing overnight can reduce midge and mosquito contact. Can be very costly to erect and maintain these structures.	√	√	√	√	√	√	
	Traps and baits	Traps are species dependent. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re infestation risk is high. The Williams fly trap has been reported to have positive effects on stable fly populations. The buffalo fly trap is effective. The curtain fly trap can also be effective. Baits are mostly effective for non-biting flies.	√	√	√	√	√	√	
Chemical – on-host	Topical repellents – pour ons, dips, sprays	Effective for vector control but high rates of resistance to some chemicals reported. Often a short-term effect. Cost of ongoing treatments can be high.	√	√	√	√	√	√	√
	Ear tags	As above.			√				√
Off-host	Residual surface sprays	Feasible but may be costly. May increase resistance in populations	√		√	√		√	

7.2 Movement of cattle and cattle products

Table 39 details control methods for vectors that may be involved in LSD transmission on conveyances that transport cattle or cattle products.

According to the AUSVETPLAN Response Strategy for LSD, movement of susceptible animals from restricted and control areas will be prohibited except under Special Permit (SpP), including movements to slaughter. Cattle movements between outside areas will not be subject to restriction (AHA 2024).

The spread of LSD over long distances has been linked to the movement of infected cattle via transportation along roads (A. Sprygin et al. 2019; Tuppurainen et al. 2020). Insects can hitchhike on vehicles with cattle and be transported over long distances (WOAH 2022). The transport of vectors by trucks could pose a risk of disease transmission over long distances, particularly through stable flies, which have been observed to rest on smooth surfaces near their preferred blood meal sources (Saegerman et al. 2018). Other vector species, like tabanids, are unlikely to contribute to long-distance spread as they prefer outdoor environments and are reported to die quickly if transported (Saegerman et al. 2018; Chihota et al. 2003a). A quantitative import risk analysis by Saegerman et al. (2018) found the yearly risk of stable flies travelling in trucks transporting cattle and horses from at risk countries to France was almost negligible, with measures such as disinfection of trucks transporting live animals important in reducing risk.

There are many unknowns regarding the transport of vectors, particularly stable flies, including their survival during transport, the persistence of the virus on/in their mouthparts and the number of bites required to transmit the virus (Saegerman et al. 2018; Kahana-Sutin et al. 2017; A. Sprygin et al. 2019). Buffalo flies and ticks could be involved in transmission during or because of transport as they can live on the cattle being transported. To minimise the risk of unintentional insect transportation, vehicles involved in the transport of cattle or associated activities (e.g. feed delivery, waste removal) should undergo thorough cleaning and decontamination, disinfection, vector control, and inspection before leaving the premises where cattle are unloaded (AHA 2024).

Appropriate on-host vector control for cattle being transported is discussed in Sections 5 and 6. The EFSA Panel on Animal Health and Welfare (AHAW) recommend that in the event of an outbreak, "*given the role of vectors in the transmission of LSD, the animals intended to be moved should be treated with insecticide or repellent against the relevant vectors, provided that the withdrawal period is respected".* They also recommend that *"transport should try to avoid hours of high activity of the vectors with high abundance in the areas where the transmission is taking place. Biosecurity measures at the establishments of origin and destination and at vehicles during the transport should be in place to reduce any risk of spread of the disease*" (EFSA Panel on Animal Health and Welfare (AHAW) et al. 2022).

When it comes to transportation of cattle products (e.g. carcases, other meat products, milk and hides), similar efforts should be undertaken to reduce vectors hitchhiking on these vehicles. However, the risk of vectors such as stable flies being transported on these vehicles is relatively low, as these insects prefer to remain in close proximity to livestock (Saegerman et al. 2018). Vehicles involved in transporting food or passengers are likewise considered to pose negligible risk for the movement of stable flies. The AUVETPLAN response strategy for LSD outlines requirements for vehicle movements in the event of a LSD outbreak, including requirements for disinsection (AHA 2024).

Vector control related to cattle on live export vessels is beyond the scope of this manual.

Table 39. Control options for vectors that may be involved in transmission of LSD on conveyances transporting cattle or cattle products.

Category	Control Method	Comments	Stable flies	Buffalo flies	Non-biting flies	Ixodid ricks
Environmental	Sanitation measures	Feasible. This includes regular cleaning of trucks to remove manure and organic matter that may attract insects. Cracks and crevices in the truck's body should be sealed to prevent insects from seeking shelter. Regular inspection of trucks for signs of infestation should be undertaken. Remove standing water sources.	√		√	
Chemical – on-host	Topical repellents – pour ons, dips, sprays	Effective for vector control but high rates of resistance to some chemicals reported. Often a short-term effect. Cost of ongoing treatments can be high.	√	√	√	√
Chemical Off-host	Residual surface sprays	Feasible. Apply to areas prone to insect infestation e.g. body of truck, wheel hubs, tires, undercarriage.	√	√	√	

7.3 Movement of non-susceptible animals

Table 40 details control methods for the most likely vectors implicated in LSD transmission on conveyances that transport non-susceptible animals.

According to the AUSVETPLAN Response Strategy for LSD, movements of non-susceptible animals from restricted and control areas are subject to risk assessment and conditions to mitigate the potential risk of vector movement, either on-host or in vehicles. Movements from outside areas are not subject to restrictions (AHA 2024).

While trucks carrying cattle are the primary concern for LSD vector spread through hitchhiking, transportation of horses should also be considered as they are preferred hosts for stable flies. Consideration should also be given to other livestock, such as sheep and goats, as stable flies are known to feed on these animals. Appropriate vector control for cattle being transported is discussed in Sections 5 and 6. Recent modelling conducted by Saegerman et al. (2018), found the yearly risk of stable flies travelling in trucks transporting horses over long-distances from at risk countries to France was almost negligible (between 5×10^{-10} and 3.95×10^{-8} transport events per year), and that this risk reduced further when truck disinsection measures were implemented.

Thorough cleaning and decontamination, disinsection, and vector control should be undertaken on trucks carrying non-susceptible livestock. This is particularly important for trucks entering properties where both horses and cattle are present, along with the vectors of interest.

Table 40. Control options for vectors that may be implicated in transmission of LSD on conveyances transporting non-susceptible animals.

Category	Control Method	Comments	Stable flies	Non-biting flies
Environmental	Sanitation measures	Feasible. This includes regular cleaning of trucks to remove manure and organic matter that may attract insects. Cracks and crevices in the truck's body should be sealed to prevent insects from seeking shelter. Regular inspection of trucks for signs of infestation should be undertaken. Remove standing water sources.	√	√
Chemical Off-host	Residual surface sprays	Feasible. Apply to areas prone to insect infestation e.g. body of truck, wheel hubs, tyres, undercarriage.	√	√

7.4 High-risk premises

Refer to Table 41 for vector control options for transmission areas. Refer to Table 30 to 37, for general control measures for any premises where cattle are kept. Refer to the AUSVETPLAN Response Strategy for LSD for specific actions required during an outbreak (AHA 2024).

A **transmission area** is defined as the location where disease transmission may occur over time due to the activity and range of vectors capable of carrying LSDV (AHA 2024). It is not a legally declared area, but aids in epidemiological modelling. In Australia, determination of the extent of the transmission area involved is based on factors such as the potential vector range, prevailing weather, wind dispersal, and host cattle movements (AHA 2024). These vector factors influence local patterns of transmission intensity and contribute to heterogeneity in exposure levels that are typical of all vector-borne transmission events (Stone et al. 2019). A **restricted area** is defined as a "*relatively small legally declared area around infected premises and dangerous contact premises that is subject to strict disease controls and intense surveillance. The limits of a restricted area and the conditions applying to it can be varied during an incident according to need*" (AHA 2024). The transmission area will be drawn around known sources of infection, as evidenced by presence of disease, presence of infected vectors, and any other confirmation of active transmission. This distance will depend on the information gained about vector numbers, distribution and competence, environmental factors (e.g. prevailing winds, rainfall, temperature, humidity), and the number and distribution of infected and susceptible animals (AHA 2023b).

Considering vector control in transmission areas, an AW-IPM approach tailored to local conditions and considering vector, geography, climate, and host characteristics should be taken. Approaches to vector control may vary significantly across different regions. The focus should be on environmental and biological controls to reduce vector populations, complemented by targeted chemical controls when necessary to minimise vector-host contact. However, while environmental and biological control measures can be effective in the long term, they lack the immediate impact of chemical agents that can swiftly "knock down" adult vector populations, making chemical agents an attractive option when responding to outbreaks. Before resorting to chemical interventions, costs and potential environmental impacts should be considered. There is currently no direct evidence of the effectiveness of chemical agents in controlling the spread of LSD (WOAH 2022). Indeed, it remains unclear whether the widespread aerial chemical spraying program in Bulgaria, covering 2.8 million hectares and costing EUR 2.9 million, significantly contributed to the control of LSDV vectors, or what environmental impact such widespread chemical application had (Casal et al. 2018).

Cattle premises located within a restricted area will fall within the transmission area. A transmission area may also include some or all of a control area. Hence, the vector control options are the same, whether a property is within the restricted area or the broader transmission area. Therefore, the vector control options outlined in Table 41 are applicable to restricted areas and other premises identified as high risk in the transmission area. In the context of vector control on premises in the restricted area, there is often a greater emphasis placed on the use of chemical agents to reduce vector-host contact in the short-term. The effectiveness of chemical agents should be assessed. For guidance on implementing vector control options on individual premises refer to Table 30 to Table 33.

Table 41. Control options for vectors that may be implicated in transmission of LSD in transmission areas (including restricted areas).

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies*	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
Environmental	Sanitation measures	It should be feasible to manage manure, decaying vegetation, spilled feed, stagnant water, leaking water troughs, around yards and in small paddocks. It may be difficult to implement these measures in large paddocks. Efforts should focus under water troughs and along fence lines. Requires ongoing effort.	√	√	√	√	√	√	
	Housing modification	Recommended if possible. Screens and impregnated netting can reduce vector-host contact. Stable flies and tabanids do not tend to fly over barriers. Housing overnight can reduce midge and mosquito contact. Can be very costly to erect and maintain these structures	√	√		√		√	
	Pasture management	Feasible. Rotational grazing and other pasture management methods (e.g. spelling paddocks) to reduce manure build-up in pasture can be initiated on smaller farms. Limited by property size. Can implement the 'paddock sweeper' program for ticks in some locations.	√	√		√			√
	Animal management	Feasible depending on property size and location. Move cattle away from bush-pasture ecotone to avoid horse flies. Consider changing calving season or use more 'tick-resistant' breeds.	√	√	√	√		√	√
	Traps and Baits	Traps are species dependent. The number of traps, location of traps and maintenance are determinants of effectiveness. May be costly to install and likely to be of limited effectiveness as re infestation	√	√	√	√	√	√	

Category	Control Method	Comments	Stable flies	Horse flies	Buffalo flies*	Non-biting flies	Biting midges	Mosquitoes	Ixodid ticks
		risk is high. The Williams fly trap has been reported to have positive effects on stable fly populations. The buffalo fly trap is effective. The curtain fly trap can also be effective. Baits are mostly only effective for non-biting flies.							
Biological	Parasitoids	May be feasible, depending on farm size and type. Dependent on number of wasps released, number of release stations, etc. Can be costly.	√			√			
	Entomopathogenic organisms	May be feasible, depending on farm size and type. Can be costly.				√			√
	Dung beetles	Useful for control of dung pats in paddocks. Can buy commercial dung beetles (costly) or rely on natural populations.	√			√			
Chemical – on-host	Topical repellents – pour ons, dips, sprays	Effective for vector control but high rates of resistance to some chemicals reported. Often a short-term effect. Cost of ongoing treatments can be high.	√	√	√	√	√	√	√
	Ear tags	As above.			√				√
Chemical Off-host	Environmental spraying	Not recommended.	-	-	-	-	-	-	-
	Residual surface sprays	Feasible in yards or other structures cattle regularly access. May increase resistance	√		√	√			

8 Uncertainties and research gaps

8.1 Vector species that transmit LSD

Several haematophagous arthropod species appear capable of transmitting LSDV; however, Australian studies identifying species capable of transmitting LSDV under field conditions are largely lacking. Given the limited research, it would be prudent to assume that any haematophagous arthropods found in Australia, especially those that favour feeding on cattle, have interrupted feeding patterns and mouthparts that penetrate the skin, could play a role in the transmission of LSD (Berg et al. 2015; ESM Tuppurainen et al. 2017). The specific species of concern are likely to differ throughout the different cattle regions in Australia, depending on the production system, vegetation, and climatic conditions (Berg et al. 2015).

Little is known regarding the species of march flies that prey on cattle, and research on mosquito pests of cattle is lacking. Moreover, the prevalence of stable flies in northern regions remains unknown. Two factors should be used to prioritise vectors species for further research, (i) abundance on or around cattle, and (ii) their preference for feeding on cattle. However, an understanding of these factors is limited in Australia, particularly in the north where LSD is most likely to arrive. Studies in remote areas which includes feral bovids are also warranted as these areas pose a heightened risk of LSD entry by wind-borne agents.

While the virus may be detected beyond the mouthparts, such as in the midgut of ticks, minimal evidence suggests this as a biological pathway. However, this possibility cannot be ruled out given evidence has been present of transovarian transmission (Foil and Gorham 2000; Chihota et al. 2001; Chihota et al. 2003a; Tuppurainen et al. 2013; Lubinga et al. 2014; Sohier et al. 2019; Sprygin et al. 2019; Issimov et al. 2020; Paslaru et al. 2022; Sanz-Bernardo et al. 2021).

8.2 Efficacy of integrated pest management

While IPM holds promise in reducing vector populations by employing diverse control measures, its efficacy in controlling LSD remains uncertain, especially given reports indicating that as few as 20 stable flies could transmit the virus to an individual animal (Haegeman 2023). Although IPM strategies may benefit intensive animal settings like dairies or feedlots when implemented before adult populations peak, their success depends on factors such as vector species, environmental conditions and cattle-related infrastructure. In northern Australia, where LSD-contaminated vectors may arrive from overseas, most IPM measures are impractical to implement. Southern Australian cattle systems on the other hand, are more amenable to many of these methods. Given the popularity of IPM as a strategy for controlling LSD, it is prudent to gain a better understanding of its true efficacy in reducing LSD spread.

8.3 Number of insects required to transmit LSD

Based on the available research, most of which has not been corroborated with field studies, it is assumed that a 'swarm' of vectors is necessary to transmit the disease between animals (Weiss 1968; Carn and Kitching 1995; Chihota et al. 2001; Chihota et al. 2003a; Sohier et al. 2019; Sprygin et al. 2020; Issimov et al. 2020; Sanz-Bernardo et al. 2021). This assumption arises due to the mechanical nature of the vectors and the need for an infective dose of live virus to be inoculated into the animals (A. Sprygin et al. 2019). Currently, it is assumed that a minimum of 36 horse flies, 50 *Aedes* mosquitoes, or >20 *Stomoxys* stable flies are necessary for transmission (Sohier et al. 2019; C. M. Chihota et al. 2001; Haegeman 2023; Hall et al. 2023). However, as discussed previously, all of these flies must be contaminated with live virus and transmit a sufficient viral load to the animal for infection to occur. The incursion risk assessment conducted by Hall et al. (2023) reviewed the data regarding the number of arthropods required to transmit LSDV when assessing Australia's incursion risk. The review found significant research gaps – thus, at this point, the evidence suggests that it is unlikely that a single contaminated arthropod can transmit sufficient virus to a single animal to elicit clinical disease. However, more research needs to be conducted to confirm these assumptions.

In the context of vector control, this means that achieving completely vector-free environments may not be necessary. However, until further research is conducted on the number of vectors required, it remains crucial to minimise vector populations to mitigate the risk (Haegeman 2023). This is particularly true for *Stomoxys* species that are known for their aggressive feeding behaviour and interrupted feeding on multiple hosts (Scoles et al. 2005; Baldacchino et al. 2013; Hall et al. 2023).

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Appendix 1. Biology of potential fly vectors of lumpy skin disease in Australia

Table A42: Biology of potential fly vectors for LSDV in Australia.

Fly	Stable fly	Horse fly/ March fly	Buffalo fly	House fly/ Australian bush fly
Scientific name	*Stomoxys calcitrans*	*Tabanidae*	*Haematobia irritans exigua*	*Musca domestica, Musca vetustissima*
Life cycle	Larval: 2–6 weeks; Adult: up to 3 weeks in warm weather, up to 6 weeks in colder weather.	Larval: months to years; Adult: 30–60 days in warm weather.	Larval: 1–2 weeks; Adult: 10–20 days in warm weather.	Larval: 7–10 days; Adult: 10–21 days in warm weather. Bushfly: larvae: 2–3 days.
Egg laying preference	Decaying organic matter (straw, hay, silage contaminated with manure).	Moist soil, marshes, vegetation around water.	Fresh cattle dung pats.	Fresh manure, decaying organic matter.
Preferred feeding site	Prefer lower legs and flanks of host.	Prefer underbelly, legs, brisket of host	Prefer back, sides and underbelly, udder, teats	Cluster around eyes, nostrils etc.
Feeding behaviour	Both sexes rasp skin to feed on blood. Aggressive, interrupted feeder. Can feed on multiple hosts to obtain a full blood meal. May remain attached to host for extended feed.	Females pierce skin to feed on blood. May feed on multiple hosts during single feeding session.	Both sexes rasp skin to feed on blood. Spend most of their time resting or feeding on cattle, only leaving when disturbed or when cattle defecate. Can feed 20–30 times each day.	Unable to pierce skin. Persistent, opportunistic feeders on exudates from eyes, nose and weeping wounds. Also feeds on manure, garbage, etc.
Preferred habitat	Drains, sedimentation ponds, paddocks, yards, stables. Basically, any area where there is fermenting moist organic matter. In grasslands, the flies are found in abundance around feeders or rotting hay.	Woodlands, grasslands, near water sources.	Areas where cattle reside. Pest in northern Australia, spreading southwards. Newly emerged buffalo flies can fly up to 10 km to find cattle. If cattle are closer, most flies will not disperse far. Movement of infested cattle is the main mechanism for introducing buffalo fly into new areas.	Attracted to feedlots or where cattle are in abundance. Can be found in open grassland, urban areas and garbage sites.
Seasonal preference	Year-round	Year-round but have strong seasonal spikes. Population abundance highest during wet season in northern Australia.	Year-round. Mostly die out over winter before reinfesting over warmer months.	Bushflies are year-round in northern Australia. In southern Australia they die out over winter and repopulate spring and summer. Monsoonal rains result in peak numbers of bushflies.

Fly	Stable fly	Horse fly/ March fly	Buffalo fly	House fly/ Australian bush fly
				Houseflies are found year-round. Summer rains cause peaks in population.

Appendix 2. Biology of potential mosquito and midge vectors of lumpy skin disease in Australia

Table A43: Biology of potential mosquito and midge vectors of LSDV in Australia.

Mosquito	Dengue mosquito	Southern House Mosquito	Common banded mosquito	Biting midges
Scientific name	*Aedes aegypti*	*Culex quinquefasciatus*	*Culex annulirostris*	*Culicoides* species
Life cycle	4 life stages Life cycle is usually 2-4 weeks. Eggs are laid at the water's edge in containers and can survive desiccation for up to 12 months. Larvae and pupae require water to develop. Females can lay eggs up to 3-5 times in a lifetime.	4 life stages Life cycle is usually 1–2 weeks. Larvae and pupae require water to develop. Females can lay eggs up to 3–5 times in a lifetime.	4 life stages Life cycle is usually between 1–2 weeks. Larvae and pupae require water to develop. Females can lay eggs up to 3–5 times in a lifetime.	4 life stages The lifespan of adults is species and temperature-dependent with tropical species typically having much shorter lifespans than temperate species. In general, it has been described between 20 days and 3 months. Adults survive between 10-20 days.
Egg laying preference	Stagnant water containers.	Polluted/ dirty water e.g., septic tanks, cesspools, etc	Sunlit freshwater pools with thick vegetation. Can breed in pools of freshwater after rain in yards, puddles	Wet, organic matter e.g. mud, compost, decaying leaf litter, manure
Preferred feeding site	Feeding site on cattle has not been studied.	Commonly legs and underbelly of host, but seen to bite most body parts	Feeding site on cattle has not been studied.	Species dependant. Some species prefer the back line, others feed on lower flanks, underbelly, and inner thighs of hosts.
Feeding behaviour	Blood feeder. Females only. Daytime. Peak activity dawn and dusk. Can take multiple short feeds to obtain a full blood meal. Will feed multiple times during the day. Prefer humans but will feed on cattle.	Blood feeder. Females only. Nighttime, but will also feed at dawn and dusk. Multiple blood meals over lifespan. Usually take short feeds to obtain a full meal and for egg development. Prefer birds but will feed on cattle.	Blood feeder. Female only. Most active for two hours after sunset and at dawn. Opportunistic feeders – humans and wide variety of mammals and birds.	Blood feeder. Female only. Most species are active at dusk, dawn and during the night. Most Australian species do not feed on cattle but some Asian immigrant species are cattle specialists.
Biting behaviour	Piercing-sucking. Can feed on multiple hosts to obtain a full blood meal.	Piercing-sucking. Can feed on multiple hosts to obtain a full blood meal.	Piercing-sucking. Can feed on multiple hosts to obtain a full blood meal.	Pool feeding. Aggressive. May feed on multiple hosts to obtain a full blood meal.

Mosquito	Dengue mosquito	Southern House Mosquito	Common banded mosquito	Biting midges
Preferred habitat	Limited to parts of Qld. Sylvan and peri-domestic polytypic forms tend to prefer rural areas, forests and woodlands.	Vegetation and man-made containers, sewers, septic tanks, sedimentation ponds, etc.	Wet and humid habitats. Rural and urban areas. Prefer feeding outdoors but may also feed indoors. Can disperse widely (up to ten kilometres).	Wet and humid habitats (wetlands, marshes). Generally poor flyers but can be dispersed over long distances with strong winds.
Seasonal preference	Year-round.	Year-round.	Overwinter in some parts. Active from late spring through to late autumn. Active year round in tropical areas but with obvious population peaks in early wet season.	Year-round. Can over winter. Seasonal preference for late spring and peak in late summer early autumn.

Appendix 3. Biology of tick potential vectors of lumpy skin disease in Australia

Table A44: Biology of potential tick victors of LSDV in Australia

Tick	Australian cattle tick	Paralysis tick	Bush tick
Scientific name	*Rhipicephalus australis*	*Ixodes holocyclus*	*Haemaphysalis longicornis*
Life cycle	4 life stages. Larval: 2–4 weeks; Nymphal: 2–6 weeks; Adult: 1–2 months. Full life cycle is between 3–12 months.	4 life stages, 3-host tick. Eggs: 60–100 days; Larval: 3–6 weeks; Nymphal: 3–10 weeks: Adult: 6–21 days. Full life cycle can be between 4–18 months depending on temperature and humidity. Can survive on the ground (grass) for long durations without a blood meal: larvae 7 months, nymphs 9 months (in winter), adults 8 months.	Larval: 1–4 weeks; Nymphal: 3–6 weeks; Adult: 2–4 months. The full life cycle can be 4–18 months, depending on the climate. Short lifespans and usually only 1 generation per annum. Hot humid climates get 2–3 generations per annum. Can survive on the ground for up to 9 months.
Egg laying preference	On the ground where the female drops off the host.	On the ground where the female drops off the host.	On the ground where the female drops off the host.
Preferred feeding site	Tick stays on a single host from larval until adult stage. Narrow range of hosts attacked. Larval ticks attach anywhere, but tend to be in largest numbers on flank, inside limbs, legs, around udder, neck, brisket.	A new host is required for each stage of life cycle. Wide range of hosts. Paralysis ticks don't spend much time on the host compared to other ticks, but when they do, they can attach anywhere and are generally found near the head and neck	A new host is required for each stage of life cycle (3 hosts). Wide range of hosts are attacked. Prefers ventral (underside) areas – brisket, udder, groin between the legs and around the tail, ears.
Biting behaviour	Piercing-sucking. 1 host tick so remain on the host until adult.	Piercing-sucking. 3 host ticks. Larvae, nymphs and adults attach and feed on different hosts. Only on cattle about 1 week at a time.	Piercing-sucking. 3 host tick. Larvae, nymphs and adults attach and feed on different hosts. Only on cattle about 1 week at a time.
Preferred habitat	Grasslands, savannas, wooded areas. Found in higher rainfall areas. Mostly limited to northern Australia – Queensland to northern WA. Movement restrictions in place to prevent introduction to southern areas.	Wet grassy forests, with high annual rainfall. Require warm humid climatic regions for survival. They are found along the east coast of Australia, in Qld, NSW.	Mostly in sub-tropical regions and some temperate areas with summer rain. Along the eastern starboard and a small patch of southwestern WA.
Seasonal preference	Year-round.	Year-round. Larvae peak in autumn, nymphs peak in autumn to spring and adults are August through to December, peaking in abundance in spring.	Year-round. Peak in abundance in spring and early summer.

Appendix 4. AW-IPM Case Study: Control and Elimination of human African trypanosomiasis (HAT) in African nations

Collaborative efforts by the WHO, FAO and the Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC), and African nations have significantly reduced Human African Trypanosomiasis (HAT) cases using a strategy of active case detection, case management and vector control. Over the past two decades, the incidence of HAT has reduced, not only because of improved medical interventions, but critically because vector control measures have substantially reduced vector density and tsetse fly-human contact in endemic areas.

Vector control programs against HAT have employed an area-wide integrated pest management (AW-IPM) approach, targeting the entire pest population to minimise reinvasion risk. Depending on the local epidemiological conditions, a broad array of tools are used to control tsetse fly populations including:

- Using 'tiny targets', which are small 50cm x 25cm mesh traps impregnated with insecticide. They are effective at controlling local populations, cheap, easy to deploy, and last approximately six months (Ndung'u et al. 2020).
- Deploying the Sterile Insect Technique (SIT) to release sterile males who mate with wild females in the environment. SIT is used within the AW-IPM framework after other tools have been used to reduce tsetse fly populations. This is because SIT is more efficacious when tsetse densities are reduced.
- Livestock protective fences (LPF) consist of insecticide-treated nets (usually about 1m high) deployed around livestock pens. They obstruct the flight routes of insects. LPF has been reported to reduce transmission of vector-borne livestock diseases and improve welfare and productivity. A case-control study in Ghana showed a significant reduction in tsetse densities and animal trypanosomiasis in the village where LPF was used to protect pigsties (Bauer et al. 2011).
- Cattle used as 'live baits': Tsetse flies prefer to feed on cattle legs and underbellies, so they target insecticide application on these parts. This is a relatively easy and cheap treatment option.

To date, measures undertaken through the HAT AW-IPM have resulted in two countries being declared free from tsetse fly (Botswana and Namibia), while 17 countries have vector control projects at different levels of intensity, coverage and consistency and five countries are in the early stages of initiating vector control programmes. In general, impacts attributed to vector interventions include improved livestock and crop productivity, improved livelihoods and incomes, increased availability of arable land, and enhanced revenue from tourism.

Summarised from the Joint FAO/WHO meeting on vector control and eliminating gambiense human African trypanosomiasis (HAT), October 2022 (FAO and WHO 2022).

Appendix 5. Biocontrol agents not available in Australia

Biological control agents for flies

Table A45. Biological control methods for flies: Sterile Insect Technique (SIT)

Details	Description	References
Action	• The technique consists of sterilising reared insects using low level ionising radiation or other techniques and then releasing then en-masse into the environment where they compete with fertile males for mates. The sterile males mate with wild females, which consequently produce sterile eggs. Through sequential releases of sterile males the target population is suppressed, or under certain conditions, eradicated. • SIT is a key plank of AW-IPM programs.	(Rochon et al. 2021; Brewer et al. 2021; Baldacchino et al. 2018; Bouyer and Marois 2018)
Target flies	SIT is not currently used for fly vectors associated with LSD transmission.	
Effectiveness	• SIT was successfully used to eradicate screwworm flies from northern and central America and Libya. Has also been successful in controlling fruit flies in Mexico, and tsetse flies in several countries in Africa. • Separate studies from the 1970s looked at using SIT for horn flies and stable flies under field conditions and showed very promising results at reducing wild populations. However, since then not much has been done to progress this research because of issues with these species having very large populations. At peak populations, there can be hundreds of wild-type flies per host and releasing large numbers of sterile flies is not practical. • In Australia, SIT has been previously used to control or eradicate Mediterranean fruit fly (*Ceratitis capitata* 'Medfly'*)* and Queensland fruit fly (*Bactrocera tryoni* 'Qfly') in most jurisdictions. SIT flies are currently only used in response to an outbreak with the aim to eradicate the incursion.	(Brewer et al. 2021; Concha et al. 2016; FAO and IAEA 2024; Bouyer and Marois 2018)

Details	Description	References
	• A team of researchers have developed an SIT technique using a repressible female-lethal genetic system, meaning only male eggs are laid in the absence of the repressor (i.e. in the field). This new technique has the potential to reduce the cost of SIT and be more efficient at population suppression. The technique is being explored for horn flies. • Efforts are underway to implement SIT for tsetse flies in Africa. • SIT is being developed to control the sheep blowfly (*Lucilia cuprina)* in Australia.	
Applicable to Australia	Not at this stage.	
Impact on animals, humans, environment	None reported for vectors of interest.	(Rochon et al. 2021)
Limitations	• Not currently available for vectors of interest for LSD transmission. • Inefficient method if the target fly populations are too high (as if often the case for stable flies and buffalo flies). SIT is most effective when the fly populations are low (e.g. when over-wintering). • The cost of SIT is prohibitive. • Likely only to be acceptable for fly species where the adults do not impact on host welfare or productivity. For example, SIT stable flies and buffalo flies will likely also need to feed on host cattle. • Need to have capacity to do large-scale rearing of insects. For example, to achieve success, the released sterile males must outnumber wild-type males by a ratio of at least 10:1, which is only obtainable when fly population are low (means fewer sterile males need to be released).	(Rochon et al. 2021; Brewer et al. 2021; Baldacchino et al. 2018; FAO and IAEA 2024)

Table A46: Biological control methods for flies: Incompatible Insect Technique (IIT)

Details	Description	References
Action	• The incompatible insect technique (ITT) is similar to SIT in that it distorts sex ratios. IIT is based on cytoplasmic incompatibility conferred by some strains of *Wolbachia* bacteria (*Rickettsiales, Ehrlichiaceae*). • *Wolbachia* occur naturally in around 50% of insect species. • When *Wolbachia*-infected males mate with uninfected females, the females become infertile. • *Wolbachia* can cause reproductive distortions in female flies and reduce overall fitness. • *Wolbachia* can also block viral replication within the insect host, although this is only relevant for biologically transmitted arboviruses like dengue fever virus. Current evidence suggests that LSDV transmission is strictly mechanical.	
Target flies	Potentially buffalo flies and stable flies (under study)	
Effectiveness	• Experiments looking to infect buffalo flies in Australia with *Wolbachia* shows promise. However, their potential for use in AW-IPM strategies to control buffalo (and horn) fly populations is still under development. One study found that IIT methods could be applicable for eradiation or control of buffalo flies in controlled areas or during over-wintering periods to retard spread south or slow rates of re-colonisation in northern Australia. • The IIT approach has been assessed for stable flies, but no further development has occurred.	(James 2020; Brewer et al. 2021; Bouyer and Marois 2018)
Applicable to Australia	• There are no commercial developments in IIT for fly vectors. Therefore, this is not a viable biocontrol option in Australia currently.	
Impact on animals, humans, environment	None reported for vectors of interest.	
Limitations	• Currently, it is not possible to accurately perform mass-sexing of reared buffalo flies. This is a problem because reared females carrying *Wolbachia* may be released alongside male flies, which renders IIT ineffective. This issue can be offset by combining IIT and SIT methods.	(Bouyer and Marois 2018; James 2020)

Details	Description	References
	• IIT is inefficient if the target fly populations are too high (as is often the case for stable flies and buffalo flies). IIT is most effective when the fly populations are low (e.g. when over-wintering). • The cost may be prohibitive for an AW-IPM program. • Likely only to be acceptable for fly species where the adult flies do not impact on host welfare and productivity. Fly impacts continue to occur for several generations until population-level control is achieved.	

Biocontrol agents for mosquitoes

Table 47. Biological control methods for mosquitoes: Sterile Insect Technique

Details	Description	References
Action	• EPF are used to control populations of mosquito larvae. • When the fungi are in water, they produce blastospores, which enter the gut of the larva and penetrate directly into the haemocoel. They germinate quickly once in the gut, killing larvae within 24 hours. • For adults, EPF reduce the likelihood for blood-feeding, survival, and fecundity. • Common EPF strains for mosquitoes include *Beauveria spp. Coelomomyces spp., Culicinomyces spp., Entomophthora spp., Lagenidium spp., Metarhizium spp., Phytium spp., Smittium spp., Fusarium oxysporum*	(Weeks et al. 2018; Wong et al. 2023)
Target mosquitoes	*Ae. aegypti, Anopheles stephensi*, *Culex quinquefasciatus* and *Culex pipiens pipiens*	
Effectiveness	• *M. anisopliae* and *B. bassiana* have been shown to be efficacious against *Ae. aegypti, Anopheles stephensi*, *Culex quinquefasciatus* and *Culex pipiens pipiens,* but efficacy is inconsistent in field trials.	

Details	Description	References
	• EPF have variable effects, depending on factors such as formulation, fungal strain and host sensitivity. It has been reported that larval mosquitoes become less susceptible to EPF with each moult, while adults become more susceptible as they age. • Non-blood-fed mosquitoes are much more susceptible than blood-fed mosquitoes. • Some studies have reported that pre-lethal or sub-lethal doses of EPF can change mosquito habitat and host-seeking behaviour, with one study reporting that the sublethal effects of *B. bassiana* on *Ae. aegypti* included a reduction in mosquito-human contact by 30%, along with a reduction in fecundity from 75 to 45 eggs/female/lifetime. • When using EPF, most target insects are treated with conidia, but conidia are not as successful for treating mosquito larvae in aquatic environments.	
Applicable to Australia	Commercial formulations of EPF for mosquitoes are not available in Australia.	
Impact on animals, humans, environment	Some strains can affect non-target arthropods.	
Limitations	• Development is still ongoing. • The application method is a major limitation when using EPF to manage mosquitos and midges.	(Weeks et al. 2018; Wong et al. 2023; Onen et al. 2023)

Biocontrol agents for ticks

Table 48. Biological control methods for ticks: Entomopathogenic fungi

Details	Description	References
Action	• EPF penetrate the cuticle of the tick. Fungal spores infect other ticks. The fungus can kill several stages of the tick.	(Samish et al. 2004; de Miranda Santos et al.

Details	Description	References
	• Dose has a critical impact on the effect of EPF on ticks: the more conidia exposed to the cuticle, the more that successfully attach. Increasing the dose increases tick mortality and shortens time to death. • Mortality of ticks infected with EPF is slow, usually ranging from one week to a month. • It is thought that EPF have a relatively long-lasting sub-lethal influence on adult female ticks. • Naturally occurring or available as commercial formulations. EPF need high humidity to germinate and sporulate.	2018; FlyBoss 2024; Baldacchino et al. 2018).
Target ticks	Ixodid species	
Effectiveness	• Individual ticks vary greatly in susceptibility to EPF infection, related to species, life stage, engorgement status, fungal species, strain, formulation, and rate challenged against. Tick eggs are highly susceptible to fungi and in one study up to 100% of the eggs exposed to fungi under laboratory conditions did not hatch. • Under lab conditions*, Metarhizium anisopliae* and *Beauveria bassiana* appear to be the most pathogenic EPF species. An Australian study found some Australian isolates of *M. anisopliae* are extremely effective at killing ticks in the laboratory, with death occurring in 100% of ticks within two days. However, field and pen trials have provided inconclusive evidence as to the commercial potential of a fungal biopesticide for tick control. For example, several studies researching on-host spray formulations of *M. anisopliae* spores on cattle infested with *R. microplus* or *R. decoloratus* ticks at various development stages found insignificant or low reductions (up to 50%) of the on-host tick populations. • An Australian trial showed that a possible *M. anisopliae* pesticide has potential for the control of buffalo flies but has limited efficacy against cattle ticks. • Another on-host study demonstrated that dipping, surface treatment and spraying all resulted in a dose dependent effect leading to faster mortality of ticks. • Other studies looked in off-host formulations of *M. anisopliaes* where the fungus is sprayed onto foliage of pasture and found that 50% or more ticks in the field became infested with the fungus after	(Samish et al. 2004; de Miranda Santos et al. 2018; Leemon and Jonsson 2008; FlyBoss 2024; Baldacchino et al. 2018; Weeks et al. 2018; Bharadwaj and Stafford 2012).

Details	Description	References
	2–4 weeks. On field application is only short-lived, with conidia reducing quickly due to UV light exposure.	
Applicable to Australia	• Commercial formulations of *Metarhizium anisopliae* are not available in Australia for ticks. • In the USA, there are a small number of products available for use against ticks. They are either field sprays, emulsions, or dips.	(Sullivan et al. 2022)
Impact on animals, humans, environment	Non target beneficial insects may be impacted (e.g., dung beetles).	
Limitations	• Can be expensive to mass produce EPF and products have a limited shelf-life. • EPF are susceptible to UV radiation. • They are slow in killing of tick hosts. • Not target specific. A newly identified local fungus species *Beauveria australis* has recently been identified to infest dung beetles. *Beauveria bassiana* has also been reported in Australian soils and is known to also decimate dung beetle populations.	(Samish et al. 2004; de Miranda Santos et al. 2018; Weeks et al. 2018; Caron et al. 2023).

Table 49. Biological control methods for ticks: Entomopathogenic nematodes (EPNs)

Details	Description	References
Action	• Belong to the families *Steinernematidae* and *Heterorhabditidae* (Order: *Rhabditida*). Naturally occurring with many different strains. • Penetrate the tick at the mouthparts, spiracles, anus, and genital pore. Once inside, they release symbiotic bacteria that kill the host insect within 24–72 h. EPN multiply within the dead tick, releasing thousands of juveniles into the environment. • Low concentration of EPN can cause sublethal effects on fertility and fecundity by significantly reducing egg mass. • Time to mortality is longer with ticks compared to other arthropods.	(de Miranda Santos et al. 2018; Samish et al. 2004)
Target ticks	Ixodid species	
Effectiveness	• EPN does not have a great efficacy on ticks. • Ticks vary greatly in susceptibility to EPN infection, generally related to species, life stage, engorgement status, nematode species, strain, formulation, and nematode concentration. • Studies have demonstrated that EPNs sprayed on soil covered with leaf litter or grass were more efficient in killing ticks compared with those sprayed on uncovered soil.	(de Miranda Santos et al. 2018; Samish et al. 2004)
Applicable to Australia	No commercial formulations available for ticks.	
Impact on animals, humans, environment	None reported	
Limitations	Environmental conditions, such as soil type, temperature, and humidity, strongly influence the pathogenicity of EPN. Therefore, their use will be limited to specific ecological niches. Genetic manipulation of EPNs could extend their range, but limited research is underway in this field.	(de Miranda Santos et al. 2018; Samish et al. 2004)

Appendix 6. Mode of actions of important chemical classes

Table 5027. Chemical control of vectors: Synthetic pyrethroids

Description	Synthetically manufactured compounds with a structure similar to naturally occurring pyrethroids (extracts from plants with insecticidal and repellent properties, e.g. chrysanthemums). Widely used in adulticides.
Mode of action	• Disrupt nervous system by keeping sodium channels open, causing constant nerve excitement. This eventually leads to paralysis and death. • Act by contact with susceptible insects. • Also has repellent effects.
Common active constituents	Deltamethrin, flumethrin, betacyfluthrin, zeta-cypermethrin, cyfluthrin
Application method	• On-host – spray on, pour-on, dip, powder, ear tags • Off-host – surface spray, residual spray, fogging, treated screens or material, baits
Target vectors	Product dependent, but can be active against flies (buffalo flies, stable flies, house flies), mosquitoes, midges, ticks (cattle ticks, bush ticks, paralysis ticks)
Effectiveness	Broad spectrum of activity, non-specific, fast acting.
Registration status	Active in Australia
Schedule	6
Impact on humans, animals, environment	• Very toxic to fish, other aquatic organisms, and beneficial insects (e.g., pollinators). Can also impact dung beetle populations. • High persistence in the environment. • May cause eye and skin irritation in people.
Resistance status	• Widespread in flies, mosquitoes, midges and ticks. • Mosquito resistance to SPs is widespread globally. Resistance to SPs was observed in 68% of sites tested across 88 endemic countries. • SP resistance is reported in buffalo fly populations. • SPs also affect non-target vectors. This can increase SP resistance in all local insects when using SP products.
Limitations	Pour-ons and sprays can contaminate dung by direct transfer in the anal area or by cattle licking the area, affecting dung microfauna. Restricted application to spraying on legs and belly may reduce the impact on dung beetles. However, this requires more frequent application, which may lead to increased resistance.
References	(FlyBoss 2024; Baldacchino et al. 2018; Rothwell et al. 2011; WHO 2022)

Table 51. Chemical control of vectors: Organophosphates

Description	Synthetic chemicals that belong to the organic esters of phosphoric acid.
Mode of action	• Cause an accumulation of the neurotransmitter acetylcholine by blocking acetylcholinesterase, an enzyme which normally breaks it down. This disrupts nerve function in insects. • Acetylcholine is common to insects and mammals, which is why OPs can be toxic to animals and people. • Kills by direct contact or ingestion.
Common active constituents	Diazinon, chlorfenvinphos, malthion, azmethiphos, coumaphos, temphos
Application method	• On-host – spray on, dip, powder, back rubber, ear tags • Off-host – surface spray, residual spray, fogging, baits
Target vectors	Product dependent, but can be active against flies (buffalo, stable flies) and ticks (cattle tick, bush tick, paralysis ticks).
Effectiveness	Broad spectrum of activity, non-specific, fast acting (insects killed within 4–8 hours of exposure).
Registration status	Active in Australia
Schedule	6 or 7
Impact on humans, animals, environment	• Very toxic to humans – subject to work safety regulations in each jurisdiction. May have an accumulative poisoning effect with repeated exposure. • Toxic to other non-target organisms, especially fish and bees. • High persistence in the environment.
Resistance status	• Widespread in flies and ticks. • OP resistance can occur in all insects when using these products because of their non-specific activity.
Limitations	• Depending on the product and formulation, it may be associated with long WHPs and ESIs. Consult the product label before using on beef cattle and dairy cattle.
References	(FlyBoss 2024; Baldacchino et al. 2018)

Table 52. Chemical control of vectors: Carbamates

Description	Synthetic derivatives of carbamic acid (from the calabar bean, West Africa).
Mode of action	• Similar mode of action to OPs. • Causes an accumulation of the neurotransmitter, acetylcholine by blocking acetylcholinesterase, an enzyme which normally breaks it down. This disrupts nerve function in insects. • Acetylcholine is common to insects and mammals, which is why carbamates can be toxic to animals and people. • Kills by direct contact or ingestion.
Common active constituents	Bendiocarb, methomyl
Application method	Off-host – surface spray, residual spray, paint, granules, powder
Target vectors	House flies, stable flies, blowflies
Effectiveness	Broad-spectrum, shorter duration of action compared to OPs
Registration status	• There are no registered carbamate-based veterinary products in Australia. • Registered agriculture products are available for use on premises (abattoir, animal housing, yards, insect breeding areas, manure).
Schedule	6 or 7
Impact on humans, animals, environment	• Moderately toxic to humans – subject to work safety regulations in each jurisdiction. May have an accumulative poisoning effect with repeated exposure. • Toxic to other non-target organisms, especially fish and bees. • Does not persist in the environment – break down within weeks to months.
Resistance status	Resistance is reported in house flies overseas. These products are not currently registered for use in flies in Australia, therefore it is unknown if resistance is present in Australia.
Other limitations	Not registered for use in Australia for flies.
References	(FlyBoss 2024; Baldacchino et al. 2018)

Table 53. Chemical control of vectors: Macrocyclic lactones

Description	• Derived from soil bacteria of the genus Streptomyces. • Commonly used to control ticks in livestock.
Mode of action	• Binds to glutamate-gated chloride channel receptors in nerve cells in insects. This causes sustained influx of chloride ions into cells and paralysis. This leads to de-attachment and expulsion of the target from the host animal. MLs are readily distributed throughout the animal's body and deposit in fatty tissues. Spinosyns (spinosad) cause involuntary and prolonged tremors in the tick nervous system resulting in paralysis and death.
Common active constituents	Ivermectin, abamectin, doramectin, moxidectin, spinosad
Application method	• On-host – oral drench, pour-on, injection ('mectins) • Off host – surface spray for premises, bait (spinosad)
Target vectors	Ticks (cattle tick), flies (buffalo flies, house flies, stable flies)
Effectiveness	• Broad-spectrum of activity, non-specific, fast-acting. • Formulation and route of administration can affect drug absorption, distribution and excretion. For example, pour-on formulations have greater variability of absorption compared to drench or injection formulations. • Insects absorb MLs either by ingestion or from direct contact. • Ivermectin is said to have a short-lived insecticidal effect.
Registration status	Active in Australia.
Schedule	5 or 6
Impact on humans, animals, environment	• MLs can be toxic to aquatic life, beneficial insects, and algae. • Can kill dung beetles. • Considered to be of lower toxicity but may be harmful if swallowed and irritating to eyes and skin.
Resistance status	Resistance to flies (spinosyns) and ticks ('mectins) has been reported overseas.
Other limitations	• Depending on the product and formulation, it may be associated with very long WHPs and ESIs. Consult the product label before using on beef cattle and dairy cattle. • Avoid repetitive use of spinosyns to avoid build-up of resistant vectors in population.
References	(FlyBoss 2024; Baldacchino et al. 2018)

Table 54. Chemical control of vectors: Bioinsecticides

Description	• Derived from natural substances such as plants, bacteria, minerals. • Preferred chemicals to use in AW-IPM programs where impacts on the environment and people needs to be minimised. • Bioinsecticides are not the same as biocontrol agents – biocontrol agents actively seek out the target insect (e.g., entomopathogenic fungi and parasitoids), whereas biopesticides are passive agents.
Mode of action	• Larvicidal action, insect-specific. • Destruction of midgut epithelium occurs within 12 hours of ingestion. • Two main types of bioinsecticides used in vector control for animals – biochemical and microbial insecticides. • Biochemical insecticides are natural products that control pests by non-toxic mechanisms. They are made up of substances that interfere with mating or use scents that attract pests to traps or baits. • Microbial insecticides consist of a toxin from a microorganism (bacteria, fungus, virus, protozoan) which is target-specific in their action. *Bacillus thuringiensis* subsp. *israelensis (*Bti) toxin is the most common for mosquitoes and flies. It binds to the dipteran larval gut receptor, causing the larva to starve. • Each Bt toxin is specific to the target insect family. *Bt israelensis* controls mosquitoes and flies. Other toxins control moths, butterflies, beetles.
Common active constituents	*Bacillus thuringiensis* subsp. *israelensis (*Bti)
Application method	• Off-host – surface spray, water soluble granules for premises
Target vectors	Mosquitoes, flies
Effectiveness	• Bti is effective in killing immature stages of mosquitoes in many habitats. • The duration of effectiveness is between 2–4 weeks.
Registration status	Active in Australia
Schedule	0
Impact on humans, animals, environment	Bti is reported to be non-toxic and only affects the target pest and closely related organisms. However, a meta-analysis found that it can have negative impacts on non-target organisms in aquatic and terrestrial systems.
Resistance status	Some naturally occurring resistance may exist through expected genetic variability in insect populations. Naturally resistant populations may eventually dominate if Bt products are used repeatedly.
Other limitations	• Only effective in small quantities and decompose quickly. Not to be used on its own to control vector populations or for long-term control. • Application is only effective in early stages of larval development because 4^{th} instar larvae do not feed before pupation. If more than 50% of the larval population is in 4^{th} star pupation Bti products are not recommended.

References	(US EPA 2023; Land et al. 2023; Boyce et al. 2013)

Table 55. Chemical control of vectors: Insect growth regulators

Description	• IGRs are synthetic compounds that mimic hormones in the immature stages of arthropods, preventing development to adult stages. • IGRs are often combined with adulticidal pesticides.
Mode of action	• IGRs are slow-acting but should remain active for 10–12 weeks. • There are three classes of IGRs – juvenile hormone mimics, chitin synthesis inhibitors, moulting disruptors. • Synthetic juvenile hormone analogs mimic the action of insect growth hormones, disrupting the normal development of insect larvae (e.g. methoprene and S-methoprene). • Chitin synthesis inhibitors block the chitin synthase enzyme, preventing larvae from developing into adults (e.g. diflubenzuron). • Moulting disruptors interfere with the formation of the cuticle to prevent moulting. This mode of action mostly targets insects from the Diptera order (flies) (e.g. cryomazine). • IGRs can also inhibit egg hatching. • Adult stages are not killed by IGRs because they do not moult. • IGRs are slow acting compounds that eliminate infestations over weeks.
Common active constituents	Cyromazine, methoprene, S-methoprene, diflubenzuron, fluazuron
Application method	• On-host – pour-on (in combination with other actives) • Off-host – surface spray, water soluble granules for premises
Target vectors	Flies (house flies, bush flies, stable flies), ticks (cattle tick), mosquitoes
Effectiveness	• Diflubenzuron is a broad-spectrum larvicide used primarily on fly larvae. • Cryomazine is a narrow spectrum larvicide used on fly larvae. This active has been reported to reduced adult stable fly emergence. • Fluazuron is narrow spectrum acaracide against ticks. • Methoprene and S-methoprene are effective against mosquito larvae. Products containing these actives are commonly used in public health orientated mosquito control programs.
Registration status	Active in Australia
Schedule	0, 5 or 6 depending on the product formulation
Impact on humans, animals, environment	• Very toxic to aquatic life. May also be toxic to spiders and beneficial insects. • Relatively safe for humans as IGRs have selective toxicity, but care must be taken when applying sprays. • IGRs can take a long time to degrade in soil environments.

Resistance status	• Reported in flies and cattle tick. • IGRs with different modes of action should be regularly rotated to inhibit resistance.
Other limitations	• These chemicals do not have an immediate effect on reducing vector populations. • IGR products may be used in combination with other actives (e.g. MLs) resulting in WHP and ESI. Always check the product label before use. • There is limited evidence of the efficacy of IGR actives against midge populations in the field.
References	(FlyBoss 2024; Baldacchino et al. 2018; Miranda 2018; Carpenter et al. 2008; Rochon et al. 2021)