Potential Impacts of Introduction and Establishment of Japanese Encephalitis Virus in the United States Swine Herd

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Introduction: In early 2022 Japanese Encephalitis Virus (JEV) infections were identified in swine breeding farms throughout Australia causing significant production losses. This paper explores those impacts and makes prediction on potential impacts of an introduction and establishment of JEV in the United States. The authors conducted interviews with Australian veterinarians and analyzed production data provided by them to identify gaps in understanding and, to the extent possible, develop the predictions. This paper focuses on potential production impacts and does not address any changes in demand for pork and pork products.

Background: Japanese Encephalitis Virus is a vectorborne virus of the genus *Flavivirus*. There is a single serotype but five genotypes[1]. JEV is a zoonotic virus maintained through a cycle involving Culex and Aedes species mosquitoes with some species of birds (e.g. wading birds such as egrets and herons), pigs, and possibly bats[2], as the vertebrate hosts[3]. Birds and pigs are the principal amplifying hosts while humans, horses and some other ruminant species are dead end hosts but develop clinical disease[4]. The main clinical signs of JEV infection in swine are reproductive failure including abortion, mummified, stillborn and deformed fetuses, or weak liveborn piglets, as well as infertility in boars[5].

Overview JEV in Australia: Following several years of drought (2017-2020) leaving the Murray - Darling River Basin at low levels significant rainfall caused widespread flooding across Eastern Australia in March of 2020. A wet summer of 2020 -2021 followed with subsequent flooding in Eastern and Central Australia in March 2021. November 2021 was the wettest in history resulting in the Murray - Darling River Basin being at over 90% capacity, followed by several months of above average rainfall in Eastern and Central Australia.

Between February 25 and March 3, 2022, JEV infection in pigs was confirmed in four Australian states by multiple veterinarians and as a nationally notifiable Category 1 Emergency Animal Disease initiated a coordinated national response and was reported to international animal health authorities[6]. Retrospective analysis detected JEV exposure in feral pigs in northern Australia in November of 2020 and in domestic pigs as early as April, 2021[6]. By mid-2022 more than 80 pig farms located over much of the southern and eastern part of Australia were infected and more than 50 positive feral swine were identified in the Northern Territory, 26 presumptive equine cases across the impacted states and one fatal case in an alpaca in South Australia[7]. Forty-two human cases were reported with seven fatalities, only one of those cases had reported occupational exposure to pigs[7]. One gilt was reported positive in November of 2022 and no other positives have been identified since that date through the first ten months of 2023.

Clinical signs of JEV were reported in sow farms and at least one boar stud. The clinical signs included an increase in abortions, increase in return to service, delayed farrowing (>118 days), decreased litter size, and increased mummies, deformed, weakborn and stillborn piglets.

The national case definition was: For a confirmed case of JE disease there must be clinical presentation AND the presentation must be recent AND demonstration of any of the following laboratory results:

1. Isolation and identification of a flavivirus, OR

2. Detection of a flavivirus by nucleic acid testing, OR

3. Immunohistochemical detection of a flaviviral antigen in association with appropriate

histopathological lesions, OR

4. Seroconversion by testing paired serum samples or a significant increase in antibody level (a

fourfold or greater rise in titre) to a flavivirus in a virus neutralisation test, OR

5. Detection of elevated levels of flavivirus–specific antibody (IgM or IgG) in cerebrospinal fluid, OR

6. Detection of elevated levels of flavivirus–specific antibody (IgM) in serum.

With clinical presentarion for pigs being:

1. Reproductive disease in sows characterised by abortion, stillbirths or mummified foetuses; paretic

or clinically affected piglets that die soon after birth, above the expected level for the enterprise

2. Shaking/trembling, ataxic or convulsing piglets (up to 6 months) that do poorly with variable pyrexia

3. Orchitis, decreased sperm number or motility in semen, or abnormal spermatozoa.

Necropsy of weakborn or stillborn piglets often demonstrated severe neurologic deficits including the absence of sulci or gyri and in some instances the absence of brain tissue. It is important to note that the case definition(s) included clinical disease thus seroconversion of weaned pigs or market hogs were not considered as cases. No clinical signs were observed in weaned pigs or market hogs.

In one boar stud approximately 50% of boars were affected. In the affected boars, ejaculates with deformed sperm progressed to zero sperm rich fraction. When necropsied, few to no sperm were observed in the epididymides and vas deferentia and scarring resulted in cystically dilated, and sometimes ruptured, tubules full of sperm. Thus, spermatogenesis continued but scarring prevented the sperm from traveling down the tubules. In one system, the boars that were retained for up to three spermatogenesis cycles did not regain fertility while another had two boars return to normal fertility more than 80 days after first aspermia.

There was significant variation in the duration and impacts observed between farms. In one affected system duration of clinical signs in farms varied between four and 29 weeks and percent affected litters ranged from one to greater than 50%. In some cases, there was a reduction in pigs born alive in subsequent litters but in most cases reproductive rates returned to normal after the outbreak on the farm subsided. Overall, it is believed that approximately 60% of the Australian pig industry was impacted by the outbreak and between 3-6% of annual production on affected farms was lost due to failure to conceive, abortion, decreased born alive and increased pre-wean mortality. Affected farms had significant financial losses estimated to be between $215,000 and $250,00 U.S. per 1000 sows.

Australian outbreak observations: The JEV outbreak in domestic pigs in Australia was observed in four geographically distant states within a week. While there was significant distance between the sites, many were within the Murray - Darling River basin and some were relatively close to rivers. It appears that movement of infected birds or mosquitos along the river basin may have played a role in the spread of JEV across such a broad area. There was no evidence in Australia that semen movements spread the virus and due to the short viremic phase and lack of evidence of spread between associated herds it is unlikely that movement of viremic sows between sites within production systems contributed to spread.

One system suggested that their farrow-to-finish sites were more impacted than were their farrow-to-wean sites although that could be a result of the farrow-to-finish sites also having more pigs on a site resulting in more amplification of the virus, while other systems did not observe increased impact to farrow-to-finish sites. It is possible that mosquito intensity is of greater risk than is type of site. While there appeared to be fewer free-range sites affected it is unclear whether that is due to fewer free-range sites, lack of diagnostic investigations/reporting, or if they were indeed somewhat protected.

The systems that shared data with us had some initial evidence that naturally ventilated gestation facilities may be more susceptible to infection than mechanically ventilated gestation buildings, although both types of facilities were observed to have outbreaks (most farrowing houses are mechanically ventilated in Australian systems). Additionally, very few of the Australian systems have deep pit manure management and open lagoons are common providing a potential breeding ground for mosquitoes and an attractant to waterfowl. There was not enough data, nor was the data consistent enough, to calculate a protective factor of mechanical ventilation in gestation.

The weather remained wet in 2023 and Australia experienced the largest outbreak of Murray Valley Encephalitis (which largely impacts humans and horses) in decades indicating that there are favorable conditions for active arboviral disease. Australian veterinarians felt that there is more emphasis placed on mosquito control in pork production sites than previously, which may account for the lack of cases observed in 2023. Serological evidence to suggest herd immunity to JEV in Australia is lacking.

Potential US impacts:

The Australian pig industry is smaller than the U.S. with 4300 pig sites and an inventory of 2.4 million pigs. This compares to the U.S. industry with an inventory of 72.2 million swine on over 60,000 farms. Approximately 90% of Australian sows are fully confined, while 5% farrow outside and raise their market hogs inside, usually on deep bedding. The remaining 5% of

Australian sows kept in free-range outdoor systems. Approximately 90% of sows on Australian farms, and virtually all sows in large systems, are kept in accordance with the APIQ (Australian Pig Industry Quality Assurance) system. While most animals are raised in APIQ certified farms, most farms are not APIQ certified since there are many thousands of pig keepers with less than ten sows that are not certified. Since mid-2022 the APIQ system has included a standard for mosquito control on APIQ certified farms[6].

While U.S. production systems may focus more on mechanically ventilated systems, including filtered systems, there are also naturally ventilated barns in use, particularly in the Southeast U.S. Some mechanically ventilated barns are curtain sided so those facilities are likely to be less efficient in excluding mosquitoes than a fully enclosed facility, and likely much less so than a filtered farm. Additionally, in the U.S., especially in the Midwest, filtration of sow farms is utilized by some systems. Very few mosquitoes are observed in the filtered barns[8], diminished numbers in tunnel ventilated barns, while some other types of mechanically ventilated barns appear to be minimally or not protective against mosquito incursions[9]. While the Australian veterinarians interviewed pointed to their lagoons and surface water storage as potential mosquito breeding grounds and a draw for water birds, U.S. swine facilities are often in areas with ample surface water even if deep pit manure management systems are used.

National Animal Health Monitoring System (NAHMS) defines mechanical ventilation as: Air flow in a swine area is created using mechanical rather than natural means (such as breezes). For example, air may be pulled in using fans on the side of the building which then flows out through vents in the ceiling. This definition is broad enough that it is difficult to determine what potential impact on mosquito incursion would be experienced due to ventilation type.

The 2021 NAHMS study reports the following breakdown of facility types for farrowing and gestation broken out by size and by region.

4. Facility types (NAHMS 2021)

A.4.a. (ic0204, ic0205) For the 13.8 percent of breeding sites (Table A.3.a.), percentage of sites by type of facility used for the majority of breeding animals and by breeding size of site:

	Percent Sites							
	Size of Site (number of sows and gilts)							
	Small (Less than 250)		**Medium** (250–499)		**Large** (500 or more)		**All sites**	
Phase and facility type	**Pct.**	**Std. error**	**Pct.**	**Std. error**	**Pct.**	**Std. error**	**Pct.**	**Std. error**
Gestation								
Total confinement with mechanical ventilation	56.5	(13.2)	26.1	(8.2)	95.2	(3.8)	87.6	(4.3)
Open building with no outside access	(D)*	(D)	(D)	(D)	4.8	(3.8)	7.3	(3.7)
Open building with outside access	29.3	(13.1)	39.2	(18.7)	0.0	(—)	4.9	(2.0)
Other	(D)	(D)	(D)	(D)	0.0	(—)	0.2	(0.1)
Total	100.0	(—)	100.0	(—)	100.0	(—)	100.0	(—)
Farrowing								
Total confinement with mechanical ventilation	82.4	(11.0)	60.7	(12.4)	98.9	(0.6)	95.1	(1.8)
Open building with no outside access	0.0	(—)	19.7	(16.2)	1.1	(0.6)	2.2	(1.2)
Open building with outside access	16.0	(10.9)	0.0	(—)	0.0	(—)	1.3	(0.9)
Other	1.7	(1.2)	19.7	(16.2)	0.0	(—)	1.4	(1.1)
Total	100.0	(—)	100.0	(—)	100.0	(—)	100.0	(—)

*Values of (D) denote too few to report.

A.4.b. (ic0204, ic0205) For the 13.8 percent of breeding sites (Table A.3.a.), percentage of sites by type of facility used for the majority of breeding animals and by region:

	Percent Sites			
	Region			
	Upper Central		Other	
Phase and facility type	**Pct.**	**Std. error**	**Pct.**	**Std. error**
Gestation				
Total confinement with mechanical ventilation	95.0	(1.9)	84.5	(6.5)
Open building with no outside access	(D)*	(D)	(D)	(D)
Open building with outside access	2.5	(1.2)	5.9	(2.9)
Other	(D)	(D)	(D)	(D)
Total	100.0	(—)	100.0	(—)
Farrowing				
Total confinement with mechanical ventilation	96.4	(1.7)	94.6	(2.5)
Open building with no outside access	2.0	(1.3)	2.2	(1.7)
Open building with outside access	(D)	(D)	(D)	(D)
Other	(D)	(D)	(D)	(D)
Total	100.0	(—)	100.0	(—)
*Values of (D) denote too few to report.				

The large percentage of US breeding sites that are mechanically ventilated contrasts with estimates provided by the Australian system veterinarians that approximately 10% of their sow herds would be housed in mechanically ventilated gestation barns. While bitterns, herons and egrets are historically considered the main waterbird species that are the main bird hosts for JEV due to lack of experimental studies it is uncertain if other bird species serve as host species that also played a role in the outbreak. There are at least two Culex mosquito species implicated in the Australian outbreak. The United States has Culex and Aedes mosquito species that are thought to be competent vectors for JEV[10, 11] (Figure 1 and 2). If JEV were to enter the US and move via water/wading birds the North to South movement could also be observed along the four waterbird flyways (Atlantic, Mississippi, Central and Pacific). While movement of viremic weaned pigs may potentially move virus from east to west (which would require mosquitoes to bite those viremic pigs and then move to a sow farm and bite sows to infect them) it is more likely to be moved via bird movements.

It is difficult to extrapolate from the Australian experience to the US. This is true because weather patterns, production locations and ventilation systems are very different in the two countries. The Australian experts we spoke with indicated that almost all of the sow barns in Australia are naturally ventilated and they speculated that outbreaks would be lower in barns with mechanical ventilation. This makes intuitive sense as mosquitos would have a more difficult time accessing barns with mechanical ventilation systems in place and almost zero change of accessing barns that are filtered. Conversations with Australian veterinarians indicated that an estimated 60% of the Australian pig industry was impacted by the virus, and on affected farms, approximately 3-6% of annual production was lost. This serves as a starting point for estimating the potential impacts for the U.S. industry.

We spoke with industry experts about the regional differences in ventilation systems throughout the United States. Based on these discussions and our own judgement, we concluded that approximately 1 million out of 3.388 million sows in the Upper Midwest (SD, ND, NE, MN, IA, WI, IL, MI, OH, IN) are housed in filtered barns with virtually no risk and the rest have a lower risk such that an estimated 40% of remaining farms would be impacted, which would be about 28% of Upper Midwest sow herd. This 40% estimate is lower than the 60% that was the case in Australia due to more mechanically ventilated barns in the Upper Midwest. In the Atlantic Region (NC, SC, VA, WV, GA, PA,) we assumed that, similar to the Australian experience, 60% of farms would be impacted due to more naturally ventilated barns. The assumed impact on the Lower Midwest (KS, MO, OK, TX, AR) and the rest of the country is 40% of farms.

The results of the calculations described above suggest that 580,620 sows in the Atlantic Region, 955,200 sows in the Upper Midwest 516,400 sows in the Lower Midwest and 83,720 sows in the rest of the US would be impacted. The total number of infected sows is 2,135,940, which is equal to 32% of the total US herd.

Farms that were infected in Australia experienced a 3% to 6% reduction in annual output. Using the same 3% to 6% values for the US suggests a reduction in U.S. output of 1% to 2%. Cash receipts for the US pork industry totaled $30.6 billion in 2022[12]. This suggests that the economic losses in impacted herds would be from $306 million to $612 million. For a 2,500 head sow farm that had achieved 30 weaned pigs per sow prior to the outbreak and assuming each weaned pig is worth $40, this amounts to a loss of $90,000 to $180,000 per year.

There is a JEV vaccine available in the U.S. for human use. There is not a veterinary vaccine for JEV approved for use in the U.S. thus vaccine use to prevent losses to swine is not available.

Unprecedented Potential to Impact Boar Studs

We did not predict the economic impact of JEV incursion into the United States on boar studs. Industry experts tell us there is redundancy with semen production although ownership interests may prevent equal access to that capacity. Additionally, many Midwest boar studs are filtered and even in other areas are otherwise built to largely exclude mosquitoes. However, as we predicted with an individual sow farm, if a boar stud were to become infected it could pose significant economic losses to that individual boar stud.

Gaps to a more robust prediction:

A detailed model of disease spread and maintenance, especially of Genotype 4, within the swine population would allow a more accurate assessment of various scenarios of virus introduction into the United States.

While the Australian veterinarians interviewed provided production data for their systems, they expressed a high degree of uncertainty around the epidemiology of the outbreak in Australia. They hypothesized that local (perhaps to the pen or barn level) risk factors influenced the extent of impact to their barns, and those risk factors had not been identified.

While this paper predicted a more likely lesser impact of JEV in the United States than in Australia due to a larger percent of the breeding herd being housed in filtered and mechanically ventilated barns, research on the mosquito protection provided by each facility type (filtered barns, tunnel ventilated, other fully-enclosed mechanically ventilated barns, curtain sided mechanically ventilated barns which may not be sealed as tightly as fully enclosed, and naturally ventilated barns) is needed to determine that potential impacts of facility type. This may include research into numbers and types of mosquitoes found inside barns in comparison to outside of barns. In addition, there may be a protective factor to increased airflow (such as may be observed in tunnel ventilated barns) even when a facility does not effectively exclude mosquito entry. One of the Australian systems was increasing airflow to greater than 1 m/second to discourage mosquito landing and feeding.

While the NAHMS information on facility type is helpful, more granular data on percentage of sows in each facility/ventilation type, as listed above, would help provide a more robust prediction. More granular data by region would add value since production veterinarians interviewed suggested that regionally there may be different prevalence of naturally ventilated facilities in the Southeast US than the Midwest, and conversely, they believed that the Midwest has a greater percentage of filtered sow farms.

A study of the competent avian hosts, and their movements, in the United States would inform the potential for virus movement. Good host species have a wide range of habitats and diet, a high tolerance to human pressures and spend at least a portion of their life cycle in large aggregations[13] while inhabiting shallow wetlands, ponds, or flooded areas while being capable of large-scale movements/migrations.[14] In Australia, these criteria included populations of species in the orders Pelicaniformes, Cicorniiformes, and Anseriformes.[14] The Australians discounted the roles of migratory shorebirds, not because they may not be competent hosts, but rather that they were not known to have congregated in large numbers in New Guinea which they believe was the origin of the outbreak. Thus, the United States could be well served to research species which meet the above criteria and their movement patterns in relationship to pig production.

While *Culex* and *Aedes* mosquitoes are found throughout the pork producing regions of the United States additional information on the ability to transmit virus of specific Culex and Aedes species found in the US would help to refine the difference of the potential for certain geographical areas of the US to be affected.

Conclusion:

On an individual sow farm a JEV break may have similar production impacts to a serious PRRS break. Using a model based on estimates of percentages of sows kept in facilities which could protect from or minimize mosquito incursion it was estimated that 580,620 sows in the Atlantic Region, 955,200 sows in the Upper Midwest, 516,400 sows in the Lower Midwest and 83,720 sows in the rest of the US would be impacted which is equal to 32% of the total US herd. Using the same 3-6% reduction in annual output observed on affected farms in Australia this would result in a total reduction of 1-2% of U.S. output. Assuming no increase in prices due to the diminished output a economic losses would be between $306 and $612 million.

The potential impact to boar studs was not estimated but on an individual boar stud affected with JEV losses could be significant with affected boars unlikely to return to production.

FIGURE 1

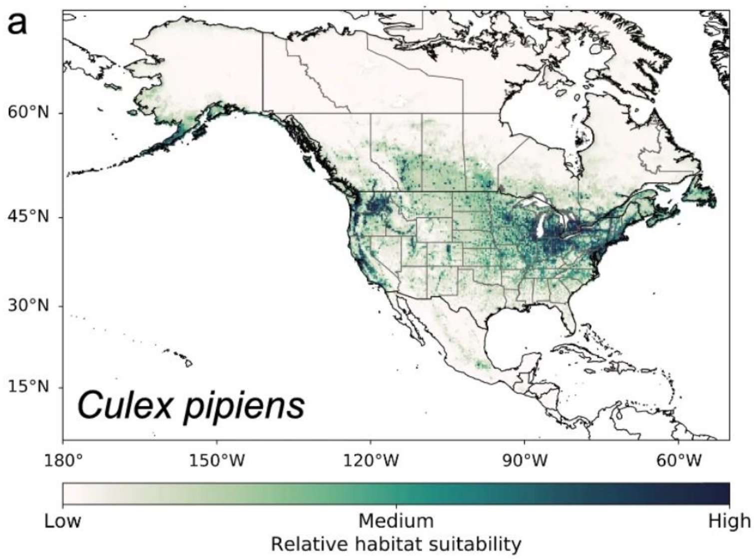
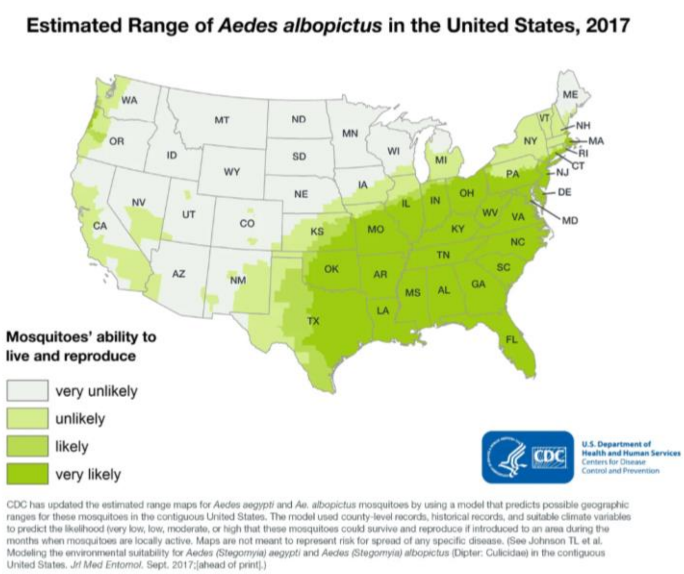


FIGURE 2



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Citations

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[1] Mohammed MA, Galbraith SE, Radford AD, et al. 2011. Infect Genet Evol 11(5): 855-862.

[2] Williams DT. 2022. Arborvirus surveillance in Australia: Pivoting to JEV. Japanese Encephalitis Virus: Emerging Global Threat to Humans and Livestock symposium. https://www.youtube.com/watch?v=v0pLoc4_wOk

[3] Endy TT, Nisolak A, 2002. Curr Top Microbiol Immunol 267:11-48

[4] Mackenzie JS, Williams DT, Smith DW. 2007. Japanese encephalitis virus; the geographic distribution, incidence and spread of a virus with a propensity to emerge in new areas. In Perspectives in Medical Virology; Emerging Viruses in Human Populations. Elsevier, pp 201-268.

[5] Williams DT, Mackenzie JS, Daniels PW. Flaviviruses. In Diseases of Swine 10th Edition. Iowa State University Press, pp 529-532.

[6] https://australianpork.com.au/sites/default/files/2022-12/APIQ_Standards_Manual_V5.2_12_2022_0.pdf

[7] Schipp M. 2022. Australia's Response to the 2022 JEV Outbreak and Lessons Learned. Japanese Encephalitis Virus: Emerging Global Threat to Humans and Livestock symposium. https://www.youtube.com/watch?v=t2SqoNvjFUg

[8] Dee S. 2023. Personal communication.

[9] Anderson, M. 2023. Personal communication.

[10] Gorris, M.E., Bartlow, A.W., Temple, S.D. *et al.* Updated distribution maps of predominant *Culex* mosquitoes across the Americas. *Parasites Vectors* **14**, 547 (2021). https://doi.org/10.1186/s13071-021-05051-3

[11]Johnson TL et al., 2017, Modeling the environmental suitability for Aedes (Stegomyia) aegypti and Aedes (Stegomyia) albopictus (Dipter: Culicdaue) in the contiguous United States. J Med Entomol.

[12] See https://downloads.usda.library.cornell.edu/usda-esmis/files/02870v85d/kk91h129k/8s45rq36g/meatan23.pdf

[13] Walsh MG, Pattanaik A, Vyas N, Saxena D, Webb C, Sawleshwarkar S, et al. A preliminary description of the ecological characteristics of wild waterbird Japanese encephalitis virus hosts in high risk landscapes in India. bioRxiv. 2022:2022.01.13.476136.

[14] Purnell, C (2022). The role of waterbirds in Australia's 2022 Japanese Encephalitis outbreak Unpublished – a rapid synthesis. BirdLife Australia, Carlton.