Computational modelling of black swan bioterror events

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Abstract: The foot-and-mouth disease (FMD) virus is one of the most contagious animal pathogens in the world, spreading readily via direct contact and contaminated objects, and under certain conditions via airborne viral plumes. FMD is present in many countries across Asia, the Middle East, Africa and South America with recent outbreaks in neighbouring Indonesia. A large outbreak in Australia could inflict economic damages of up to A$80 billion over ten years, primarily from loss of export markets. The detection of FMD on a farm will lead to the entire herd being culled. Mass culling and disposal of carcasses has deep financial, social and environmental impacts as evidenced during the 2001 UK FMD outbreak (Knight-Jones & Rushton, 2013)

The Australian Department of Agriculture, Fisheries and Forestry invests heavily in the protection of Australia from emergency animal diseases such as FMD. This occurs pre-border (e.g., regional initiatives such as supporting Indonesia with FMD vaccine supplies and technical expertise), at the border (e.g., passenger and freight screening), and post-border (e.g., preparedness and planning for incursions through simulation exercises) (Hester et al., 2024).

Outbreak scenarios of interest quite often assume accidental introduction, for example, FMD virus conveyed via fomites by a returning traveller, or the illegal importation of contaminated meat products for commercial purposes. A wilful introduction of FMD virus into an FMD-free country such as Australia is a plausible act of bioterrorism. FMD infected hosts and contaminated material are accessible in endemic countries, and the virus can remain infectious for long periods on inanimate objects. The lag between infection and the appearance of clinical signs provides a window for a perpetrator to disappear before detection and official investigation.

The Australian Animal Disease Spread (AADIS) model is essentially a flight simulator for epidemiologists to explore outbreak scenarios and the cost-effectiveness and resource implications of control options (Bradhurst et al., 2015; www.aadis.org). AADIS is a stochastic model and explicitly incorporates uncertainty, heterogeneity, and human factors. This means that for any given outbreak scenario, many simulations must be run to allow trends to emerge, and outcomes are expressed as distributions. AADIS occasionally generates black swan outbreaks that unexpectedly balloon up to catastrophic size and impact, but these are typically rare and disregarded as statistical outliers.

A modelling study was conducted to investigate the influence of a wilful and targeted introduction of FMD on the likelihood of a black swan outbreak. First, the AADIS model was used to generate 10,000 FMD outbreaks, randomly seeded in the state of Victoria. Ten black swan outbreaks arose, and these were analysed for similarities with respect to region, season, production systems, and livestock movement patterns. A further 10,000 outbreaks were then seeded targeting the previously identified high-risk incursion criteria to quantify the influence of wilful strategic seeding of FMD as opposed to accidental seeding based more on chance.

The odds of a black swan outbreak increased from 1 in 1000 under random seeding of infection to 1 in 30 when infection was introduced in cooler months, high farming density areas (down to specific local government areas), specific intensive production systems with low biosecurity, and farms with imminent movements to saleyards.

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Keywords: FMD, AADIS, biosecurity, epidemiological modelling, black swans

