**BACKGROUND AND JUSTIFICATION**

Zoonoses, pathogens that are transmitted from animals to humans, have been a public health risk since time immemorial. Increases in the frequency of human-wildlife interactions have reached historic rates due to anthropogenic influences such as climate change and landscape modification (Martin et al, 2018 and Faust et al, 2018). As contact rates increase, the risk of zoonotic disease spillover becomes a greater threat to global biosecurity and public safety. Despite the potential danger, there are considerable gaps in our knowledge of the dynamics that drive zoonotic disease transmission (Plowright et al, 2017).

Henipavirus is one example of an emerging zoonotic disease of great concern. One species in particular, Hendra virus, has been afflicting Eastern Australia for decades. Hendra virus is a fatal paramyxovirus transmitted from Old World fruit bats, commonly known as flying foxes (*pteropus*), to horses and subsequently humans. Hendra virus has been under investigation since the first outbreak in Queensland, Australia in 1994. Since then, an additional 58 outbreaks have been observed nearly every year in both Queensland and New South Wales. Each of these outbreaks have contributed to the death of livestock, and some have led to human fatalities.

It is known flying foxes act as the reservoir host for Hendra virus. Infected bats shed the pathogen in their feces and urine underneath daytime roosts (also called camps). The disease can then be transmitted to horses exposed to these areas, and from the horses it can easily be spread to humans (Kessler et al, 2018). Unfortunately, knowledge of the transmission process alone is not enough to deter the propagation of Hendra virus.

Congestion in coastal communities around Brisbane, the Gold Coast, and other similar locals have compelled inland expansion of suburbs and hobby-farms. In addition to encroaching into native flying fox habitat, residents of these communities often provide resource subsidies in the form of fruit-bearing trees and shrubs (Altizer et al, 2018). In response to extreme fragmentation of native vegetation and degradation or shortage of nutritious food in the environment, flying foxes have been establishing roosts closer to human-occupied spaces more and more every year (Altizer et al, 2018). The synchronous migration of humans and flying foxes into the territory of the other has put this part of Australia in a precarious position.

There is no indication the rate of human-wildlife interactions will begin to decline in this region without intervention. It is important that effective management strategies be introduced in order to prevent future Hendra virus outbreaks from occurring. The dynamics are immensely complex and operate on a wide-range of scales, therefore investing in research to better understand this system is vital to the implementation of any management technique.

**PROJECT OVERVIEW**

This project tracked flying fox camps, horse properties, and spillover events in Queensland and New South Wales, Australia, in the year 2011. The guiding research question was; do characteristics related to history (circumstances of establishment and patterns of occupation over time) and composition (species present and their population sizes) of flying fox camps affect the risk of Hendra virus spillover to horses? We hypothesized that flying fox camps that are recently established during a food shortage, that are continuously occupied, and that contain black flying foxes are more likely to be the source of Hendra virus spillover compared to camps with other attributes.

In order to conduct this investigation, data describing spillover events, horse properties, and flying fox camps were compiled. The spillover event dataset (also referred to as infected premises, or IP), consisted notably of geographic coordinates, the state it occurred in, as well as the month the outbreak was first recorded. The horse property dataset also contained geographic coordinates and the state it was registered in. The horse properties were reduced from a state-level collection to what was defined as the study area for the project. The study area was decided to be everything within the minimum bounding shape of 100km buffers drawn around each of the 17 spillover events. Because flying foxes typical stay within a 20km radius of their roost (their feeding area), it was appropriate to assume a 100km bound would not comprise any results. Unfortunately, due to conflicting reports in the sources used to compile the horse property dataset, information about the number and type of horses present at each paddock could not be used in this analysis. Lastly, the camp dataset had the following features: descriptive and spatial information, occupation status, establishment history, population counts for black flying foxes, grey-headed flying foxes and little red flying foxes in the months of June, July, August and October, information about the feeding area of the roost and the land use around it, as well as derived fields describing spatial relationships with surrounding horse properties (distance and number within the typical feeding radius).

Two statistical frameworks were determined appropriate for this analysis, each with their tradeoffs and benefits. A Cox-Proportional Hazard Model was used to leverage a case-control study design where each spillover event acted as a case. The model was stratified (matched) on state and month, therefore the controls were all other horse properties that intersected a 20km buffer drawn around each camp that was occupied in a given month in a given state. For example, controls for a spillover event that occurred in June in Queensland were generated by: 1) subsetting horse properties in Queensland 2) subsetting camps in Queensland 3) drawing 20km buffers around each remaining camp that was occupied in June 4) randomly sampling from the remaining horse properties that intersects any of the 20km buffers. The covariate data for each of the cases and controls were taken from the nearest camp that was occupied in the corresponding month. Genetic testing in previous studies supports the assumption that the nearest camp to a spillover event can be attributed as the culprit for the outbreak. Therefore, deriving variables for testing from the nearest camp was biologically sound. One important note with this design is that in an attempt to eliminate double-entries, any camp that was the closest camp to a spillover event could not be factored into determining potential controls.

The second statistical framework used was a generalized linear model with a binomial distribution and logit-link function. In this approach, the predictor variable was classified as a binary outcome. A value of “true” was applied to any camp that was the closest camp to a spillover event and occupied in the same month the event occurred. A value of “false” was applied to all other camps. The null premise in this approach was that no statistical difference exists between the characteristics of the event-related camps and non-event camps. Differences would therefore be attributed to chance or covariates beyond the scope of the study.

**RESULTS**

A visual exploration of the risk factors behind the research question bolstered the validity of the hypothesis. When comparing the proportions of event-related camps and non-event camps in relation to establishment history, occupation status, and distance to the nearest horse property, clear patterns of aggregation of event-related camps around specific values were illuminated, suggesting statistical relationships might be measurable in these covariates.

A univariate generalized linear regression was run for each of the variables of interest. The best performing AIC-tested models related to occupation status and history of establishment. According to the cursory analysis, continuous occupation by black flying foxes had the most significant effect with an odds ratio of 21.029 (p < 0.01). Following that were the effects of being established during the food shortage years 2007 or 2010 (5.627, p < 0.01) and distance to the nearest horse property (0.999, p < 0.01).

These preliminary results seem to fall in step with observations made in the field. Peggy Eby, one of the leading experts on the Hendra system, theorizes camps formed during a food shortage, continuously occupied, and close to horse properties are likely to be drivers of Hendra virus spillover. These propositions make sense biologically as well. Camps that are established during a food shortage have bats that are malnourished and unhealthy. Unhealthy organisms have weaker immune systems and more likely to shed viruses into the environment. Camps that are continuously occupied are likely to be in areas with high concentrations of human-provisioned food sources. The native food sources of flying foxes have boom and bust cycles, and historically camps would migrate across the landscape following these pulses. However, despite being less nutritious, fruit-bearing trees tended to by humans are more consistent than their native counterparts and flying foxes seem to be aggregating to these places and staying for longer periods of time. In sum, long-term aggregations of unhealthy bats in areas near livestock and humans should arguably be considered a genuine public health risk for the people of Australia.

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