*Epidemiology & Infection*

**Predicting arboviral disease emergence using Bayesian networks: a case study of dengue virus emergence in Western Australia**

S. H. Ho, P. Speldewinde, A. Cook

**Supplementary Material**

**Table A1:** Spatial data and sources

|  |  |  |  |
| --- | --- | --- | --- |
| **Spatial Data** | **Source Map** | **Agency (release data)** | **Ref** |
| **Transport features** | | | |
| **Railway lines** | Global Map Australia 1M | National Mapping Division, Geoscience Australia (July 2004) | 23 |
| **Road lines** | Global Map Australia 1M | National Mapping Division, Geoscience Australia (July 2004) | 23 |
| **Seaports** | Ports map, in Overlays (contextual) for use with MCAS-S Version 3 software | Multi-Criteria Analysis Shell for Spatial (MCAS-S) Decision Support Version 3 : DATA - 2011; ABARES, Department of Agriculture (October 2011) | 24 |
| **Major airports** | Coordinates of four major WA airports serving international and/or Queensland routes were obtained and mapped on ArcGIS | | - |
| **Human population features** | | | |
| **Urban areas** | Section of State (SOS) ASGS Edition 2011 Digital Boundaries in ESRI Shapefile Format | Australian Bureau of Statistics  (October 2012) | 25 |
| **Rural settlements** | Global Map Australia 1M | National Mapping Division, Geoscience Australia (July 2004) | 23 |
| **CLIMATIC FEATURES** | | | |
| **Mean air temperature** | Average seasonal maximum, minimum, & mean temperature (1961 – 1990) | Climate Data Online, Bureau of Meteorology, Australia (Current) | 22 |
| **Mean total rainfall** | Average seasonal rainfall (1961 - 1990) | Climate Data Online, Bureau of Meteorology, Australia (Current) | 22 |
| **Mean relative humidity (3pm)** | Average seasonal 3pm relative humidity (1976 - 2005) | Climate Data Online, Bureau of Meteorology, Australia (Current) | 22 |
| **Vector climatic niches** | | | |
| ***Ae. aegypti*** | Climatic niche modeled using MaxEnt | | - |
| ***Ae. albopictus*** | Ecoclimatic Index map of potential *Ae. albopictus* distribution throughout Australia | Russell, et al. Commun Dis Intell Q Rep. 2005; 29(3): 296 – 8 | 5 |

**A detailed description of the risk model**

**Part A: ‘Endemicity’ risk**

This part models the overall risk of *Aedes aegypti*, *Ae. albopictus*, and dengue virus (DENV) becoming established/endemic to Western Australia (WA). It integrates the predicted climatic niches of the two vectors with the size of the human population, the density of the transport network, and the frequency of DENV introduction. The tables below show how the conditional probability tables (CPTs) of all ‘child’ nodes were populated by a points-based system developed specifically for this project [see *1*].

**Table A2:** Points of parent node states of **Transport\_Connectivity**.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Railway\_Density** | | **Seaport\_Nearby** | | **Airport\_Nearby** | | **Road\_Density** | |
| **High** | 3 | **Yes** | 3 | **Yes** | 3 | **High** | 3 |
| **Medium** | 2 | **No** | 0 | **No** | 0 | **Medium** | 2 |
| **Low** | 1 |  | |  | | **Low** | 1 |
| **Zero** | 0 | **Zero** | 0 |
| \* Every transportation mode was assigned equal influence on the posterior distribution of **Transport\_Connectivity**.  \* The maximum score for this node was limited to 3 (i.e. as long as a seaport/airport is present, or the density of roads/railways is high, then **Transport\_Connectivity** = **High**.    *Illustrative calculation (double-underlined states):*  *Total score in this example = 2+3+0+3 = 8*  *Since maximum possible score = 3, and the total score cannot exceed it, the score in this example is taken to be equal to 3.*  *Scaled score = 3/3\*100 = 100%*  *The probability distribution of* ***Transport\_Connectivity*** *states was then interpolated from a predefined table.* | | | | | | | |

\*\*N.B.: For such CPTs, it is not the absolute magnitude of the points that is of concern. Rather, what is important is the size of the points relative to other parent node states.

**Table A3:** Points of parent node states of **Human\_Popn\_Density**.

|  |  |  |  |
| --- | --- | --- | --- |
| **Settlements\_Density** | | **Urban\_Areas\_per\_Grid** | |
| **High** | 6 | **High** | 9 |
| **Medium** | 4 | **Medium** | 6 |
| **Low** | 2 | **Low** | 3 |
| **Zero** | 0 | **Zero** | 0 |
| \* Greater weight was assigned to urban populations to reflect the importance of urban environments as habitats for *Aedes* mosquitoes.  \* The maximum score for this node was limited to 9, i.e., as long as the magnitude of urban areas is high, then the human population density at that location is considered **High**.  *Illustrative calculation (double underlined states):*  *Total score = 4+6 = 10*  *Since maximum possible score is 9, the score in this example is the maximum score (9).*  *Scaled score = 9/9\*100% = 100%*  *Probability distribution of* ***Human\_Popn\_Density*** *states was subsequently interpolated from a predefined table.* | | | |

**Table A4:** Points of parent node states of **Likelihood\_of\_vector\_intro**.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Ae\_aegypti\_**  **climatic\_niche** | | **Ae\_albopictus\_**  **climatic\_niche** | | **Transport\_Connectivity** | | **Human\_Popn\_Density** | |
| **Yes** | 3 | **Yes** | 3 | **Very\_High** | 3 | **Very\_High** | 3 |
| **No** | 0^ | **No** | 0^ | **High** | 2 | **High** | 2 |
|  | |  | | **Medium** | 1 | **Medium** | 1 |
| **Low** | 0 | **Low** | 0 |
| **Very\_Low** | \* | **Very\_Low** | \* |
| \* For this node, the maximum score = 3+3+3+3 = 12.  \* **Likelihood\_of\_vector\_intro** = 100% **Very\_Low**, regardless of all other parent node states, if **Transport\_Connectivity** and **Human\_Popn\_Density** take these states.  ^ If the states of both climatic niches are **No**, then **Likelihood\_of\_vector\_intro** = 100% **Very\_Low**, regardless of all other parent node states. | | | | | | | |

**Table A5:** Points of parent node states of **Likelihood\_of\_virus\_intro**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Likelihood\_of\_vector\_intro** | | **Freq\_DENV\_Intro** | | **Human\_Popn\_Density** | |
| **Very\_High** | 3 | **Above\_Average** | 2 | **Very\_High** | 3 |
| **High** | 2 | **Average** | 1 | **High** | 2 |
| **Medium** | 1 | **Below\_Average** | 0 | **Medium** | 1 |
| **Low** | 0 |  |  | **Low** | 0 |
| **Very\_Low** | \* |  |  | **Very\_Low** | \* |
| \* **Likelihood\_of\_virus\_intro** = 100% **Very\_Low** regardless of all other parent node states. | | | | | |

**Table A6:** Points of parent node states of **DENV\_Endemic\_Risk**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Likelihood\_of\_vector\_intro** | | **Likelihood\_of\_virus\_intro** | | **Human\_Popn\_Density** | |
| **Very\_High** | 3 | **Very\_High** | 3 | **Very\_High** | 3 |
| **High** | 2 | **High** | 2 | **High** | 2 |
| **Medium** | 1 | **Medium** | 1 | **Medium** | 1 |
| **Low** | 0 | **Low** | 0 | **Low** | 0 |
| **Very\_Low** | \* | **Very\_Low** | \* | **Very\_Low** | \* |
| \* **DENV\_Endemic\_Risk** = 100% **Low**, regardless of all other parent node states. | | | | | |

**Part B: ‘Infection’ Risk**

This part models the risk of a dengue outbreak occurring at a particular location, if the vector(s) and virus have become established.

The state of **DENV\_Infection\_Risk** was restricted by the state of **DENV\_Endemic\_Risk**, because being downstream of the latter node, it should not have a state that exceeds the state of its parent (i.e. a situation where the infection risk = **High** while the endemic risk = **Medium** or **Low**).

**Table A7a:** Restriction of **DENV\_Infection\_Risk** by **DENV\_Endemic\_Risk.**

|  |  |  |  |
| --- | --- | --- | --- |
| **DENV\_Endemic\_Risk** | **DENV\_Infection\_Risk** | | |
| **High** | **Medium** | **Low** |
| **High** | √ | √ | √ |
| **Medium** |  | √ | √ |
| **Low** |  |  | √ |

**Table A7b:** Points of the other parent node states of **DENV\_Infection\_Risk**.

|  |  |
| --- | --- |
| **Potential\_Transmitting\_Vectors** | |
| **Very\_High** | 4 |
| **High** | 3 |
| **Medium** | 2 |
| **Low** | 1 |
| **Very\_Low** | 0 |

**Table A8:** Points of parent node states of **Potential\_Vector\_Popn\_Size**.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Seasonal\_Air\_Temperature** | | **Seasonal\_Rainfall** | | **Relative\_Humidity\_3pm** | |
| **Below\_15C** | \* | **Below\_50mm** | 0 | **From\_0\_to\_30** | 0 |
| **From\_15\_to\_18C** | 0 | **From\_50\_to\_100mm** | 4 | **From\_30\_to\_60** | 4 |
| **From\_18\_to\_21C** | 2 | **Above\_100mm** | 8 | **From\_60\_to\_100** | 8 |
| **From\_21\_to\_24C** | 4 |  | | | |
| **From\_24\_to\_27C** | 6 |
| **From\_27\_to\_30C** | 8 |
| **From\_30\_to\_33C** | 6 |
| **From\_33\_to\_36C** | 2 |
| **From\_36\_to\_39C** | \* |
| **Above\_39C** | \* |
| \* **Potential\_Vector\_Popn\_Size** = 100% **Very\_Low**, regardless of any other parent node’s state. This was based on results obtained by [*2*], which showed that the population growth rate of *Ae. aegypti* is positive between 14oC and 36oC.  \* The literature contains conflicting reports regarding the influence of rainfall and *Aedes* population size, which could be because *Ae. aegypti* is a peridomestic species that often thrives in artificial containers, amongst other factors. Here, we prefer to include a rainfall effect, with vector populations increasing with higher quantities of precipitation. A Queensland study showed that monthly rainfall between 0 and 200mm is positively correlated with locally acquired DENV infections [*3*].  \* The influence of relative humidity on mosquito population size is well-established [e.g. *4*, *5*]. | | | | | |

**Table A9:** Points of parent node states of **F\_Adult\_Lifespan**.

|  |  |  |  |
| --- | --- | --- | --- |
| **Relative\_Humidity\_3pm** | | **Seasonal\_Air\_Temperature** | |
| **From\_0\_to\_30** | 0 | **Below\_15C** | \* |
| **From\_30\_to\_60** | 4 | **From\_15\_to\_18C** | 6 |
| **From\_60\_to\_100** | 8 | **From\_18\_to\_21C** | 6 |
|  | | **From\_21\_to\_24C** | 8 |
| **From\_24\_to\_27C** | 8 |
| **From\_27\_to\_30C** | 6 |
| **From\_30\_to\_33C** | 4 |
| **From\_33\_to\_36C** | 2 |
| **From\_36\_to\_39C** | 0 |
| **Above\_39C** | \* |
| \* **F\_Adult\_Lifespan** = 100% **Unsuitable\_Temp**, regardless of the state of **Relative\_Humidity\_3pm**.  \* The effect of air temperature on vector population survival was estimated from [*6*]. | | | |

**Table A10:** Points of parent node states of **EIP** (extrinsic incubation period).

|  |  |
| --- | --- |
| **Seasonal\_Air\_Temperature** | **EIP** |
| **Below\_15C** | Above\_20\_days |
| **From\_15\_to\_18C** | Above\_20\_days |
| **From\_18\_to\_21C** | From\_10\_to\_20\_days |
| **From\_21\_to\_24C** | From\_10\_to\_20\_days |
| **From\_24\_to\_27C** | From\_10\_to\_20\_days |
| **From\_27\_to\_30C** | From\_0\_to\_10\_days |
| **From\_30\_to\_33C** | From\_0\_to\_10\_days |
| **From\_33\_to\_36C** | From\_0\_to\_10\_days |
| **From\_36\_to\_39C** | From\_0\_to\_10\_days |
| **Above\_39C** | From\_0\_to\_10\_days |
| \* The influence of air temperature on DENV’s extrinsic incubation period was estimated from [*7*]. | |

**Table A11a:** Restriction of **Potential\_Transmitting\_Vectors** by **Potential\_Vector\_Population\_Size.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Potential\_Vector\_Population\_Size** | **Potential\_Transmitting\_Vectors** | | | | |
| **Very\_High** | **High** | **Medium** | **Low** | **Very\_Low** |
| **Very\_High** | √ | √ | √ | √ | √ |
| **High** |  | √ | √ | √ | √ |
| **Medium** |  |  | √ | √ | √ |
| **Low** |  |  |  | √ | √ |
| **Very\_Low** |  |  |  |  | √ |

**Table A11b:** Points of parent node states of **Potential\_Transmitting\_Vectors**, excluding **Potential\_Vector\_Population\_Size**.

|  |  |  |  |
| --- | --- | --- | --- |
| **F\_Adult\_Lifespan** | | **EIP** | |
| **Very\_Long** | 10 | **From\_0\_to\_10\_days** | 10 |
| **Long** | 9 | **From\_10\_to\_20\_days** | 8 |
| **Medium** | 8 | **Above\_20\_days** | 6 |
| **Short** | 7 |  | |
| **Very\_Short** | 6 |
| **Unsuitable\_Temp** | \* |
| \* **Potential\_Transmitting\_Vectors** = 100% **Very\_Low**, regardless of any other parent node state. | | | |

**References:**

1. Ho SH, Speldewinde P, Cook A. A Bayesian belief network for Murray Valley encephalitis virus risk assessment in Western Australia. *International Journal of Health Geographics*. 2016 Jan 28;15:6. doi: 10.1186/s12942-016-0036-x.
2. Yang HM, Macoris ML, Galvani KC, Andrighetti MT, Wanderley DM. Assessing the effects of temperature on the population of *Aedes aegypti*, the vector of dengue. *Epidemiology & Infection*. 2009 Aug; 137: 1188 – 1202. doi: 10.1017/S0950268809002040.
3. Hu W, Clements A, Williams G, Tong S, Mengersen K. Spatial patterns and socioecological drivers of dengue fever transmission in Queensland, Australia. *Environmental Health Perspectives*. 2012 Feb; 120: 260 – 266. doi: 10.1289/ehp.1003270.
4. Azil AH, Long SA, Ritchie SA, Williams CR. The development of predictive tools for pre-emptive dengue vector control: a study of *Aedes aegypti* abundance and meteorological variables in North Queensland, Australia. *Tropical Medicine & International Health*. 2010 Oct; 15: 1190 – 1197. doi: 10.1111/j.1365-3156.2010.02592.x.
5. Yamana TK, Eltahir EA. Incorporating the effects of humidity in a mechanistic model of *Anopheles gambiae* mosquito population dynamics in the Sahel region of Africa. *Parasites & vectors*.2013 Aug 9; 6: 235. doi: 10.1186/1756-3305-6-235.
6. Brady OJ, Johansson MA, Guerra CA, Bhatt S, Golding N, Pigott DM, et al. Modelling adult *Aedes aegypti* and *Aedes albopictus* survival at different temperatures in laboratory and field settings. *Parasites & vectors*. 2013 Dec 12;6: 351. doi: 10.1186/1756-3305-6-351.
7. Tjaden NB, Thomas SM, Fischer D, Beierkuhnlein C. Extrinsic incubation period of dengue: knowledge, backlog, and applications of temperature dependence. *PLoS Neglected Tropical Diseases*. 2013 Jun 27; 7: e2207.