An Excel Spreadsheet Tool for Exploring the Seasonality of *Aedes* Vector Hazard for User-Specified Administrative Regions of Brazil

Desmond H. Foley, PhD
David B. Pecor, BS

Abstract

Aedes-vectored viruses are a major concern for active-duty military personnel working in South and Central America at certain times of the year. Knowledge about the seasonal changes of vector activity is important as it informs time-sensitive vector control, prophylaxis, and travel decisions. To assist in-country and extralimital efforts to anticipate when vector hazards and the risks of transmission are highest, we developed an Excel spreadsheet tool that uses published monthly habitat suitability models to display various aspects of average *Aedes* seasonality for user-defined second order administrative areas of Brazil. This tool expands on those previously developed by the authors for the contiguous United States, with the aim of translating global habitat suitability models into user-friendly formats to provide actionable intelligence for areas of interest.

The risks to military personnel deployed to the US Southern Command (SOUTHCOM) countries from *Aedes* vectored viruses such as chikungunya (CHIKV), dengue (DENV), yellow fever (YFV), and Zika (ZIKV) should not be underestimated. A recent study[1] found active-duty travelers and those visiting friends and relatives among US Department of Defense (DoD) beneficiaries travelling to chikungunya-outbreak regions in the Americas had a composite attack rate for CHIKV, and DENV infection of 3.7%. The authors point out the risk of returning travelers with subclinical infections causing secondary transmissions in nonendemic regions (contiguous United States), and the importance of pretravel counseling to ZIKV-outbreak regions due to the shared vector, *Aedes aegypti* (L.) of CHIKV, DENV, YFV and ZIKV. Although *Ae. albopictus* (Skuse) is thought to be a competent vector of ZIKV,[2] *Ae. aegypti* has been implicated as the primary transmitter of the virus in human populations in the recent outbreak in the Americas.[3,4]

In response to the 2016 World Health Organization declaration of a public health emergency of international concern over ZIKV linked disease, the Walter Reed Biosystematic Unit produced MS Excel tools (http://vectormap.si.edu/Project_ESWG_ExcelZika.htm) that use published average yearly habitat suitability models and average monthly temperature data to predict the timing of *Aedes* vector hazards for contiguous United States (CONUS) military facilities.[5] Excel-based tools were constructed to assist entomologists and other health personnel understand whether ZIKV transmission is likely to occur at a location and when they should conduct vector surveillance and control. Foley and Pecor[5] concentrated on DoD facilities but emphasized that the approach could be used with any habitat suitability models and for any area of interest. The ability to incorporate near real-time and forecast temperature data improved accuracy in the short term compared to the use of average monthly temperature data, which were more suited for longer term planning.

For tropical areas compared to temperate ones, temperature is less dominant among climatic drivers of intra-annual changes in mosquito suitability, which limits the applicability of the approach of Foley and Pecor[5] for many areas of SOUTHCOM. However, the availability of recently published global monthly habitat suitability models for *Ae. aegypti* and *Ae. albopictus*[6] presents an opportunity to extend to new areas our approach for providing vector hazard seasonality data.

Bugoch et al[6] used monthly climatic suitability models for autochthonous transmission of ZIKV around the world, conditional on the predicted occurrence of competent *Aedes* mosquito vectors. To account for seasonal variation in the geographical range of ZIKV suitability, they produced maps for each month of the year. They used mosquito species distribution models for *Ae. aegypti* and *Ae. albopictus*[7] (originally fitted to annual data and covariates) to make monthly predictions by use of new monthly covariates for temperature-persistence suitability,[8] relative humidity, and precipitation. They refined these seasonal maps by scaling their values so that the sum of all monthly maps equaled the annual mean map of Kraemer et al.[9] Final global monthly vector maps show predictions of areas with high likelihood for observation or detection of mosquito populations, which were assumed to be sufficiently abundant to enable transmission of vector-borne diseases to humans.

The extended Figure 6 in the article by Faria et al[10] shows the 12-monthly suitability maps for ZIKV transmission of Bugoch et al[6] for the Americas. Faria et al[10] used linear regression to find that, for each Brazilian region, there was a strong association between estimated climatic suitability and weekly Zika notified cases (adjusted $R^2>0.84$, $P<.001$). They also found that, similar to previous findings from DENV outbreaks, notified ZIKV cases lag climatic suitability by about 4 to 6 weeks in all regions, except northeast Brazil, where no time lag was evident.

In this article, we demonstrate the potential utility of global monthly habitat suitability models to explore *Aedes* seasonality for administrative areas of Brazil. Building on our experience with the Excel user interface developed for CONUS military facilities, we designed a tool that shows the intensity of *Aedes* hazard at any time point throughout the year.

Materials and Methods

Twelve monthly raster layers of 0.04166665 degrees resolution were obtained for *Ae. aegypti* habitat suitability.[6,9,10]

We used the Global Administrative Areas (GADM) v 2.8* Administrative regions 2nd order administrative level polygons for Brazil, but some editing of the file was necessary before use. Some names were used multiple times so it was necessary to create a field in ArcMap 10.4 (Environmental Systems Research Institute, Redmond, CA) that concatenated Admin 1 (State) and 2 (District) so that each row in the feature table had a unique name combination. Of a total of 5,505 polygons, 8 were outlying islands (Espírito Santo_Ilha Trindade, Espírito Santo_Ilhas de Martim Vaz), and others incompletely overlapped the raster coverage (Bahia_Madre de deus, Minas Gerais_Santa Cruz de Minas, Rio Grande do Norte_Fernando de Noronha, Rio Grande do Sul_Capela de Santana, Santa Catarina_Floriniapolis, São Paulo_Suzanápolis). These were not considered further in the analysis. Santa Catarina_Florianópolis, which is comprised of a peninsula and nearby island are present in GADM as 2 polygons; the island (Florianopolis) and the mainland portion (Floriniapolis [note difference in spelling]).

*http://www.gadm.org/

We created a point layer from the polygon layer by using Data Management Tools>Features>Feature to Point tool and added longitude and latitude to the points by using Data Management Tools>Features>Add XY Coordinates. For the XY coordinates of centroids, the island row was selected and the mainland XY was deleted. However, for the population analysis (LandScan) data from the 2 polygons were combined. Other issues involved the need to aggregate some polygons and correct the names of several others. Extraction of all administrative area centroid raster values (ie, average values) was first obtained for polygons using the Zonal statistics as Table tool and, where needed, the Extract values to points tool. This approach was needed because smaller polygons would not produce results using the Zonal statistics as Table tool, which necessitated using the raster data associated with the points for these facilities administrative areas. We used the human population density according to LandScan 2011.† This was accomplished using the summary output in the Zonal Statistics as Table tools in ArcMap.

Seasonality: Ranking

Seasonality can be presented as a graph of the 12-month pattern of habitat suitability, abundance, etc. Interpretation and comparison of the pattern in one area to other areas can be subject to human error, due to variation in the y-axis, which may mask the underlying pattern. For this reason, we explored the use of rank and related metrics to define important aspects of seasonality for use in semiautomated calculations of vector hazard. For sites that exhibit a seasonal pattern in *Ae. aegypti* habitat suitability, monthly data were standardized by ranking (1 to 12) in Excel (RANK.EQ) to allow comparison within and among areas of interest, both in terms of the relative suitability and the direction (rise=1, fall=-1) of change in suitability with the next time period. Ideally, metrics automatically derived from the rank should inform the user that for the month in question, suitability scores are near the annual peak or lowest point, scores are set to increase or decrease, or scores are moving in

†LandScan 2011. People/1 sq km. This product was made using the LandScan (2011) High Resolution Global Population Data Set, the copyright to which is held by UT-Battelle, LLC, which operates the Oak Ridge National Laboratory under contract to the US Department of Energy. The US Government has certain rights in the data set. Neither UT-Battelle, LLC, nor the US Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of the data set. Information about LandScan is available from the Oak Ridge National Laboratory at: http://www.ornl.gov/sci/landscan/.

a certain direction. Scores derived for one location can readily be contrasted with those from another.

Average habitat suitability values were calculated for 2 consecutive months to create finer temporal resolution (2 weeks) that were ranked (1 to 24). In addition to rank (1 to 24) and rise/fall (1, -1), we constructed metrics that measured accumulated rise/fall values, to show the duration of the rise and fall extending into the future (future trend or forecast) and the past (past trend or hind cast). We scored a rise as 1 and a no rise as -1, and considered that if change in rank was unidirectional, the rise/fall value would be the same as the preceding rise/fall value.

Instances where a plateau or trough was present can be disguised by the ranking process, due to the exaggeration of minor differences in values. One solution was to round up suitability values to three decimal places to tie the ranks of similar scores. Equal Rank ascending in Excel sometimes resulted in the maximum being less than 24 due to tied ranks. To address this, we calculated the maximum rank in a separate column and changed the highest rank values to 24. This had the effect of exaggerating the jump in rank to the maximum of 24 in a minority of cases, but simplified the identification of peaks and troughs. Figure 1 displays an idealized seasonal pattern of rank values with 6 important points in a typical seasonal cycle and the output for various metrics.

Seasonality: Multivariate Analysis

To help visualize seasonality spatially, we created Interpolated surfaces (Spatial Analyst Tools>Interpolation>Kriging) for the rank of each month (12 months) using the point shapefile for each second order administrative area, and then created a mask around each point of 100 km (Analysis Tools>Proximity>Buffer), with all buffers dissolved together. Then we clipped interpolated surfaces by the mask (Spatial Analyst Tools>Extraction>Extract by Mask), and created a 3-band (red, green, blue) principle component layer summarizing the 12 interpolated surfaces to give a summary of the yearly seasonal pattern (Spatial Analyst Tools>Multivariate>Principle Components). We also developed iso clusters (Spatial Analyst Tools>Multivariate>Iso Cluster Unsupervised Classification) based on 2 and 6 classes for the 12 interpolated surfaces, then conducted zonal statistics for these iso clusters on the original 12 monthly habitat suitability models. The overlay map show the 5 regions described in Faria et al,[10] the outlines of the states, and the color-coded *Aedes* seasonality map for Brazil. The graphics capabilities are discussed further in the Seasonality Graphics Presentations section on page 25.

Results

An Excel tool was constructed (Figure 2) with the following components:

User Controlled Inputs

These comprise drop-down lists and dependent drop-down lists:

- Select State
- Select District
- Select Date

Automatically Generated Values

Aedes hazard this date: The more red that extends to the right, the higher the *Aedes* hazard at that location during the user-defined time period. The sum of the 12-month values equals the yearly hazard value. Bars indicate the probability of mosquito occurrence (0-1.0).

Annual *Aedes* hazard this place: The more red that extends to the right, the higher the *Aedes* hazard at that location across the whole year. Bars indicate the probability of mosquito occurrence (0-1.0).

Rank this date (1 low, 24 high): The rank from the lowest *Ae. aegypti* probability (=1) to the highest (=24) for each of 24 two-week periods for the particular location selected.

Maximum rank this location: The maximum rank over 24 two-week periods for the particular location selected. Note that maximum rank can be less than 24 due to tied scores.

Future trend (rising 1, falling -1): Is the *Ae. aegypti* probability going to rise (1) or fall (-1) in the next 2-week period? Stationary values do not change the prevailing score.

Past trend (hind cast): Ascending number of consecutive times that the probability of *Ae. aegypti* has risen (positive) or fallen (negative) as time advances, eg, “12” means that the following period will be the 12th successive time that values have increased, and -2 means that the following period will be the second successive time that values have decreased. Flat (zero trend) periods are counted as a continuation of the prevailing trend.

Future trend (forecast): Descending number of consecutive times that the probability of *Ae. aegypti* is predicted to rise (positive) or fall (negative) as time advances, eg, “1” means that 1 successive period of rising values is predicted to occur, -12 means that 12 successive periods of falling values are predicted to occur. Flat (zero trend) periods are counted as a continuation of the prevailing trend.

Vector Hazard score (0-1.0): (Rank)/(Maximum rank) × (Annual *Aedes* hazard for the district chosen)

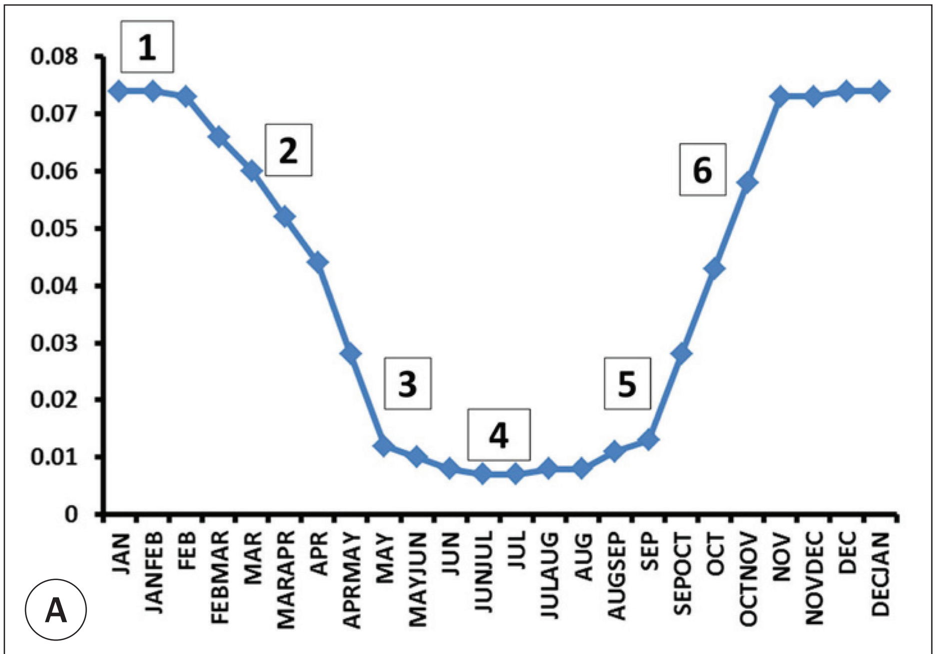
In theory, this scale could range from 0 to 1.0 based on the highest rank of vector distribution and activity throughout the year at the location of interest. Users should not rely solely on this metric to assess hazard.

Area (sq km): Area of the second order administrative region.

Number of people: Estimated number of people within the second order administrative region according to Landscan.

Average density of people (sq km): Average density of the second order administrative region derived from Landscan.

Control advice: A text description of where in the seasonal cycle of *Aedes* hazard this time and place represents. Warning: text advice is based on changes in rank, which can result in unexpected results. For example, although probability may change over time in a minor way, as in the off-season, this will be translated to different ranks, which can exaggerate the perception of change and lead to spurious advice. The user is advised to always consult the accompanying graph to gauge the veracity of the automated advice. Advice for each position of the cycle can be tailored by editing contents of cells EJ17:EJ24.



B

	Date point					
	1	2	3	4	5	6
Rank this date (1 low, 24 high)	24	16	8	1	9	18
Maximum rank this location	24	24	24	24	24	24
Future trend (rising 1, falling -1)	1	-1	-1	-1	1	1
Past trend (hindcast)	13	-4	-8	-11	5	9
Future trend (forecast)	1	-8	-4	-1	9	5
Vector Hazard score (0 - 1.0)	0.49	0.33	0.16	0.02	0.18	0.37

Figure 1. Typical seasonal pattern of modelled Aedes probability over a year divided into 2 week periods for Espírito Santo-Alfredo Chaves, Brazil. Section A: Boxed numbers indicate important date points in this seasonal pattern, as described in the text. Section B: Outputs for various metrics for the 6 date points shown in section A.

Possible advisory warnings that could be triggered for the 6 time periods shown in Figure 1 include:

1. *Aedes* hazard is at the highest expected level for this location. Maximize vector control and community education.
2. *Aedes* hazard is high for this location but falling. Maintain vector control and community education.
3. *Aedes* hazard is near a low point (could be more than one) for this location. Minimize vector control and community education. Be aware that peak in cases can lag peak in vectors.
4. *Aedes* hazard is the lowest for this location. Prepare for scaling up vector control.
5. *Aedes* hazard is starting to rise for this location. Initiate vector control and community education.
6. *Aedes* hazard is near a high point for this location. Maximize vector control and community education.

Further refinement of these advisory warnings should include consultation with vector control and public health personnel.

Seasonality Graphics Presentations

In addition, Figure 2 presents a graph which displays the seasonal pattern in *Aedes* suitability (blue line) and the time period selected (red line), and a map of Brazil with the location of the administrative region selected. Figure 3 shows the results of clustering *Aedes* seasonality into 2 and 6 clusters and according to the first 3 principal components (PCs). With 2 iso clusters, Brazil is divided into a northern cluster and a geographically larger southern cluster. The northern cluster shows a peak in March to April and a trough in July to December, while the southern cluster peaks in December to March and exhibits a pronounced trough in May to September. With 6 iso clusters, the northeastern region shows a more complicated pattern for Brazil. Mean monthly values for each cluster are shown in Figure 3. The continuous PC map shows the most complicated pattern.

The Excel file for Brazil is freely available via the VectorMap website, http://vectormap.si.edu/.

Comment

Knowledge of vector seasonality is powerful intelligence about when vector to human contact is expected, thereby providing clarity on the timing of vector hazard and disease transmission risk. In this article, we demonstrate the potential utility of global habitat suitability models to predict *Aedes* (*Ae. aegypti*) seasonality for administrative areas of Brazil. We created a simple Excel spreadsheet interface that calculates metrics and displays various aspects of seasonality for hazard and risk assessment for *Ae. aegypti* vectored diseases such as dengue, chikungunya, yellow fever, and Zika. We believe that this approach adds value to monthly habitat suitability models by allowing a wide variety of users to explore seasonal patterns for any area of interest. Knowledge about the seasonal changes in vector hazard is important as it informs time-sensitive vector control, prophylaxis, and travel decisions.

Faria et al[10] found that, for each Brazilian region, there was a strong association between estimated climatic suitability and weekly Zika notified cases and that notified ZIKV cases lag climatic suitability by about 4-6 weeks in all regions, except northeast Brazil, where no time lag was evident. The observation that *Aedes* seasonality iso clusters (Figure 3) are most diverse in northeast Brazil may account for the absence of lag, for example, if transmission occurred in iso clusters 3, 5 or 6 that experience earlier suitability for *Aedes,* cases may appear around the time of peak suitability for the other iso cluster areas.

This tool could be extended for other areas of interest where a polygon or point feature delimiting the area is available. The authors are currently exploring extending this tool to other countries such as Colombia, Puerto Rico, and Thailand. If monthly models of habitat suitability or abundance for *Ae. aegypti* or other vector species become available, these can be used with the current Excel interface.

There are a number of limitations with our approach, a few of which are discussed herein: As the primary outputs of the zonal statistics used here were mean values, areas of interest should not be too large, or cover topologically diverse areas, as the range of values can show high diversity not adequately captured in the mean. Ideally, areas should show a clear seasonal pattern, as areas that are not suitable for the vector or have uniformly low

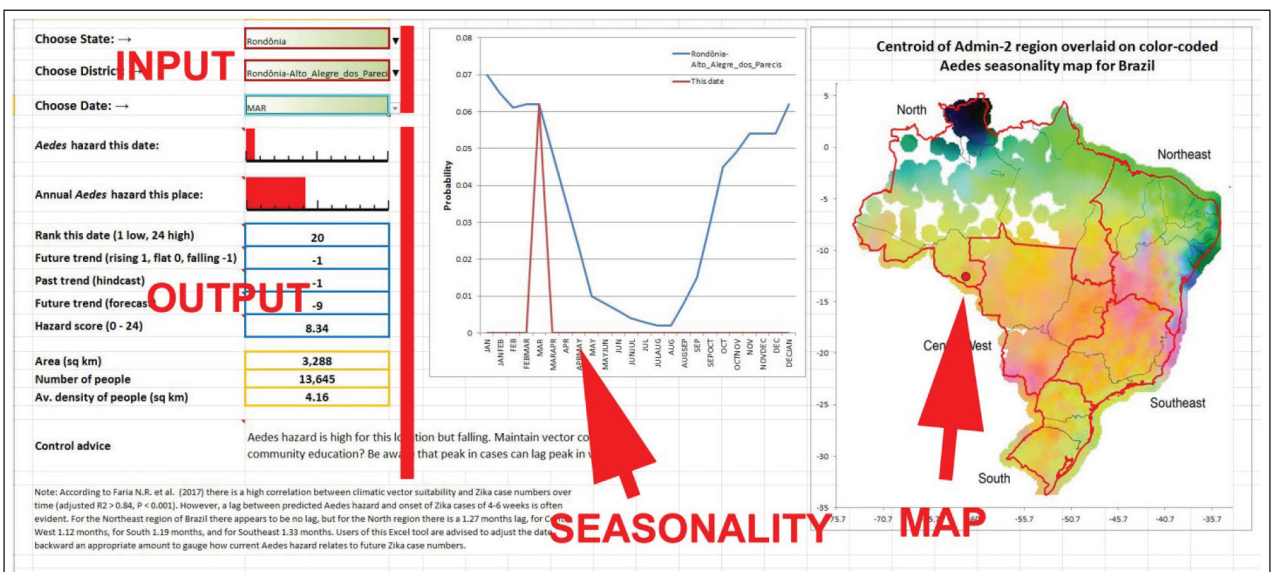


Figure 2. Output sheet for the Brazil *Aedes*/Zika Excel tool showing (left) inputs for location and date and outputs; (center) output line chart; and (right) map of Brazil with location.

or high suitability will give spurious results for the metrics that rely on ranking used here. The use of ranks can introduce a false sense of seasonal change and should always be considered alongside the actual values; the graph of change in habitat suitability values in the tool is provided for this purpose. Auto generated textualized suggestions regarding response to the position in the annual seasonal cycle of vector hazard is an aspect of this tool under development and the user should show caution in following these suggestions. The seasonal predictions are only as good as the model underpinning this tool; the current model may not accurately show what happens in future years. The relationship of vector habitat suitability to disease risk is not always obvious and appears to vary depending on the region. In addition, consideration of lag and congenital Zika syndrome should take into consideration the full 9 months of pregnancy. Users of this Excel tool are advised to adjust the date backward an appropriate amount to gauge how past *Aedes* hazard relates to current Zika case numbers. Finally, ZIKV can be imported and spread by nonvector transmission routes (eg, sexual transmission[13]), so a level of caution is recommended when trying to relate vector hazard with disease risk.

Our aim was to create an easy to use interface between monthly vector habitat suitability models and areas of interest for those lacking the time and skills to use learn and deploy GIS software. Ideally, this platform would be made available via a web-based interface. However, many users need to access this tool in austere environments where internet connectivity is unreliable or completely unavailable. The MS Excel-based platform can be downloaded before deployment and run on any laptop or desktop computer without the need for an internet connection. The Excel tool we developed is an accessible and adaptable platform for entomological decision-making that makes use of readily available data and models. As a new model becomes available, it can be easily incorporated into this tool. Validation of the output from this tool using mosquito surveillance results, and obtaining user feedback, would be useful goals for future research.

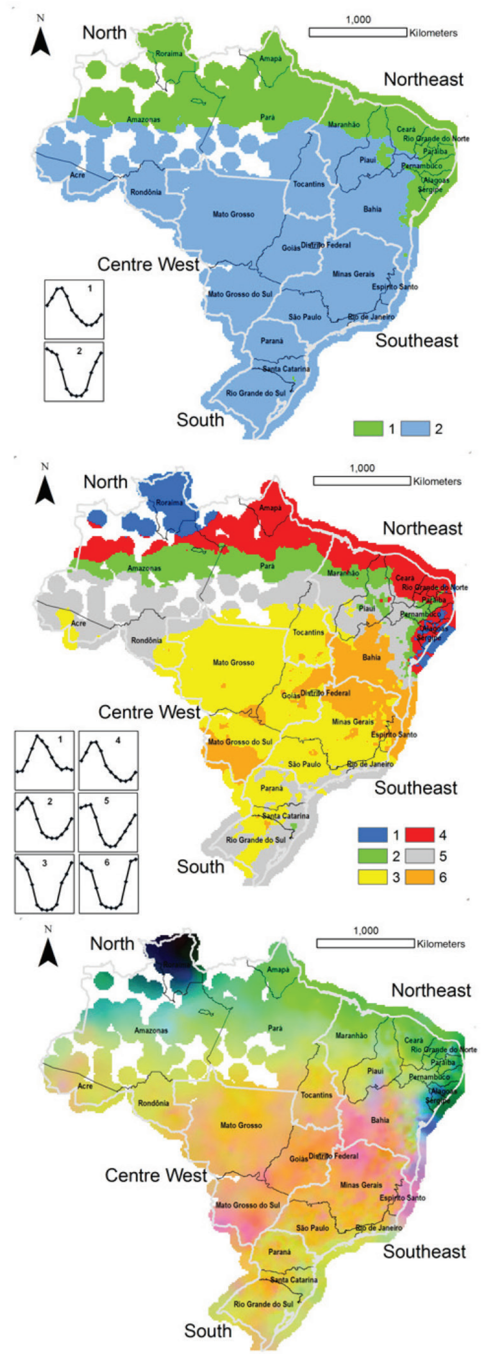


Figure 3. *Aedes aegypti* seasonality for second order administrative regions of Brazil reduced to 2 iso clusters, 6 iso clusters, and 3 (red, green, blue) principal components. Note the mean seasonality (probability per month) as graph for each iso cluster.

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Authors

Dr Foley is a Research Entomologist at the Walter Reed Biosystematics Unit, Entomology Branch, Walter Reed Army Institute of Research, and a Research Associate of the Entomology Department within the National Museum of Natural History, located at the Smithsonian Institution, Museum Support Center, Suitland, Maryland.

Mr Pecor is a Research Technician at the Walter Reed Biosystematics Unit, Entomology Branch, Walter Reed Army Institute of Research, located at the Smithsonian Institution, Museum Support Center, Suitland, Maryland.

Aedes aegypti (courtesy of the CDC)

Aedes albopictus (courtesy of the CDC)