

Rift Valley Fever Modeling and Vulnerability Analysis

DHS Priority Areas Addressed	<input checked="" type="checkbox"/> Prevention <input type="checkbox"/> Detection <input checked="" type="checkbox"/> Response <input type="checkbox"/> Recovery <input type="checkbox"/> Education/Risk Communication				
Proposal Section Addressed	Sections 5.1.2 and 5.3.3				
Investigators	U of MD: David Hartley (at Georgetown University since 15 April)				
Objectives	Deliverables	Progress Toward Deliverables	Percent Complete		
Develop and refine geospatial model of Rift Valley fever transmission and spread	Model design document for aspatial outbreak model	In the first year of the project an aspatial model was researched, developed, and analyzed. The result was a biologically-informed dynamical model of RVF that produces temporal estimates of the number of vectors and hosts infected & infectious with, and immune & susceptible to, RVF virus. Data was gathered to produce model parameter estimates. Important gaps in the data available to make these estimates were identified. The result of the development process was the production of a first-time model of this disease. This model, and analysis thereof, was published in the peer-reviewed literature recently (Holly D. Gaff, David M. Hartley, Nicole P. Leahy; An epidemiological model of Rift Valley fever, Electron. J. Diff. Eqns., Vol. 2007(2007), No. 115, pp. 1-12.)	100%		
	Prepare report describing sensitivity analysis of aspatial outbreak model	Given the challenges in estimating parameter values for the RVF model due to lack of laboratory and observational studies, sensitivity analysis provided guidance to the key parameters that drive the system. Such analysis has the potential to identify areas of future research that may focus on collecting the most-needed data. As we developed the model, we simultaneously built the tools needed to make the model runs needed for this analysis. We developed C++ code to carry out the Latin hypercube sampling technique to explore the changes in model output to varying parameter input. We explored the impact of fluctuating parameter values on the model output. This type of input would reflect the impact of changes in environmental conditions on parameters such as birthrates. This analysis was described in Gaff, Hartley, Leahy 2007.	100%		

	Prepare data needs document	<p>We worked with the Texas A&M GIS group to investigate and compile the various data needs for the RVF model. We met with Doug Tolleson, Jennifer Jacobs, and Michael Ward at Texas A&M periodically in 2006-07. We discussed data needs and the flow of input data from their datasets to our model as well as the flow of output from our model back. We received a preliminary, sample livestock model template.</p> <p>We have received multiple datasets from the GIS core group, including temperature and rainfall information for the CONUS and similar information for the Horn of Africa region in 2006-2007. We used this data to understand, within the context of the model, transmission potential based in US and African regions at various times of the year. The results from the African analysis show good agreement between areas identified as “at risk” in Kenya, according to the model, in November 2006-January 2007 and observations of an epidemic of RVF during the same time period. This initial “validation” study was written on into an internal record and is currently being prepared as a manuscript to a peer-reviewed journal.</p> <p>Based on the findings of the sensitivity analysis, additional research and literature review has been pursued on mosquito survival through winter and harsh summers; the effect of temperature on larval development; the effect of temperature on adult reproduction and survival; and the variation in feeding preferences by genus and species. These findings will be incorporated into the model. Additionally, a subject matter expert workshop was held in April 2007 to further elucidate data needs and gaps.</p>	100%
	Prepare model design document for spatial spread model	We explored options for methods of extending the existing model to a spatial framework. We analyzed in depth three distinct approaches. First, and most promising for the long run, we evaluated applying a metapopulation approach. This will provide the flexibility of being able to analyze the spatial spread based on knowledge of livestock movement. The short-term shortcoming, however, is that livestock transportation models are very limited at present. Secondly, we developed a methodology to use the existing aspatial model to evaluate the variability of RVF transmission risk across time and space (described above). We have used GIS data to populate the model, and the results highlight the places that introduction could be possible in naïve areas or that outbreaks could be expected in endemic areas. Lastly, we evaluated a Monte Carlo approach to assessing spatial risk and cattle consequence based on estimates of livestock and vector populations in time and space coupled with estimates of epidemiological attack, morbidity, and mortality rates.	100%
	Prepare report describing sensitivity analysis of spatial spread model	We have executed an analysis of the United States in terms of potential animal consequences given RVF introduction, using the Monte Carlo approach described above. That analysis focused on quantifying the stochastic fluctuation in consequence given the uncertainties involved in all data. The results of this analysis included point estimates (median) and percentiles of the resulting distributions of consequence. A formal sensitivity analysis of the metapopulation model is outstanding, pending further development of a transportation model and the coding of the metapopulation model.	75%
	Prepare research codes of the aspatial and spatial spread models	Research codes (in R or C++) exist for all models coded to date.	100%
Apply models to vulnerability analysis for Rift Valley fever	Prepare simulation module design document	The Monte Carlo simulation for a US introduction has been described in an internal NCFAZDD report as well as in a formal report to DHS/NBACC. A mathematical formulation of the metapopulation model was documented in an interim report.	100%
	Prepare written summary of vulnerability analyses	The published paper describing the baseline aspatial model, in conjunction with the manuscript that is being prepared on the 2006 Kenyan outbreak, in combination describe the methodology for RVF vulnerability analysis. Similarly, the reports on the Monte Carlo simulation constitute a summary of the alternative stochastic vulnerability analysis.	100%

Highlight for Research Briefs

Interpretive Summary

- We have developed a biological-based, dynamic model of RVF where one did not exist previous to the existence of the NCF AZDD. Analysis suggests that the baseline aspatial model is robust and requires minimal computational overhead. It exploits existing data from the scientific literature, subject matter experts, and related NCF AZDD projects. The model has undergone an initial round of validation, based on data from endemic areas in Africa, and has been applied to assess risk of introduction in the US. Current applications of the model include refining the spatial generalization of the baseline model and investigating the efficacy of potential control strategies. Development and refinement of the model is ongoing.

Results and Interpretations

- Baseline model development. We have formulated and analyzed a new mathematical model of the epidemiology of Rift Valley fever (RVF), an Old World, mosquito-borne disease affecting both livestock and humans. The model is an ordinary differential equation model for two populations of mosquito species, those that can transmit vertically and those that cannot, and for one livestock population. We have analyzed this model to find the stability of the disease-free equilibrium (computed R_0) and tested which model parameters affect this stability most significantly (sensitivity analysis). The methodology has passed peer review. This model is the basis for future research into the predication of future outbreaks in the Old World and the assessment of the threat of introduction into the New World. It is also the starting point for a spatial, metapopulation model.
- Model validation. We have taken initial steps toward model validation and developing spatio-temporal risk assessment methodologies. Rift Valley fever emerges periodically throughout East Central Africa, causing morbidity and mortality in human and agricultural populations. We developed an approach that utilizes spatio-temporal temperature and rainfall data to produce regional maps of estimated epidemic potential (R_0) for months of the year. Agreement between model predictions and RVF case reports for Kenya in 2006-07 was observed (see figure), suggesting that the model produces results that are consistent with observation in the Old World. Whilst additional analyses are required, we see no reason why the model cannot therefore be applied to the New World. This work will be subjected to peer-review shortly.

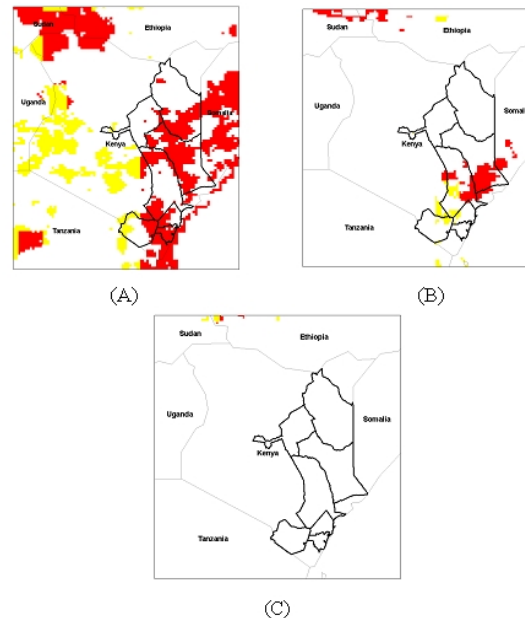


Figure. Epidemic potential in Kenya. Yellow denotes increased risk ($0.5 < R_0 < 0.75$), red denotes high risk ($R_0 > 0.76$). Districts reporting disease activity during the period December 2006-January 2007 are outlined in black. (A) November 2006; (B) December 2006; (C) January 2007.

- Methodology development. In order to assist DHS/NBACC in their recent BTRA and also to prepare a database with which output from the fully spatial can be compared when it is complete, we developed a simplistic Monte Carlo simulation of epidemiologic consequence, assuming that RVF has been introduced to the US. The model made use of openly-available livestock population estimates, data from the research literature, and subject matter expert elicitation to estimate exposure rates, attack rates, abortion rates, and morbidity and mortality rates for different classes of animals. The methodology made use of model-based maps of R_0 , generated for the US using the approach described above. Several hundred thousand runs were made to simulate four different scenarios. Thus, in addition to modeling estimates of disease impact, we now have a body of data that we can use to interpret the results of the fully spatial ODE model in the future as it is refined.
- Control Measures. To further exploit this model, a study of the estimated effectiveness of four potential control measures (mosquito larvicide, mosquito adulticide, cattle vaccination, and cattle culling) that might be employed should RVF be introduced into the US is underway. These results will also have implications for control of endemic disease in the Old World.

Technology Transition

Engagement with DHS/NBACC and their contractor Battelle has resulted in the application of NCFAZDD expertise and epidemiologic models to their biannual biothreat risk analysis (BTRA). This has involved integration of epidemiologic consequence estimated with economic models. This engagement represents one clear and present avenue to technology transition for future planned BTRAs.

Status of Funding

We are on budget at present.

Mechanisms for Utilized for Communication

1. Scientific publication
2. Speaking at national symposia and workshops
3. Presentations to federal working group meetings
4. Organization & participation in subject matter expert workshops