Climate Impacts on Vector-Borne Disease Transmission: Global and Site-Specific Analyses

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The United Nation's Intergovernmental Panel on Climate Change estimates an unprecedented global rise of 2.0°C by the year 2100. Such change can affect serious infectious diseases, including dengue fever and malaria. Both large-scale iterative modeling and site-specific microclimatic analysis of disease ecology are needed in tandem to address health effects of climate change scenarios.

In two separate studies of dengue and malaria transmission, both General Circulation Models (GCMs) of global climate change and site-specific climate analysis are used respectively to investigated climate change impacts on dengue fever and malaria transmission risk. For the first study, analysis was conducted using the integrated MIASMA model to link GCM projections of climate with a vectorial capacity model of transmission. Preliminary results indicate climate conditions being more suitable to dengue transmission, given viral introduction. An expansion of potential epidemic risk both geographically and temporally is inferred from this study. In the malaria study, preliminary results from regression analysis show mosquito biting rates to correlate to ambient temperature and rainfall. Parasite development was also shown to relate to temperature and humidity. Further interdisciplinary cooperation and multi-scaled analytical approaches will be required to better assess the potential effect of climate change on malaria and dengue.

According to the United Nations' Intergovernmental Panel on Climate Change (IPCC), anthropogenic greenhouse gas emissions are significantly altering the earth's climate. By the year 2100, average global temperatures are projected to rise by 2.0 (range 1.0 to 3.5°C)⁰. This projected rise in temperature represents a four-fold faster rate of warming than that observed over the past century. These IPCC figures even assume a reduction in global economic growth rate, slowed population growth over the next half century and improved conservation measures. These projections are consistent with climate sensitivity to atmospheric CO₂ concentrations observed from ice core data extending over 158,000 years. Sea level also is expected to rise by about 34-52 cm. by the year 2100², as a result of ocean thermoexpansion and by melting of glaciers.

While uncertainties always will accompany predictive climate modeling, there is increasing agreement between climate projections arising from varying methodologies in multiple climate centers internationally. The medical community is beginning to examine the consequences that these projections may portend for public health, and the World Health Organization considers global warming as a serious public health challenge for the future³.

Infectious agents which cycle through cold-blooded insect vectors to complete their development are quite susceptible to subtle climate variations. In temperate regions, climate change would affect vector-borne diseases by altering the vector's range, reproductive and biting rates, as well as pathogen development rate within the vector host⁴.

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Malaria and dengue fever serve as prime examples of climate sensitive diseases. Malaria generally extends to the 15°C winter isotherm, since parasite development does not occur below this temperature. Temperature and humidity are among the most important factors for disease transmission. Climatic factors that increase the inoculation rate of Plasmodium pathogens, as well as the breeding site availability of Anopheles mosquitoes, are considered the most important cause of epidemic outbreaks of malaria in non-endemic areas. Malaria has been observed in non endemic high elevations in Africa during unseasonably warm conditions. In Zimbabwe, temperature defines malaria distribution as well, since malaria incidence and prevalence are strongly linked to altitude.

Regarding dengue fever, freezing temperatures kill overwintering eggs of Aedes aegypti, the mosquito carrier of dengue and yellow fever. Warming trends, therefore, can shift vector and disease distribution to higher latitudes or altitudes, as was observed in Mexico when dengue reached an altitude of 1,700 meters during an unseasonably warm summer in 1988. In an earlier study in Mexico, the most important predictor of dengue prevalence in communities was found to be the median temperature during the rainy season.

Temperature also drives epidemic dynamics of dengue transmission. Warmer water temperatures in breeding vessels reduces the size of emerging adults that subsequently must feed more frequently to develop an egg batch. Viral development time inside the mosquito also shortens with higher temperatures, increasing the proportion of mosquitoes that become infectious at a given time. Thus, mosquitoes bite more frequently and are potentially more infectious at warmer temperatures.

Analysis will be required at varying levels of geographical and temporal scale, and with varying degrees of integration. Ideally, numerous assessments done at the local and regional level can provide empirical analysis needed to guide preventive health measures. However, the scale of climate change predictions is not yet reliable at this level. Mathematical modeling can be useful in evaluating very longterm climate variability, where prospective studies are infeasible and historical studies may lack similarity with the unprecedented accelerated climate changes projected by climatologists.

This paper briefly summarizes preliminary results from two ongoing studies that illustrate the importance of both "top down" modeling approaches and "bottom up" or site-specific analysis to achieve a more comprehensive understanding of the potential effects of climate change.

SUMMARY OF METHODS FROM BOTH STUDIES

Global Model for Potential Dengue Fever Risk

For the "top down" modeling study, the potential spread of dengue fever due to climate change was achieved by using the Modeling framework for the health Impact Assessment of Man-induced Atmospheric changes (MIASMA) model described by Martens, et al. Here, monthly averaged GCM outputs of temperature were linked to dengue-specific parameters used in dengue transmission models developed by Focks et al. These parameters were combined within the Vectorial Capacity model of disease transmission, defined as the daily rate of expected infectious inoculations by a given mosquito population per infected human; that is, the capacity of a given vector to transmit disease.

The climate change scenarios were derived from three transient general circulation models (GCMs): the Max Planck Institute model, ECHAM, the United Kingdom Meteorological Office transient model, UKTR, and the Geophysical Fluid Dynamics Laboratory model, GFDL89.

Site-Specific Regression Analysis of Malaria and Climate

Weekly man-biting rate entomological data near Kisumu, Kenya collected from 1985 to 1988, were analyzed against meteorologic data over that time period. Variables recorded at Kisumu included: hourly temperature, dew point, wind speed, wind direction, cloud cover, and daily precipitation. From these values, weekly values (maximums, minimums, and averages) were calculated and compared to the weekly mosquito data.

Regression analysis was conducted to determine differences between the primary Anopheline vectors in this region, A. gambiae and A. funestus. Differences in ecological niches are known for these species with regard to breeding sites. To study the effect of rainfall on the man biting rate, MBR was plotted versus the amount of precipitation for these two different species.

RESULTS

Dengue: Global Modeling

Preliminary results show that dengue epidemic potential increases with a relatively small temperature rise, indicating fewer mosquitoes are necessary to maintain or spread dengue in a vulnerable population. The length of seasonal transmission increased in five major cities that differ both in climate and extent of dengue transmission. Expected transmission from baseline climate data matched observed dengue incidence at these sites, giving validity to our model results. Globally, all three climate GCMs showed an increase of epidemic potential, particularly in temperate regions.

Malaria: Species-Specific Analysis

The two species react very differently to the change in the precipitation. The slope for A. gambiae is much greater than...
the slope for A. funestus. The $R^2$ for A. funestus is fairly small indicating that there is very little relationship between precipitation and biting rates of this mosquito. The relationship is stronger for A. gambiae. The key point is that difference in the slopes is significant. Thus emphasizing the fact that each species would react differently to the same climatic (in this case, precipitation) change.

**DISCUSSION**

To address the health effects of global climate change, studies must both accommodate the global nature of climate projections, and address the biological and ecological influences of climate on diseases at the local level. Also, complex integrated models are only as good as the basic science used to build such models. Root and Schneider have described a research paradigm called "Strategic Cyclical Scaling 17)," whereby iterative analysis involves the combined knowledge gained from alternating both large- and small-scale studies. The two studies described above help illustrate this concept. While they unfortunately do not address the same infectious disease, previous studies can be applied to these analyses to highlight key information gaps regarding effective health risk assessment of climate change.

For example, an estimated one million additional fatalities per year could be attributed to climate change by the middle of the next century, according to the global malaria model developed by Martens and colleagues 18). While this study represented a major step forward in climate change/health assessment, from the interspecies dynamics noted in the above Kenyan analysis, new information of mosquito response to precipitation can augment future climate change assessments; many Anopheles mosquito species transmit malaria, and if each species responds uniquely to varying precipitation, such information will be essential to improving validity of model projections.

What effect will global climate change have on dengue fever risk? To start with, an important climate-driven simulation model, DENSiM, has been developed by Focks and colleagues 18) that has been validated in the laboratory, five field studies in New Orleans on larval habitat, and predicted ovipositional activity of Ae. aegypti in seven cities in the southeastern U.S 18,19. As an integrated, site-specific model, predicted entomological indices closely match observed data. However, projections of climate change are at a resolution of scale approximating grid boxes over 200 kilometers diameter. Therefore, global scale or "top down" modeling, such as described above, can augment the site-specific DENSiM analysis of dengue transmission, since it is not feasible to obtain the numerous variables necessary to run the full-blown model on a global scale.

**CONCLUSION**

Scenario-based analysis of longterm future impacts must accompany conventional historical empirical studies 20), to adequately address the environmental health hazard posed by global climate change. Integrated mathematical modelling will be required for simulating complex global-wide climatological and ecological interactions. Accepting inevitable uncertainty, modeling can help in the analysis of these interactions. Yet, more emphasis needs to be placed on the iterative process of modeling, rather than on the numerical outputs which are generated. That is, in the process of model building, a deeper understanding may emerge as researchers begin to identify key gaps in data via heterogeneous, multi-scaled and multidisciplinary investigation.

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