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Human Demography, Environmental Change and the Emergence of Arboviruses

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In the past 2/3 of a century [or essentially my lifetime] the earth's population has tripled from < 2.5 to > 7.0 billion people. Although the overall growth rate has decreased to 1.1% per year, this decline has not been evenly distributed, with some countries having 0 or even negative growth and other emerging economies retaining rates > 4% per year. Despite this overall decline in the growth rate, the actual number of people continue to increase and world population size projections are as high as 10.5 billion by 2050. Concurrent with this growth has been an urbanization of the population, with more than half of the earth's people now living in cities. This rapid urbanization has often surpassed infrastructure development, leaving much of the population to reside in sprawling slums without adequate housing, piped water or sewage. Commerce and tourism have required the increase and improvement of travel, and this improved connectivity among urban centers has allowed rapid population intermixing and exchange. Human commensals and pathogens have exploited this rapid and extensive connectivity allowing the invasion of new peridomestic habitats and immunologically naïve host populations.

The resources required to support this burgeoning global population is astounding, especially since the average body size and therefore per capita caloric consumption of humans is also increasing. To meet this demand, much of the arable earth has been transformed into intensive agriculture that frequently must be irrigated and fertilized to produce multiple crops per year. The energy requirements for heating, agriculture and transportation have produced ever increasing emissions and altered the composition of the earth's atmosphere resulting in long term climate change and warming. These latter trends have allowed the range extensions into temperate latitudes of tropical vector species and pathogens formerly constrained by winter severity.

Collectively population growth, urbanization and agriculture have simplified ecosystem complexity and therefore reduced biodiversity and thereby created anthropogenic habitats highly suitable for a limited number of commensal species. Parallel to the human population increase and loss of ecosystem complexity therefore has been the marked population explosion of domestic/peridomestic commensal species, including many vectors and hosts of arboviruses.

Arboviruses [arthropod-borne viruses] are a taxonomically diverse assemblage of viruses that are transmitted among vertebrate hosts by a diverse group of blood-feeding arthropod vectors, especially mosquitoes. Because arthropods are poikilotherms, transmission patterns typically are tied closely to warm temperatures that 1) decrease the duration of immature development and thereby increase the rate of population growth and size, 2) decrease the duration of blood digestion and thereby increase the frequency of blood-feeding and host contact, and 3) decrease the duration of the incubation period of the pathogen within the arthropod thereby allowing transmission earlier in life by more individuals. Collectively these temperature-driven population parameters result in the seasonality of transmission patterns that typically peak in mid to late-summer. At temperate latitudes transmission subsides with the onset of cooler temperatures that arrest vector activity and often stimulate diapause. Recent warming trends at northern latitudes have shortened this winter interlude and conversely lengthened the transmission season, precipitating outbreaks of tropical viruses at northern latitudes. For example, unprecedented 10°C temperature anomalies in Saskatchewan, Canada, during 2003 and 2007 were accompanied by large epidemics of West Nile virus.

In combination, environmental change related to human population increase, urbanization, ecosystem simplification and climate change have created new environments suitable for vector mosquitoes including the Yellow fever mosquito (*Aedes aegypti*), the Asian tiger mosquito (*Aedes albopictus*) and the common house mosquito (*Culex pipiens* complex). The two *Aedes* species lay drought resistant eggs and thrive in areas where water is stored in and around the home. *Ae. aegypti* is of African origin and was dispersed by water carried on sailing ships and is now circumtropically distributed, setting the stage for the historic movement of Yellow fever virus into the Americas, chikungunya into Asia, and dengue fever circumtropically. *Ae. albopictus*, a species of Asian origin, has been moved around the world with the used tire trade and is now firmly established in parts of Africa, Europe and the Americas. Recently, this species was responsible for the re-emergence of chikungunya virus which tracked the distribution of this vector from East Africa to several Indian Ocean Islands to India and SE Asia, and finally to Italy, clearly demonstrating the significance of international connectivity. The rapid movement of the virus in infected humans was best demonstrated by the overlapping patterns of human cases of chikungunya virus on Reunion Island off the African coast and imported cases diagnosed among returning tourists in France during 2005-06. Fortunately, neither vector *Aedes* species was established in France, precluding autochthonous transmission. In contrast, a significant outbreak occurred in Northern Italy where *Ae. albopictus* populations had become established during the previous decade.

The *Culex pipiens* complex which apparently originated in the Ethiopian region is comprised of *Cx. quinquefasciatus* at southern latitudes and *Cx. pipiens* and the underground ecoform *molestus* at Northern latitudes, with considerable introgression throughout. The immature stages are all extremely tolerant of eutrophic conditions and have exploited above and below ground municipal wastewater management [or mismanagement] systems in urban and suburban environments throughout the world. The ability of *pipiens* to

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hibernate has allowed the persistence of populations at temperate latitudes. Extensive introgression of *quinquefasciatus* genes into *pipiens* populations, perhaps facilitated by climate warming, seems to have altered the overwintering strategy of this species as well as perhaps expanded its host range to include more human blood feeds. Coincidentally, the English sparrow [*Passer domesticus*] has intentionally and unintentionally become established throughout the world's cities. In combination with the increase in commensal native species such as House finches, American robins and American crows that also exploit urban environments in North America, the stage was set for the invasion of the New World by West Nile virus. The invasion and ensuing epidemic in the New York area undoubtedly was facilitated by 1999 being the hottest summer in recorded history.

The explosive increase in the world's human population resulting in environmental and climate change and the anthropogenic transport of vector species has set the stage for ensuing outbreaks of arboviral disease within an expanding urban habitat. Previously, vector borne diseases were usually acquired moving from the safe home environment into a wetland, forest of jungle setting, whereas now the viruses seem able to readily invade the domestic or peridomestic setting by shedding their sylvan enzootic cycles. Climate change and enhanced interconnectivity among urban centers can only exacerbate this scenario and increase the frequency of tropical viruses invading northern latitudes.