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A dynamic transmission model of eastern equine encephalitis virus

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Abstract

Eastern equine encephalitis virus (EEEV) is one of several arthropod-borne viruses (arboviruses) endemic to the United States. Interactions between arthropod (mosquito) vectors and avian amplification host populations play a significant role in the dynamics of arboviral transmission. Recent data have suggested the hypothesis that an increased rate of successful feeding on young-of-the-year (YOY) birds might play a role in the dynamics of EEEV transmission. To test this hypothesis, we developed a model to explore the effect of the interactions of the vectors and avian host populations on EEEV transmission. Sensitivity analyses conducted using this model revealed eleven parameters that were capable of disproportionately affecting the predicted level of EEEV infection in the vertebrate reservoir and vector populations. Of these, four parameters were related to the interaction of the vector with young-of-the-year birds. Furthermore, adult birds could not substitute for young-of-the-year in initiating and maintaining a predicted enzootic outbreak of EEEV. Taken together, the model predicted that young-of-the-year birds play a key role in establishing and maintaining enzootic outbreaks of EEEV.

Keywords: Arbovirus; Avian; Mosquito; Stella; Alabama

1. Introduction

Arthropod-borne viruses (or arboviruses) are transmitted primarily between reservoir hosts by blood-feeding arthropods (e.g. insects, ticks and mites) that serve as vectors for these agents. Because arboviruses

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infect two very different types of hosts (vertebrates and invertebrates) the transmission dynamics are often quite complex. The interaction between the reservoir host species and the arthropod vector is the one of the most important factors in determining whether an arboviral infection can be sustained in a given environment (Black and Moore, 1996). Thus, knowledge of the dynamics of arboviral transmission ultimately requires an in-depth understanding of how the vertebrate reservoir and arthropod vector interact.

In North America, the most important arboviral infections from a public health perspective are those that cause encephalitis (the arboviral encephalitides) There are five major arboviral encephalitides in North America: eastern equine encephalitis (EEE), Saint Louis encephalitis (SLE), LaCrosse encephalitis (LAC), western equine encephalitis (WEE) and west Nile encephalitis (WN) (Tsai, 1991). The viruses associated with these infections are classified in several different taxonomic families, but they share important features of their life cycles. For example, with the exception of LAC, all are commonly infections of the endemic avifauna. Transmission from bird to bird in the enzootic cycle is generally thought to occur primarily through the action of ornithophilic mosquitoes, i.e. those species that feed primarily or exclusively upon birds (Tsai, 1991).

Of the arboviruses endemic to the United States, EEEV is particularly dangerous. In the southeast, horse infections with EEE virus occur commonly in the summer months, accompanied by sporadic human cases. Infection with EEE virus in both mammalian hosts is highly virulent, with death resulting in about 70% of the symptomatic cases. Most survivors have residual neurological sequelae and health care during acute phase illness and afterwards may result in the expenditure of several million dollars per person (Villari et al., 1995).

Previous studies of EEEV transmission in the southeastern USA have suggested that vector mosquitoes in this region (including *Culiseta melanura*, *Coquillettidia perturbans*, *Aedes vexans* and *Culex erraticus*) targeted particular avian species (Hassan et al., 2003). Furthermore, most blood meals derived from the most commonly fed-upon birds were confined to a rather narrow time frame that coincided with the breeding season of the targeted birds. This suggested that the vector mosquitoes were taking more blood meals from nestlings than from adult birds (Cupp et al., 2004a; Hassan et al., 2003). These findings are consistent with previous observations that have suggested that nestlings and young-of-the-year (YOY) are more often successfully fed upon by arboviral vectors than are adult birds (Blackmore and Dow, 1958). Furthermore, laboratory studies have suggested that nestlings and YOY of some species also develop infectious circulating viremias more rapidly than adult birds and peak viral titers present in nestlings are as high as or higher than those seen in adult birds (McLean et al., 1995). Taken together, these observations suggest that mosquitoes might be feeding intensively on YOY of the chosen host species and that this concentration might increase the intensity of EEEV transmission (i.e. the incidence rate in the vector and amplification host populations).

Here, we report the development of a model for the transmission of EEEV that concentrates upon the interaction of the vector and avian reservoirs. This model contains separate modules for adult birds, YOY and mosquitoes, allowing us to test the hypothesis that feeding on YOY may affect the dynamics of EEEV transmission.

2. Materials and methods

2.1. Development of the model

The model was created using Stella® (Wallis et al., 2002), a software package specifically designed for modeling dynamic systems. Stella® has been utilized by other researchers to create models of ecological (Angelini and Petrere, 2000; Costanza and Voinov, 2001; Gertseva et al., 2004; Suplicy et al., 2003; Vitale et al., 2003), economic (Costanza and Voinov, 2001), physiological (Narayana et al., 1997) and clinical (Anderson et al., 2002) systems. Our model contains three interacting modules; adult birds, YOY and mosquitoes (Fig. 1). It is structured to run for a single transmission season (200 days in Alabama). The adult bird module models in-migration, mortality, infection and recovery of adults. Natality as a function of time and the size of the adult bird population and mortality, infection and recovery of young birds is captured in the YOY module. The third module captures the population dynamics of the mosquito vector. EEEV transmission and the growth of the virus are