On the Population Dynamics of the Malaria Vector

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Abstract A deterministic differential equation model for the population dynamics of the human malaria vector is derived and studied. Conditions for the existence and stability of a non-zero steady-state vector population density are derived. These reveal that a threshold parameter, the vectorial basic reproduction number exist and the vector can established itself in the community if and only if this parameter exceeds unity. When a non-zero steady-state population density exists, it can be stable but it can also be driven to instability via a Hopf bifurcation to periodic solutions, as a parameter is varied in parameter space. By considering a special case, an asymptotic perturbation analysis is used to derive the amplitude of the oscillating solutions for the full nonlinear system. The present modelling exercise and results show that it is possible to study the population dynamics of disease vectors, and hence oscillatory behaviour as it is often observed in most indirectly transmitted infectious diseases of humans, without recourse to external seasonal forcing.

Keywords Vector-breeding sites · Human habitat · Threshold · Hopf bifurcation

1. Introduction

For many centuries, vector-borne diseases, among all infectious diseases of humans, have constituted a major cause of human mortality and morbidity. Even with the recent advances in the biomedical sciences, vector-borne diseases still seriously threaten world health. For example, about 1.5–3 million people, mostly children, die of malaria every year (WHO, 2005). It is well known that the malaria parasite is transmitted from human-to-human by the Anopheles sp. mosquito, and that the transmission cycle is essentially driven by the human biting habit of the mosquito. Now, the female Anopheles mosquito bites a human being for the sole purpose
of harvesting blood that she needs for the development of her eggs. The malaria parasite has exploited the mosquito’s life style by adapting its life cycle so that part of it is in the human being and the other part in the mosquito. This way, the mosquito can then propagate the parasite, from human-to-human, as it forages for blood meals within the human population. Transmission of most indirectly transmitted diseases of humans follow the same pattern: The vector, in most cases an insect, interacts with a human being, and depending on the disease status of both organisms, will either infect or be infected. In the process of this interaction, the vector may loose its life. However, it can be assumed that after each successful interaction, the payoff, in terms of reproductive gains, to the vector is significant when compared with the loss, in terms of volume of blood, endured by the human. Given the wide range of ecological conditions under which blood-sucking arthropods search for host, however, a general theory of disease vector behaviour from the perspective of mathematical modelling and behavioural ecology is important to make epidemiology a more predictive science.

For a disease vector to feed on a human, it must actively seek the human host. Some disease vectors live, feed and breed entirely on the organism they parasitize. In the case of the mosquito, the vector responsible for the transmission of several human diseases, including malaria, only the adult female needs blood meals. This mosquito can systematically target and identify human beings (Giles and Warrel, 1993; McCall and Kelly, 2002) and once attracted, it may seek and bite humans as many times as possible until it takes a blood meal. Some species of the mosquito prefer human blood (anthropophilic) while others prefer animal blood (zoophilic). Some prefer to bite indoors (endophagic), and others prefer to bite outdoors (exophagic). Some species prefer to rest within the habitat of the human from which they take their blood meal (endophilic) while others prefer to rest outdoors (exophilic). Once a good blood meal has been taken, the vector searches for, and moves to, a convenient breeding site: Usually a swamp or humid area. Such breeding sites may host several species of mosquitoes (Jae and Bernard, 1997). The vector’s preference for a particular swamp depends on the distance from a human settlement and perhaps also on safety from predators (Wrona and Dixon, 1991; Yuval et al., 1993).

The *Anopheles* sp. mosquito, like several other insect vectors, goes through several separate and distinct stages of development (metamorphosis). The eggs are laid on water and after about 2–3 days, they hatch into larva. In about 4–10 days, the larva change into pupa. The pupa then changes into the adult mosquito in about 2–4 days. The duration of the whole cycle, from egg laying to an adult mosquito eclosion varies between 7 and 20 days, depending on the ambient temperature of the swamp and the mosquito species involved (Giles and Warrel, 1993). However, eggs can remain unhatched in hibernation mode for longer periods of time.

It is well known in ecology and biology that maintaining an appropriate seasonality is a basic ecological requirement for all organisms. That is, critical life history events must occur at the appropriate time to optimize the chances of survival of the species. Thus, oscillations, including time periodicity, in the population numbers of an insect species, are naturally measurable features of the insect’s population dynamics. Powell and Logan (2005) review the mathematical relationship between