Impact of Environmental Changes on Mosquitoes and Disease Transmission

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Abstract
Mosquitoes are excellent indicators of environmental changes caused by man, especially as environmental degradation promotes the proliferation of mosquito species with adaptive plasticity which can develop in suburban areas and can carry and transmit pathogens to humans and animals. Therefore, environmental changes are evaluated as risk factors of emerging mosquito borne diseases. The current knowledge of diversity and relative abundance of mosquito vectors as a function of habitat change, survival rate of several mosquito species, as well as their biting rates leading to the rapid spread and emergence of new diseases is not comprehensive. Noteworthy, the interaction between vector-host-parasite in natural environment can be disrupted when deforestation occurs. This review provides useful knowledge for vector control, while allowing the monitoring of biological indicators of environmental changes caused by man, an important step in understanding the dynamics of mosquito vector distribution under changing environment.
Keywords: Deforestation, parasite, biodiversity, vector,

Background
The transmission dynamics of vector borne parasites under natural condition is determined by factors affecting three main components; the pathogens, the vectors and its vertebrates host. Most studies focus on the interaction between the parasites and their host while other studies integrates all the three main groups (Ferraguti *et al*. 2013). Vector and community as well as habitat characterization may have an important but different impact on the prevalence, richness and evenness of vector borne parasite. Although much is known about the biology of mosquitoes and their role in disease transmission, little is known about how rapid environmental changes can affects the community of mosquitoes and its dynamics. Due to habitat changes, mosquitoes are been expose to new host and at an unprecedented rate which can lead to the emergence and spread of diseases (McCallum & Dobson, 2002; Lafferty, 2009). In a socio-ecological context, the increasing human population coupled with greater demand for agricultural land, has led to an incremental habitat changes in tropical countries where malaria, a mosquito borne disease is endemic. Anthropogenic land-use change is considered a key driver of disease emergence because it can result in novel interactions among vectors, hosts and diseases. In tropical regions, emerging pathogens have been associated with a range of land-use activities including deforestation, habitat fragmentation, urbanization, bush meat hunting, gold mining and road construction (Laurance *et al*. 2013).

However, climate warming or any factor that alters the microclimatic conditions of mosquitoes (e.g., deforestation) in the highlands may facilitate the persistence of the mosquito population. Furthermore, changes in precipitation and humidity are also expected to occur under climate change scenarios; the synergistic effects between temperature and precipitation are expected to have major effects on the ecology of mosquitoes and mosquito-borne diseases. Increased precipitation may affect larval habitat availability and stability, and habitat productivity. The association between precipitation, vector abundance, and malaria prevalence has been well supported (Afrane *et al*. 2012). Meta-analysis on the impact of environmental changes on the development and reproduction of malaria vectors that include large number of study sites and various mosquitos' species may reveal general principle on the effects of environmental changes on malaria vectors and the underlying biological mechanisms. In principle, the biology of mosquitoes, diversity, and pathogens carried by the mosquitoes in response to environmental changes is essential for building predictive models and control strategies.

Environmental changes on Host, Parasite and Vector association
Outbreaks of vector-borne diseases have increasingly been linked to human activities. Landscape changes through activities such as forestry, ranching, and agriculture, may influence disease epidemiology in a variety of ways (Patz *et al*. 2000); either directly through effects on interactions between pathogens and their vectors and hosts or indirectly by alterations in disease dynamics through changes in vector ecology. The study of mosquito ecology is essential in understanding the epidemiology of different diseases and monitoring environmental changes caused by man, especially as environmental degradation promotes the proliferation of mosquito species with adaptive

plasticity which can develop in suburban areas and can carry and transmit pathogens to humans and animals (Ribeiro *et al*. 2012; Hoshi *et al*. 2014; Wang *et al*. 2016). These investigations provide useful information on vector control while also monitoring biological indicators of environmental changes caused by man (Ribeiro *et al*. 2012; Hoshi *et al*. 2014). Despite the role of mosquitoes as disease vectors of human and animal diseases, mosquito-borne pathogens respond to changing dynamics on multiple transmission levels and appear to increase in disturbed systems, knowledge of mosquito diversity and the relative abundance of mosquito vectors as a function of habitat change is limited (Thongsripong *et al*. 2013). Because of the risk associated with invasive species and the emergence and spread of vector borne diseases, it was portended that an improved understanding of mosquitoes in response to deforestation in order to understand the risk of emerging mosquito-borne diseases due to environmental changes and can provide powerful tool for the implementation of more effective and efficient vector population control program (Nikookar *et al*. 2015). Environmental changes, such as habitat fragmentation and global climate change, can influence the evolutionary trajectories of parasites by affecting interactions between the pathogen and the arthropod vector, the host, or a combination of both (Loiseau *et al*. 2012; Ventim *et al*. 2012; Okanga and Cumming, 2013). This is particularly important as correct identifications of problem are necessary for the management and control of vector species, including prevention of epidemics of infectious diseases (Huang & Rueda, 2015; Huang & Rueda, 2015, 2016, 2017).

Mosquito biodiversity and environmental change

Biodiversity of mosquitoes is an important aspect of medical science and is destined to emerge as a new significant and integral aspect of human life. Biodiversity of mosquito communities may change across landscapes through multiple mechanisms, including changes in habitat affecting species, relative abundance and the invasion of new species. The introduction of human-adapted vectors can both introduce new human pathogens as well as reduce the relative abundance of other species, or their relationships to hosts, leading to biodiversity loss and changes in infectious disease distribution.

Mosquito abundance is often influenced by environmental factors such as temperature, rainfall, water quality, and habitat (Smith *et al*. 2004; Okanga and Cumming, 2013). Vector groups for both human malaria (Anopheles mosquitoes) and avian malaria (Mostly *Culex* and *Aedes* mosquitoes) demonstrate sensitivity to temperature changes (Rueda *et al*. 1990; Okanga and Cumming, 2013). Mosquitoes have adapted to breed in almost all natural temporary, semi-permanent and permanent water bodies and some species, have more recently adapted to breed in a variety of water bodies associated with man, including ground water sites (pools, rivers and lakes) and container sites including bottles, cups, and tyres, (Pires & Gleiser, 2010; Mattah *et al*. 2017). The seasonal variations can also directly affect the growth, development and activities of mosquito species and in wet season with the larval indices found to be greater as compared to the dry season (Preechaporn, Jaroensutasinee, and Jaroensutasinee 2007). Initiation of an ovipositional flight is linked with environmental factors, especially rainfall, relative humidity, temperature, and wind speed. Chemical contaminants can potentially disrupt this process by modifying the quality and attractiveness of the aquatic habitats and vector biologists are faced with the challenge of determining the impact of these chemicals on mosquito ecology, behavior, and ability to transmit pathogens (Kibuthu *et al*. 2016).

In 2013, when studying mosquito vector diversity across different habitats in Central Thailand, (Thongsripong *et al*. 2013) observed that female mosquito abundance was highest in rice fields and lowest in forests with a higher diversity of mosquito fauna in the forest and fragmented forest habitats and lower diversity in the urban area. In addition, the distributions of species of medical importance differed significantly across habitat types and were always lowest in the intact, forest habitat. These results represented an important first step for understanding the dynamics of mosquito vector distributions under changing environmental features across landscapes of Thailand. Understanding vector community dynamics in the face of anthropogenic changes could form the basis for understanding the emergence and persistence of mosquito borne diseases (Thongsripong *et al*. 2013).

Despite the role of mosquitoes as disease vectors of human and animal diseases, mosquito-borne pathogens respond to changing dynamics on multiple transmission levels and appear to increase in disturbed systems, the current knowledge of mosquito diversity and the relative abundance of mosquito vectors as a function of habitat change is limited (Thongsripong *et al*. 2013). Because of the risk associated with invasive species and the emergence and spread of vector borne diseases, an understanding of mosquito biodiversity, especially in a forests undergoing environmental degradation, will be required to analyse the risk of emerging mosquito-borne diseases due to deforestation and provide a powerful tool for the implementation of more effective and efficient vector population control program (Nikookar *et al*. 2015).

Environmental change and diseases transmission risk

Deforestation has been advocated as one of the most negative effects produced by humans, leading many organisms to local extinction and reducing biological diversity (Cintra *et al*. 2013). The loss of biodiversity from

anthropogenic origins may greatly affect human health. Indeed, biodiversity changes through fragmentation and degradation of natural habitats, increase in proximity of wildlife to humans and their domestic animals, results in increased health risks through increased transmission of zoonotic and vector borne disease (Kutz *et al*. 2005; Keesing *et al*. 2010; Morand *et al*. 2014). High biodiversity can protect human health by reducing the risk of disease transmission due to the diversity of hosts, also called the "dilution effect". On the contrary, reduced biodiversity can increase the risk of disease transmission by concentrating the source pool on few available and competent hosts (Keesing *et al*. 2010). Hence, the preservation of intact ecosystems and their endemic biodiversity should reduce the prevalence of some infectious diseases, in particular transmission of zoonotic pathogens such as West Nile Virus transmitted by *Culex* species (spp) (Reisen *et al*. 2004; Ezenwa *et al*. 2007; Kramer *et al*. 2008; Keesing *et al*. 2010).

Our expanding and increasingly globalized human population has seen the emergence of new infectious diseases and the resurgence of familiar diseases such as dengue and influenza to epidemic proportions. At the same time, our environment has experienced substantial ecological disturbance due to habitat destruction, invasive species and climate change, with dramatic losses of native species and ecosystems (Thongsripong *et al*. 2013). Anthropogenic changes specifically have been linked to the recent emergence of certain infectious diseases. For example, in Malaysia, the emergence of Nipah virus has been linked to agricultural intensification (Epstein *et al*. 2006). In Australia, urban habituation increased the number of fruit bats in contact with humans and domestic animals, resulting in the emergence of Hendra virus (Plowright et al. 2011). In the eastern United States, forest fragmentation and urbanization led to reduced host diversity, allowing disease-competent rodent hosts to dominate the community, contributing to the emergence of Lyme disease (Logiudice *et al*. 2003). Moreover, there are numerous mosquito borne zoonotic virus strains (Semliki Forest, Sindbis, Spondweni, Uganda S, O'nyong-yong, Bwamba, Bunyamwera, and Shuni viruses, just name a few) and other animal pathogens (for example multiple avian malaria), which currently have little history of serious symptoms in humans and animals, lurking in the African tropic forests which may undergo adaptive changes in response to deforestation to cause more severe pathogenic consequences. Examples of previously benign viruses lurking for millennia in African forests that have in recent times become more dramatic globally because of host and vector switching due to minor viral genome mutations include Zika and Chikungunya viruses (Caglioti *et al*. 2013; Vest 2016).

Thus, in these and many other cases, anthropogenic environmental changes disturb ecological relationships in communities and consequently affect the distribution and relative abundance, or biodiversity, of organisms involved in disease transmission. Such situation may bring human and other animal populations closer to novel sources of parasites, and provides opportunities for novel pathogens to ''jump'' into human populations which might lead to the emergence and spread of new diseases (Lafferty, 2009; Lee & Brumme, 2013). Deforestation due to illegal logging, agriculture, and land projects such as housing has been implicated in faster larval-to-pupa and pupa-to-adult rate in mosquito vectors, thus increasing the survival rate of several mosquito species, as well as their biting rates leading to the rapid spread and emergence of new diseases (Vittor *et al*. 2006; Wang *et al*. 2016).

Temperature, rainfall and relative humidity are other factors that have also been linked/correlated with mosquito abundance; and increase mosquito abundance together with urbanization processes can lead to increase disease transmission (Chaves *et al*. 2012; Sang *et al*. 2015; Cavalcanti & Cavalcanti, 2017).

Environmental Changes on mosquitoes bio ecology
Environmental changes can affect the distribution and prevalence of infectious diseases by making conditions more (or less) conducive for the survival of vectors and by prompting mass movement of human and animal populations. These changes can include loss of biodiversity and habitat, increasing temperature, rising sea levels, and climatic instability leading to longer and more severe periods of drought or rainfall (Brattig *et al*. 2019). More important, perhaps, is the impact that large-scale deforestation may have on disease emergence. According to (Hansen 2013), the global rate of tropical deforestation appears to be increasing rapidly and the International Timber Organization reports of 2011 reported deforestation occurs in parts of Africa at a rate of nearly 1% per year. Deforestation can transform whole ecosystems, and thus affect disease transmission (Taylor, 1997) and can affect water temperature, breeding site availability, and decrease relative humidity and available resting sites, thus affecting mosquito fitness and parasite development (Afrane *et al*. 2012).

Mosquitoes as bio indicators of Environmental changes
A bio-indicator is a living organism whose presence and abundance reflects or gives an idea of the health of the ecosystem. Mosquitoes are known and used as excellent indicator species because they are sensitive to environmental variables such as temperature and precipitation (Gong, Degaetano, and Harrington 2007; Morin and Comrie 2010). An environment with the presence and persistently high density of known mosquito vectors is considered unhealthy because such conditions increase the risk of disease transmission (Mardihusodo, 2006). For mosquito-borne diseases affecting humans, in the concept of bio-indicators, mosquito vector whether infected or

not infected with a certain pathogen at a certain time can be categorized as bio-indicators (Mardihusodo, 2006). Research into human health issues using an ecosystem approach must inherently be multidisciplinary to take into account the range of systems and processes involved. A major advantage in using disease outbreaks as bioindicators of even subtle ecosystem disruptions is that the health of human populations is generally subject to more widespread and more accurate surveillance than is ecosystem health (Jardine, Cook, and Weinstein 2008).

Conclusion

Environmental change has great impact on the ecology, biodiversity of mosquitoes and subsequently influences their role in disease transmission by affecting the normal relationship between mosquitoes and their host in their natural enviroment. Because of the high sensitivity of mosquitoes to environmental changes (for instance they are affected by a slight temperature change), they serve as indicators of the impact of environmental changes on mosquito community and insect borne disease. Hence adequate measures need to be implemented to curb alterations in mosquito borne disease transmission when environmental changes occur as well as possible control strategies to reduce the risk of vector borne infections and their transmission potentials.

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