EcoHealth 1, 19–24, 2004
DOI: 10.1007/s10393-004-0008-7

ECOHEALTH

Reviews

Mosquito-borne Diseases as a Consequence of Land Use Change

Douglas E. Norris

Johns Hopkins Bloomberg School of Public Health, The W. Harry Feinstone Department of Molecular Microbiology and Immunology, The Johns Hopkins Malaria Research Institute, 615 N. Wolfe Street, Room E5008, Baltimore, MD 21205

Abstract: Human modification of the natural environment continues to create habitats in which mosquitoes, vectors of a wide variety of human and animal pathogens, thrive if unabated with an enormous potential to negatively affect public health. Historic examples of these modifications include of impoundments, dams, and irrigation systems that create havens for the mosquitoes that transmit malaria, dengue, and filariasis. Additionally, contemporary deforestation appears to be associated with the expansion of mosquito distributions and the increase in mosquito-borne disease transmission. These observations are not unique to the developing world, as urban sprawl also contributes significantly to mosquito habitats and offers a sanctuary to some vector populations. With foresight and planning, most of these systems can be appropriately managed to control vector populations and pathogen transmission. The key to disease control is developing an understanding of the contribution of human landscape modification to vector-borne pathogen transmission and how a balance may be achieved between human development, public health, and responsible land use.

Key words: vector, ecology, habitat, mosquito

INTRODUCTION

Mosquitoes serve as vectors for a wide variety of human and veterinary pathogens. Mosquito-borne pathogens range from the parasites that cause malaria and filariasis to those responsible for hemorrhagic and encephalitic viral infections. These disease outbreaks are inherently associated with water sources and water use, as mosquitoes are inexorably linked to aquatic breeding sites for the immature stages (see Mosquito Biology Generalized). Human alteration of the environment continues to exacerbate mosquito-borne diseases by creating or expanding mosquito breeding habitats. These land use alterations may be unavoidable, however, a better understanding and recognition of the effects of habitat modification may lead to better land use strategies.

The effects of land use change on vector-borne diseases, in whole or in part, has been reviewed in several recent articles (Mouchet and Carnevale, 1997; Gratz, 1999; Patz et al., 2000; Vasconcelos et al., 2001; Molyneux, 2003). Although these articles present many examples of human land use modification on the vector-borne disease burden, they do not attempt to address relative contributions of these processes that are not evenly distributed in the global context.

Published online: March 25, 2004

Correspondence to: Douglas E. Norris, e-mail: dnorris@jhsph.edu

Mosquito Biology Generalized

More than 3,000 species of mosquitoes are recognized worldwide. While only a fraction of these are involved in disease transmission, many species can locally expand to high population densities that may present a considerable nuisance to human populations and may even be dangerous for animal populations (e.g., stress and blood loss, especially to young animals).

All mosquitoes share essentially the same pattern of biological development. Eggs are deposited on or near the surface of an existing or expected water source (e.g., within an expected flood zone). Aquatic larva hatch and develop through four instars or growth stages, while feeding on detritus, algae, and biofilms. A few species (although nonvectors) are even predaceous. This aquatic environment need not be voluminous, as mosquitoes can develop in just a few millimeters of water ranging from near freezing to temperatures in excess of 40°C. Habitat may include, for example, fresh or brackish water in ponds, stagnant pools, slow-moving streams, geothermal pools, tree holes, water pooling in artificial containers, bromeliads, crevices, hoof prints, and shallow depressions. Virtually anything that can hold water may provide a habitat to one species of mosquito or another. The larvae may take from a few days to several weeks to develop, depending on temperatures, nutrient levels, and competition for resources. After larval development, a brief pupal stage ensues, rarely lasting more that 48 hours. Adults emerge from the pupal casing, take flight, and mate. Male mosquitoes are relatively short-lived and feed primarily on nectar for energy. Female mosquitoes may feed on nectar for energy, and most species start searching out blood meals soon after mating to provide protein and nutrients to support egg development. After successfully taking a blood meal, digestion, and egg production, the female mosquito seeks out a suitable larval habitat (depending greatly on species) in which to deposit her eggs and the cycle repeats.

Effects of Land Use Change

Natural mosquito habitats in many regions of the world are abundant even without human environmental modification. Human alteration of the environment, regardless of intent (i.e., clearing land for subsistence agriculture or dam construction for hydroelectric power and recreational use) often exacerbates existing mosquito-associated problems by expanding habitats, creating new habitats, or altering habitats in such a way that limited mosquito populations may explode with the availability of new habitats.

The effects of land use change by humans have long been recognized as a factor in the exacerbation of mosquito-borne diseases. Some forms of habitat alteration have been well studied and documented while the effects of other human environmental changes are just now being recognized or rediscovered. These alterations can be placed into several broad and overlapping categories including water retention systems, deforestation, agricultural development, and urbanization. In addition to these alterations, human behavior associated with each of these landscape modifications may contribute significantly to disease transmission.

Water Management

Water management is a broad category that overlaps significantly with other categories and includes ponds, dams, irrigation systems (e.g., canals and ditches), paddies (discussed under agriculture), waste water systems (e.g., cess pits, septic tanks) and storm water management (discussed under urbanization). The relative contribution of these irrigation/impoundment strategies to vector habitats varies considerably (Fig. 1). Most of these systems, however, serve to increase potential mosquito habitat by increasing the surface area of locally available water sources or serve to create new mosquito habitats by introducing water into regions where naturally occurring surface water might be rare or limited (e.g., irrigation into desert regions) (Amerasinghe and Ariyasena, 1990). Among these, the creation of large reservoirs by damming rivers, as well as microdams, are well documented to be associated with increased malaria transmission (Alemayehu et al., 1998). Open waste water systems (e.g., cess pits, septic tanks) function somewhat differently as they increase organically enriched water sources for immature mosquitoes and refugia for adult mosquitoes close to human settlements. Although these sources are suitable only for a limited group of mosquito species, many of these species are associated with transmission of pathogens, such as filariasis and yellow fever (Nwoke et al., 1993; Chavasse et al., 1995; Regis et al., 1995).

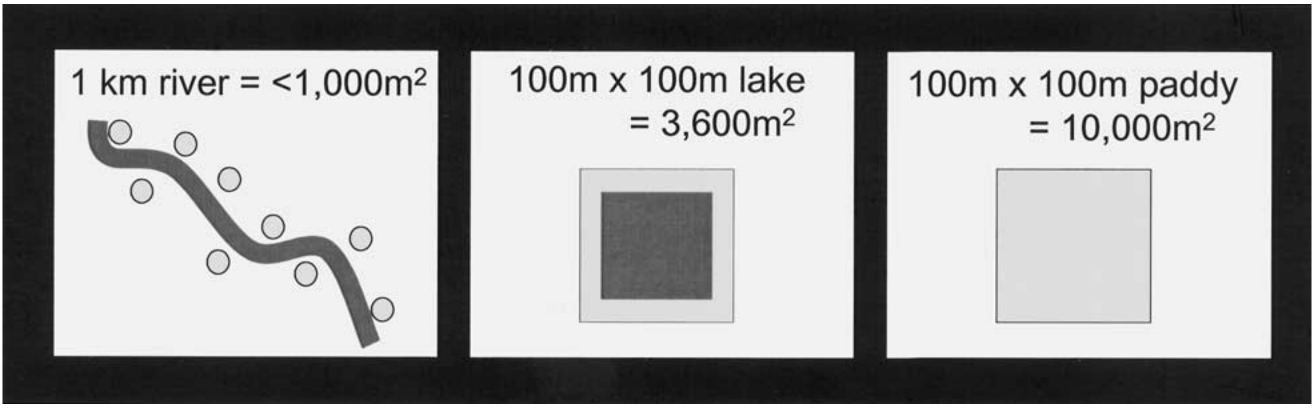

Figure 1. This figure illustrates that the relative contribution to vector habitat of a river, lake, and paddy of equal surface area (10,000 m^2) are inherently different, depending on the specific characteristics of that system. In general, immature mosquitoes prefer relatively shallow, slow moving water for development. Therefore, stream flow is often too rapid, although overflow pools along a river or stream may serve as an ideal habitat. A 1-km section of river 10-m wide may be associated with approximately 1000 m^2 of overflow pools. Similarly, the center of a lake is often too deep and mosquitoes are found to develop predominantly within the first 10 m from shore (3600 m^2). Rice paddies, alternatively, are essentially shallow lakes with emergent vegetation and are ideal for the development of many mosquito species (10,000 m^2).

Deforestation

Deforestation may be a result of a variety of human activities including, but not limited to, logging operations, clear-cutting for agricultural development, and road construction. Deforestation has been one of the major human activities associated with the resurgence of yellow fever and malaria in the Americas as well as the emergence of lesser-known mosquito-borne viruses (Walsh et al., 1993; Carmago et al., 1994; Vasconcelos et al., 1997). Not only has removal of intact forest resulted in the emergence of newly recognized pathogens, but these activities also allow for shifts in relative vector abundances leading to significant disease transmission by vector species that may not have been previously incriminated (Tadei and Dutary Thatcher, 2000; Conn et al., 2002). Although "deforestation" is the activity associated with these disease manifestations, it is important to recognize that the actual process of altered transmission might be very different among the limited examples provided here. The felling of trees, for example, is a mechanism by which yellow fever virus is transported from the forest canopy, where it is maintained as in a "sylvatic" enzootic cycle in monkeys and mosquitoes, to the forest floor where humans become exposed and help perpetuate the "urban" transmission cycle. In contrast, malaria in South America has reemerged as removal of the forest canopy has created a suitable habitat for the expansion of vector mosquitoes. In deforested areas of the Amazon basin, *Anopheles darlingi* has arisen as the predominant vector of malaria. Yet this mosquito is not found in intact forests as it prefers the sunlit pools created by the removal of the canopy.

Deforestation also attracts and clusters humans for agriculture, road building, and logging. As *Plasmodium*-infected individuals enter the area, the vector and environment have already been modified in favor of transmission resulting in both small and large epidemics. In Africa, similar shifts in vectors have occurred due to habitat modification and fragmentation favoring mosquitoes with higher vectorial capacities (Manga et al., 1995). Vectorial capacity is a measurement of the efficiency of vector-borne disease transmission. This measurement is usually calculated as the number of infective bites received daily or annually by a single host. Vectorial capacity takes into account the density of vectors, length of gonotrophic cycle, daily survivorship of the vector, extrinsic incubation period, and the competence of that vector for the pathogen of interest. In this case, deforestation resulted in the establishment of *An. gambiae* as a malaria vector around a newly constructed airport. Just 3 km away from the deforested area, *An. gambiae* had no role in malaria transmission.

Agricultural Development

Agricultural development not only increases the risk of vector-borne disease by placing people in vector habitats, but is often associated with activities that directly alter environmental conditions in favor of mosquitoes (e.g., deforestation, water management) (Ramasamy et al., 1992). In addition to direct effects, agricultural development and related activities are also associated with sedimentation and runoff. Although well-known as a source of pollutants, sedimentation of rivers and reservoirs slows or blocks stream flow and may significantly decrease water depth (Dian and Changxing, 2001). Mosquitoes prefer warm, shallow water with little to no flow, suggesting that sedimentation is an ideal process for creating suitable mosquito habitat. Agricultural development may also alter local climate such that an apparently minute change in local temperatures may be enough to alter the vectorial capacity of available vectors. Even small increases in temperature may increase the development time of mosquitoes, increase mosquito population densities and shorten the extrinsic incubation period of the pathogen resulting in enhanced transmission. This process has recently been implicated for increases in malaria transmission in the African highlands (Lindblade et al., 2000).

One of the most important agricultural modifications associated with mosquito-borne diseases is the rice paddy. These shallow bodies of water with emergent vegetation and little flow are ideal habitats for the development of immature mosquitoes (Fig. 1). In many regions of the world, contiguous rice paddies may cover immense areas resulting in unimaginable mosquito densities. Documentation of higher vector densities near large-scale ricefields is abundant, although the effects on malaria transmission appear to be dependent on local population immunity (Ljumba and Lindsay, 2001; Ljumba et al., 2002). In this respect, communities with unstable malaria transmission and relatively low immunity may see enormous increases in malaria due to increased vector abundance, whereas communities with relatively stable malaria transmission are likely to see little change in malaria prevalence by this mechanism. Regardless of these observations, a growing body of evidence suggests that communities near large-scale irrigation projects in Africa may benefit from improved local economies and the availability of better health care (Ljumba and Lindsay, 2001; Ljumba et al., 2002).

URBANIZATION

Like agricultural development, urbanization exposes humans to a new set of adapted pathogens and vectors, as well as being a process associated with other activities known to alter vector habitats and behavior (e.g., water management, deforestation). In urban settings, runoff, sedimentation, and sewage management cause problems similar to those in the rainforests of South America and reservoirs of Asia. However, one of the environmental modifications that is somewhat unique to urban settings worldwide are the kilometers of pipe underneath the streets of almost every large city that constitute the subterranean storm water handling system. This man-made habitat appears to be very suitable for *Culex* mosquitoes, notorious vectors of many viruses such as Ross River virus in Australia and West Nile virus in both the Old and New World (Byrne and Nichols, 1999; Kay et al., 2000b). In fact, the potential risks from these breeding sites and refugia may be higher than previously expected. Researchers in Australia have found that subterranean habitats may account for as much as 78% of the vector mosquitoes during the dry season when surface water is scarce (Kay et al., 2000a). Additionally, these researchers have found that dengue virus exposure (transmitted by Aedes mosquitoes) is approximately 2.5 times greater for people living within 160 meters of a well or service manhole (Russell et al., 2002). The contribution of subterranean and surface storm water systems to vector abundance and disease transmission is unknown for most regions, and vector specialists are rarely consulted before implementation. Small urban regions like Nassau County, New York, where West Nile virus emerged in the United States, have approximately 650 recharge basins, 70,000 street basins, 200 miles of streams, and 50 ponds (Nasci et al., 2001). In the United States, as in this example, these are habitats that should be monitored more closely with the spread and threat of West Nile virus and the propensity of these systems to harbor *Culex* mosquitoes that are involved in the transmission cycle of this virus (Geery and Holub, 1989).

In addition to sewers and storm water systems, a contributing source of mosquito habitats that is uniquely associated with man worldwide, are artificial containers. These range from bottle caps and flower vases in cemeteries to swimming pools, 55-gallon drums, discarded tires, and junkyards. Virtually any container that can hold water can serve as mosquito habitat and the source of large mosquito populations. The elimination of many of these sources could significantly reduce mosquito populations and the threat of disease transmission, but this solution is difficult to implement.

Summary and Recommendations

Land use change has an enormous impact on local ecology and habitats that effect mosquito abundance, species composition and, ultimately, pathogen transmission. The effects of habitat alteration on vector populations are compounded by a wide variety of factors, making predictions on vector abundance and disease prevalence difficult without the appropriate surveillance operations in place. For example, an increase in competent malaria vectors may not be locally significant in terms of pathogen transmission, unless there is an indigenous population of infected persons or an influx of malarious and/or susceptible individuals from another region, as seen in South America. Similarly, urban development in many parts of the world occurs without the consultation of entomologists, epidemiologists, and healthcare specialists to address issues such as storm water management, urban refugia, and vector control. Working groups composed of representative experts focused on these types of issues may be able to develop sound urban development strategies, allowing for necessary urban and human expansion while reducing undesirable environmental effects leading to an increased disease burden.

Acknowledgments

I thank Dr. Charles Apperson for introducing me to the importance of storm water management to vector control, and Aimee West for valuable editorial comments.

References

Alemayehu T, Ye-ebiyo Y, Ghebreyesus TA, Witten KH, Bosman A, Teklehaimanot A (1998) Malaria, schistosomiasis, and intestinal helminthes in relation to microdams in Tigray, northern Ethiopia. *Parassitologia* 40:259–267

Amerasinghe FP, Ariyasena TG (1990) Larval survey of surface water breeding mosquitoes during irrigation development in the Maahaweli Project, Sri Lanka. *Journal of Medical Entomology* 27:789–802

Byrne K, Nichols RA (1999) *Culex pipiens* in London Underground tunnels: differentiation between surface and subterranean population. *Heredity* 82:7–15

Carmago LMA, Ferreira MU, Krieger H, de Carmago EP, da Sila LP (1994) Unstable hypoendemic malaria in Rondonia (Western Amazon Region, Brazil): epidemic outbreaks and work associated incidence in an agro-industrial rural settlement. *American Journal of Tropical Medicine and Hygiene* 51:16–25

Chavasse DC, Lines JD, Ichimori K, Marijani J (1995) Mosquito control in Dar es Salaam. I. Assessment of Culex quinquefasciatus breeding sites prior to intervention. *Medical and Veterinary Entomology* 9:141–146

Conn JE, Wilkerson M, Segura MNO, De Souza RTL, Schlichting CD, Wirtz RA, et al. (2002) Emergence of a new neotropical malaria vector facilitated by human migration and changes in land use. *American Journal of Tropical Medicine and Hygiene* 66:18–22

Dian Z, Changxing S (2001) Sedimentary causes and management of two principal environmental problems in the lower Yellow River. *Environmental Management* 28:749–760

Geery PR, Holub RE (1989) Seasonal abundance and control of *Culex* spp. in catch basins in Illinois. *Journal of the American Mosquito Control Association* 5:537–540

Gratz NG (1999) Emerging and resurging vector-borne diseases. *Annual Review of Entomology* 44:51–75

Ljumba JN, Lindsay SW (2001) Impact of irrigation on malaria in Africa: paddies paradox. *Medical and Veterinary Entomology* 15:1–11

Ljumba JN, Mosha FW, Lindsay SW (2002) Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania. *Medical and Veterinary Entomology* 16:28–38

Kay BH, Ryan PA, Russell BM, Holt JS, Lyons SA, Foley PN (2000a) The importance of subterranean mosquito habitat to arbovirus vector control strategies in North Queensland, Australia. *Journal of Medical Entomology* 37:846–853

Kay BH, Sutton KA, Russell BM (2000b) A sticky entry-exit trap for sampling mosquitoes in subterranean habitats. *Journal of the American Mosquito Control Association* 16:262–265

Lindblade KA, Walker ED, Onapa AW, Katungu J, Wilson ML (2000) Land use change alters malaria transmission parameters by modifying temperature in a highland area of Uganda. *Tropical Medicine & International Health* 5:263–274

Manga L, Toto JC, Carnevale P (1995) Malaria vectors and transmission in an area deforested for a new international airport in southern Cameroon. *Annales de la Societe Belge de Medecine Tropicale* 75:43–49

Molyneux DH (2003) Common themes in changing vector-borne disease scenarios. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 97:129–132

Mouchet J, Carnevale P (1997) [Impact of changes in the environment on vector-transmitted diseases]. *Sante* 7:263–269 (in French)

Nasci RS, Newton NH, Terrillion GF, Parsons RE, Dame DA, Miller JR, et al. (2001) Interventions: vector control and public education (panel discussion). *Annals of the New York Academy of Sciences* 951:235–254

Nwoke BE, Nduka FO, Okereke OM, Ehighibe OC (1993) Sustainable urban development and human health: septic tanks are a major breeding habitat of mosquito vectors of human diseases in south-eastern Nigeria. *Applied Parasitology* 34:1–10

Patz JA, Graczyk TK, Geller N, Vittor AY (2000) Effects of environmental change on emerging parasitic diseases. *International Journal of Parasitology* 12-13:1395–1405

Ramasamy R, De Alwis R, Wijesundere A, Ramasamy MS (1992) Malaria transmission at a new irrigation project in Sri Lanka: the emergence of *Anopheles annularis* as a major vector. *American Journal of Tropical Medicine and Hygiene* 47:547–553

Regis L, Silva-Filha MH, de Oliveira CM, Rios EM, da Silva SB, Furtad AF (1995) Integrated control measures against *Culex quinquefasciatus*, the vector of filariasis in Recife. *Memorias do Instituto Oswaldo Cruz* 90:115–119

Russell BM, McBride WJH, Mullner H, Kay BH (2002) Epidemiological significance of subterranean *Aedes aegypti* (Diptera: Culicidae) breeding sites to dengue virus infection in Charters Towers, 1993. *Journal of Medical Entomology* 39:143–145

Tadei WP, Dutary Thatcher B (2000) Malaria vectors in the Brazilian amazon: *Anopheles* of the subgenus Nyssorhynchus. *Revista do Instituto de Medicina Tropical de Sao Paulo* 42:87–94

Vasconcelos PF, Rodrigues SG, Degallier N, Moraes MA, da Rosa JF, da Rosa ES, et al. (1997) An epidemic of sylvatic yellow fever in the southeast region of Maranhao State, Brazil, 1993–1994: epidemiologic and entomologic findings. *American Journal of Tropical Medicine and Hygiene* 57:132–137

Vasconcelos PFC, Travassos da Rosa APA, Rodrigues SG, Travassos da Rosa ES, Dégallier N, Travassos da Rosa JFS (2001) Inadequate management of natural ecosystem in the Brazilian Amazon region results in the emergence and reemergence of arboviruses. *Cademos de Saúde Público, Rio de Janeiro* 17(Suppl):155–164

Walsh JF, Molyneux DH, Birley MH (1993) Deforestation: effects on vector-borne disease. *Parasitology* 106(Suppl):S55–S75