Acta Tropica 163 (2016) 121–129

Contents lists available at ScienceDirect

Acta Tropica

journal homepage: www.elsevier.com/locate/actatropica

Abundance and distribution of immature mosquitoes in urban rivers proximate to their larval habitats

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ARTICLE INFO

Article history:
Received 13 July 2016
Received in revised form 31 July 2016
Accepted 6 August 2016
Available online 8 August 2016

Keywords:
Polluted urban rivers
Immature mosquito density
Water quality parameters
Habitat factors
Mosquito species

ABSTRACT

Whether ecological restoration of polluted urban rivers would provide suitable breeding habitats for some mosquitoes was not clear yet. It was therefore important to determine how altered river conditions influence mosquito ecology. Monthly data on water quality and larval density were obtained to determine the effects of river systems on the distribution and abundance of immature mosquitoes in two coastal cities in Eastern China. In total, 5 species within two genera of mosquitoes were collected and identified in habitat with vegetation from three positive rivers. *Culex pipiens pallens* was the most abundant and widely distributed species. A new species (*Culex fuscanus*) was reported in certain districts. Physico-chemical parameters of river water were important, but not the only, set of influences on immature mosquito breeding. Aquatic vegetation could increase the likelihood of mosquito breeding while artificial aeration might prevent the approach of mosquitoes. Slow-moving water might be a new potential marginal habitat type for some Culex and *Aedes albopictus*. Variation of river system with ecological restoration might influence the abundance and distribution of immature mosquitoes.

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1. Introduction

River water quality is one important factor that directly influences the health of humans and other organisms (Li et al., 2014). In recent years, the environmental policy of ecological restoration has become progressively more popular as a way of improving the water quality of polluted urban rivers affected by point- or nonpoint-source pollution (Hwang et al., 2014; Short, 2013). River restoration is a priority and needed now and in the future. Simultaneously, urban wet environments, particularly wetlands, have been described as “mosquito-friendly habitats” and may pose threats to neighboring human populations (Patrick et al., 2008; Dale and Knight, 2008). Calhoun et al. (2007) indicated that water flow rates > 15 kilogallons/min would eliminate almost all larval mosquitoes in Tanyard Creek, and highest mosquito densities were associated with stagnant and slow-moving water. Urban wet environments may also change the distribution and abundance of mosquitoes, increasing the risk of mosquito-borne diseases such as malaria, Japanese encephalitis, and dengue fever. These mosquito-borne diseases have caused millions of illnesses and deaths annually around the world, particularly in tropical and subtropical countries (Becker et al., 2010; Schaffner et al., 2013).

Although only adult females directly interact with humans, the distribution and abundance of mosquito species are mainly regulated by ecological processes at the immature stages, especially the egg (e.g.,desiccation) and larval (e.g., competition and predation) stages (Juliano, 2009). Mosquitoes breed in almost all kinds of lentic habitats, resulting in complex larval communities (Manguin and Boete, 2011). Generally speaking, all the immature mosquito (eggs, larvae and pupae) stages could not develop without water (Becker et al., 2010). The larval aquatic stage is an important part of the mosquito life cycle, and habitat factors may strongly influence subsequent adult distribution and abundance (Mwangangi et al., 2012). Knowledge of the effects of habitat factors on larval production is essential to understanding the spatial and temporal distribution patterns of mosquito vector species (Grillet et al., 2010).

Many environmental variables can have a direct or indirect effect on mosquito oviposition (Yee et al., 2010) and subsequently on larval distribution, density, and development (Stein et al., 2011).

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http://dx.doi.org/10.1016/j.actatropica.2016.08.010
0001-706X/© 2016 Published by Elsevier B.V.

Field studies have indicated that, by recognizing key habitat factors, mosquitoes can select suitable habitats for egg deposition (Hamady et al., 2012). The suitability of a site for mosquito breeding depends on complex interactions of biotic factors such as competitors (Reiskind and Wilson, 2008), predators (Shaalan and Canyon, 2009), and food availability (Gildas et al., 2014). In addition, abiotic factors such as precipitation (Koenraadt et al., 2004), temperature (Marta et al., 2015) and water quality parameters also influenced breeding (Michelle et al., 2013). Understanding how these factors influence the abundance and distribution of mosquito larvae would be essential for the design and implementation of integrated vector management programs (Mwangangi et al., 2013).

Numerous studies have evaluated mosquito breeding habitats. Different mosquito species might inhabit different habitats. Discarded vehicle tires (Yee et al., 2010), household water storage containers (Nsa et al., 2013) and marshes (William et al., 2012) seemed to be the positive larval habitats for *Aedes* and *Culex*. However, little attention has been paid to urban rivers, especially small and medium rivers characterized by subcritical flow. The vegetation used in ecological restoration of polluted urban rivers could affect the breeding environment by weakening both wind speed and the amount of sunlight reaching aquatic habitats. Literature indicated that vegetation should protect mosquito larvae from predation and from being swept or flushed away by running water (Paaijmans et al., 2007). Dense vegetation may also provide good foraging conditions for mosquito larvae; moreover, stagnant water may benefit the hatching of mosquito larvae as it becomes warmer with less oxygen (Becker et al., 2010). Similar to wetland systems, such restoration efforts can also provide newly emerged adult and gravid mosquitoes with conveniently shaded resting sites (Muturi et al., 2008). Rivers polluted with industrial contaminants (e.g. heavy metal irons) may have lower mosquito densities (Mireji et al., 2008), while rivers polluted with high nutrient loading may have higher mosquito densities. Pollutants such as organic matter, nitrogen and phosphates from urban rivers provide necessary food for the development of mosquito larvae (Andrea et al., 2014).

The optimal water characteristics for larval development were considered as neutral pH, low salt concentration, and a relatively low level of suspended particulate matter (Julien et al., 2010). Previous studies reported that larval density was associated with ammonia concentrations (Gardner et al., 2013), pH, chloride, and sulfate (Moussa et al., 2014), and bacteria and dissolved organic carbon (Leisnham et al., 2005). Khawling et al. (2014) indicated that the abundance and diversity of culicine and anopheline larvae were strongly associated with pH, temperature, dissolved oxygen, alkalinity, phosphates and chloride concentrations. Given these factors, it is essential to determine, first, whether ecological remediation measures will turn small and medium rivers into optimal habitats for mosquito breeding and, second, how different habitat factors influence the abundance and distribution of mosquitoes.

According to report of Shanghai Municipal Commission of Health and Family Planning, the morbidity of dengue and Japanese encephalitis in Shanghai 2015 was 0.01 and 0.08 per 0.1 million population respectively, of which, incidence of dengue was twice as high than 2014. In addition, Zhejiang Provincial Center for Disease Control and Prevention reported that the morbidity of dengue and Japanese encephalitis in Wenzhou 2015 was 0.11 and 0.04 per 0.1 million population respectively. Human cases often occurred in or near areas with abundant vector and host populations (Carver et al., 2015), thus, more attention should be paid on the abundance and distribution of mosquito and its latent risk of disease to human in the regions.

This study evaluated factors affecting larval populations in six urban rivers in two coastal cities in Eastern China. Specifically, physico-chemical water quality parameters, environmental conditions of the rivers, and seasonal variations were surveyed as determinants of larval distribution and abundance. Evaluating the composition and quality of larval mosquito habitats helps us to understand their breeding features and implement appropriate larval control strategies. So as to better comprehend how to mitigate disease incidence and promote human and environmental health concurrently. Our specific objectives were to (1) assess water quality of six urban rivers, (2) investigate the use of rivers for mosquitoes of potential medial importance, and (3) ascertain the influence of larval habitat factors on distribution and abundance of immature mosquitoes.

2. Materials and methods

2.1. Study rivers

Surveys were conducted monthly between August 2013 and July 2014 in six urban rivers in the cities of Shanghai and Wenzhou in Eastern China (Fig. 1). Both Shanghai and Wenzhou city belong to subtropical marine monsoon climate, the annual average temperature, relative humidity and annual rainfall of Shanghai and Wenzhou are approximately 17.3 °C and 18.1 °C, 75% and 78%, 1234.4 mm and 1818.0 mm, respectively. There are total 33 127 rivers including great rivers in Shanghai and 1 104 rivers in Wenzhou according to Shanghai Water Authority and Bureau of Wenzhou Water Resources respectively. River systems were selected based on their potential for harboring larvae (Calhoun et al., 2007). Higher incidence of mosquitoes has been associated with smaller (<0.2 ha) rather than larger water body (Chanda and Shisler, 1980). Therefore, sampling was performed in six small and medium (<3 ha) rivers (Fig. 1) with average length (L), width (W) and depth (D): Gongye (GY, 856 m (L) × 10 m (W) × 1.2 m (D)), Danjiang (DJ, 570 m (L) × 6 m (W) × 1.0 m (D)), Liwa (LW, 630 m (L) × 34 m (W) × 1.7 m (D)), Zhenru (ZR, 1 800 m (L) × 9 m (W) × 1.5 m (D)), Shanxia (SX, 1 200 m (L) × 12 m (W) × 1.4 m (D)) and Jiushan (JS, 1 750 m (L) × 13 m (W) × 1.3 m (D)).

The six rivers located in mixed residential and industrial areas (GY), squatter settlements (DJ), university campus (LW), old residential areas (ZR) of Shanghai city, and urban villages (SX) and city center (JS) of Wenzhou city, respectively. The plant compositions of six rivers were summarized as follows: river GY contained *Acorus calamus, Alternanthera Philoxeroides* and *Pontederia cordata*; water surface of river DJ was covered with *Lemna minor* entirely; aquatic plants of river LW consisted of *Ceratophyllum demersum*, *Potamogeton crispus*, *Nymphaea tetragona* and *Lotus flower*; river ZR contained *Phragmites australis*, *Acorus calamus*, *Nymphaea tetragona* and *Canna indica*; *Arundo donax var. versicolor*, *Canna indica*, *Hydrocotyle vulgaris*, *Myriophyllum verticillatum*, *Cyperus alternifolius*, and *Pontederia cordata* were found in both river SX and river JS. Rivers except river DJ with no treatment measures were implemented with phytoremediation and artificial aeration by our team during 2005–2012. But today, working aerators (NOZZLE-A2200, OBAO, China) were available in river SX and JS among the six rivers. About one aerator per 100 m fixed in the two rivers.

2.2. Water sample collection and analysis

From August 2013 to July 2014, monthly sampling at 32 sampling points (i.e. GY 5, DJ 3, LW 5, ZR 7, SX 5 and JS 7) was conducted with the aid of boats in six urban rivers, approximately one site per 200 m. Sampling was not conducted during inclement weather events such as typhoons. Water samples from each labeled site were collected with sterile 1000 mL polyethylene terephthalate bottles. All water samples were transported to the Laboratory of Environmental Engineering, East China Normal University, and

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