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Spatio-temporal dynamics of mosquitoes in stream pools of a biosphere reserve of Southern Western Ghats, India

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ABSTRACT

The spatial and temporal dynamics of mosquitoes in stream pools were examined in a biosphere reserve of the Southern Western Ghats, India. The immature mosquitoes in stream pools were collected from stream substrates of bedrock pool, boulder cavity and sand puddle. The collected larvae and pupae were reared and identified. In total, 16 species from four genera of mosquitoes were collected. The mosquito species from *Culex* and *Anopheles* were predominantly occurred. The bedrock pool had the highest diversity and abundance of mosquitoes. The statistical analyses showed that the substrate specificity and the seasons were positively related to the distribution of mosquitoes rather than spatial pattern. This study described the spatial and temporal pattern of mosquitoes in stream pools of the Southern Western Ghats. This information would be helpful to National Vector borne disease control program for surveillance and control.

1. Introduction

An increasing number of studies are providing the possible interactive effects of climate and urbanization on vector-borne diseases. The epidemiology of vector-borne diseases are directly influenced by climate change and variability, which affect the human health (Ramasamy and Surendran, 2012; Thomson, 2014). According to World Health Organization, vector-borne diseases account more than 17% of all infectious diseases. Among insects, mosquitoes are the major vector for transmitting vector-borne diseases (Campbell-Lendrum et al., 2005). Mosquitoes can breed in a variety of aquatic environments and even very small amount of water in any substrate (McFeeters, 2013). In general, mosquitoes cannot breed successfully in lotic waters, whereas some mosquito species breeds in streams when they dry up (Gaines, 2014).

Among the 43 genera of mosquitoes, three genera of *Aedes*, *Anopheles* and *Culex* generally breed in stagnant waters (Rattanarithikul et al., 1995; Muturi et al., 2007). Many species of these genera are the major vectors of life threatening diseases like dengue, malaria and Japanese encephalitis (Kovendan et al., 2012). Since forested areas have the highest number of streams, the assessment of mosquitoes in streams is an integral part of disease surveillance and control programs. Subsequently, wild animals are reservoirs of infectious diseases and possible to spread the parasites through mosquitoes (Simpson, 2002). Therefore, ecological profiles of mosquitoes in forest areas are imperative to control of vector species, tribal health monitoring and conservation of wild animals.

Several studies on mosquitoes concerning diversity (Bernues-Baneres and Jimenez-Peydro, 2013; Bond et al., 2014), behavior (Cator et al., 2013; Braack et al., 2015), effect of environmental variables (Courtney et al., 2012; Parham et al., 2012), host-specificity (Ventim et al., 2012; Takken and Verhulst, 2013), vector potential (Ramasamy and Surendran, 2012; Turell et al., 2013); and control measures (Bukhari et al., 2013; Alphey, 2014; Strode et al., 2014) have been conducted. Collins and Glenn (1991) highlighted the importance of spatial and temporal dynamics in species regional abundance and distribution and these factors were widely applied in mosquitoes monitoring and vector-borne disease surveillance areas (Ganser and Wisely, 2013; Lin et al., 2014). Several studies on mosquitoes have been conducted in urban and associated areas, but sporadic reports with less attention have received in the distribution of mosquitoes in stream pools. In this study, we investigated the spatial and temporal dynamics of mosquitoes in stream pools of a biosphere reserve of Southern Western Ghats, India.

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2. Materials and methods

2.1. Study area

Mosquitoes were collected in ten streams from the Agasthyamalai biosphere reserve (ABR) of Southern Western Ghats (Fig. 1). It is located in Tamil Nadu and Kerala Provinces (08° 08′–09° 10 N, 76° 52′–77° 34′ E) and its total surface accounts for 3500.36 km^2 of which 1828 km^2 is in Kerala and 1672.36 km^2 is in Tamil Nadu states. ABR is influenced by two monsoons (South–West and North–East monsoon) and annual rainfall generally ranged up to 5000 mm. ABR consists of moist deciduous and rain forests, and have varieties of plants and animals, and is also home to ancient Kanikaran tribes. This topography consist of many perennial hill streams and rivers. The major rivers of this region are Kallada, Vamanapuram, Karamana, Neyyar, and Thamirabarani rivers. These geographic regions are suitable for the development of mosquitoes, especially in the habitat of lotic environments.

2.2. Sampling

In stream, bedrock, boulders, pebbles, sand, leaf litter, and woody debris are the major substrates. At time of post monsoon or low stream flow, these substrates provide an ideal breeding habitat for mosquitoes. During the pilot survey, we found that the major breeding habitats of mosquitoes are bedrock pools, boulders cavities and sand puddles in streams (Fig. 2). Since, we sampled in these three substrates of each study site. To study the spatial pattern, 10 streams were selected in ABR and samplings were done between August 2013 and July 2014. Of 10 streams, Kallada River was selected for studying temporal pattern. Physical characteristics of temperature, depth, and color of water were recorded. The presence of floating and emergent vegetation was noted and their proportion in the respective habitat was recorded. The chemical characteristics of pH, conductivity, total dissolved solids and dissolved oxygen were measured using portable water analysis tester (PCS Testr 35, Eutech instruments, India). The water color was observed visually and categorized as light yellow, yellow, light green, and transparent.

Up to 10 dips were taken at intervals along the edge of each stream substrate using a standard mosquito circular dip net (10 cm in diameter × 10 cm depth). The larvae and pupae for each habitat were placed in a plastic container (5 cm in diameter × 5 cm deep) half filled with respective habitat water and transported to the laboratory where they were reared until adult emergence. The larvae, pupae and emerged adults were preserved in 99–100% ethanol. Adult specimens were identified by taxonomic keys (Das et al., 1990; Reuben et al., 1994) and the same specimens were also identified in Centre for Research Medical Entomology (ICMR), Madurai. Generic and subgeneric abbreviations of mosquito species were followed by Reinert (1975).

2.3. Data analysis

At each sampling site, diversity indices of Shannon–Wiener, Simpson, Dominance and Evenness were estimated. Shannon–Weiner index was graphically presented to illustrate the variation in sampling sites. Similarities in species composition were calculated using Jaccard's index based on a presence–absence matrix of the mosquito fauna. Beta diversity indices of Whittaker, Harrison, Cody, Routledge, Wilson–Shmida, Mourelle, and Harrison were calculated. Turkey's pairwise analysis was used to test the habitat similarity between sampling sites. The faunal structure with environmental variables among sampling sites and effect of seasonality on mosquitoes were subjected multivariate analyses of Principal Component Analysis (PCA) and Correspondence Analysis (CA) following ln $(x+1)$ transformation to normalize the distribution and eliminate zero values (Dinakaran and Anbalagan, 2007). Kruskal–Wallis test was used to test the significant relationship between CA axes values with seasonality. All statistical analysis was performed by using PAST version 3.06 (Hammer et al., 2001).

3. Results

3.1. Physico–chemical profiles

The physical and chemical parameters of sampling sites are given in Table 1. The average water temperature was 28.7 °C. The site of Keeriparai had the maximum temperature, and Madathara site had the minimum temperature. The mean water depth of bedrock pools, boulder cavities and sand puddles were 11, 7, and 10 cm, respectively. The total dissolved solids level was identical to all sampling sites, and the mean value was 175.36 mgL^{-1}. The average dissolved oxygen, pH and conductivity were 9.45 mgL^{-1}, 6.7 and 226 μS/cm, respectively. The floating vegetations in stream substrates were green algae, grasses, leaves of *Pongamia*, *Terminalia*, *Bambusa* and *Artocarpus* sp., and they ranged from 0 to 70%. The water color ranged from transparent to dark yellow. The physico–chemical parameters measured in the Kallada River of Southern Western Ghats are given in Table 2. The bedrock pools were not shown during October and November due to heavy rain or flood and these pools were dried during summer (April and May), boulder cavities filled with water in all months except summer (March–May) and sand puddles were found during post monsoonal periods (August–September and December–March).

3.2. Diversity and distributional pattern

A total of 15,528 of larvae belonging to 16 species and four genera of Culicidae family were collected from three substrates in 10 streams of Southern Western Ghats. Among sampling sites, Five falls stream had the maximum number of species (14 species), whereas, Nambiyar stream harbored the minimum number of species (10 species). *Ae.* (*Och.*) *pseudotaeniatus*, *Cx.* (*Lut.*) *fuscanus* and *Cx.* (*Cux.*) *vishnui* had the widest distributional range, whereas *Tx.* (*Tox.*) *splendens*, *Ae.* (*Stg.*) *vittatus* and *An.* (*Cel.*) *mirans* had the narrowest distribution range (Fig. 3). The alpha diversity indices (Shannon (H), Simpson (1-D), Dominance (D) and Evenness) indicated that the highest diversity found in Five falls stream and the lowest diversity was in Nambiyar stream (Fig. 4). Among the distribution of mosquito species in sampling sites, Five falls and Manimutharu streams had the highest similarity (0.9) and other sites showed partial to low similarity revealed by the Jaccard's similarity index. The same pattern was observed in the beta diversity indices (Table 3).

The bedrock pool contributed more than 47% of total abundance of mosquitoes followed by 32% in sand puddles and 21% in boulder cavities. In each stream, 80–90% of taxa were restricted to the bedrock pools, 40–60% of boulder cavities and 30–40% of sand puddles. *Ae.* (*Stg.*) *vittatus*, *Ae.* (*Och.*) *pseudotaeniatus*, *An.* (*Cel.*) *culicifacies*, *An.* (*Cel.*) *jamesii*, *An.* (*Cel.*) *karwari*, *An.* (*Cel.*) *mirans* and *Tx.* (*Tox.*) *splendens* preferred in the bedrock pool than other two substrates. *An.* (*Cel.*) *stephensi*, *Cx.* (*Lut.*) *fuscanus*, *Cx.* (*Lop.*) *bicornutus*, *Cx.* (*Cux.*) *tritaeniorhynchus* and *Cx.* (*Cux.*) *barraudi* coexisted with bedrock pool and boulder cavities. *Ae.* (*Stg.*) *aegypti*, *Cx.* (*Cux.*) *tritaeniorhynchus*, *Cx.* (*Cux.*) *vishnui* and *C.* (*Ocu.*) *bitaeniorhynchus* favored with sand puddles.

3.3. Spatial pattern

Turkey's pair-wise analysis was used to test the substrate similarity in each stream. It is clearly shown that the high similarity