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Source: Journal of Insect Science, 7(32) : 1-10

Published By: Entomological Society of America

URL: https://doi.org/10.1673/031.007.3201

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Mosquito species associated within some western Himalayas phytogeographic zones in the Garhwal region of India

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Abstract

Thirty four species of mosquitoes (Diptera: Culicidae) were collected across three phytogeographic zones; tropical (300 to 1000 m), sub tropical (1000 to 2000 m) and temperate (2000 to 3000 m) in the Garhwal region of India. They included 5 genera: *Aedes, Anopheles, Armigeres, Culex* and *Uranotaenia*. Of these, the immature forms of 23 species were recovered from different breeding habitats. The larval habitats were seepage pools, river beds, rice fields, tanks, forest pools, ditches, streams, rock holes, tree holes, intradomestic containers and shallow pits. Three groups and two separate individual species were associated, based on breeding habitat similarity by means of cluster analysis. The characters taken into consideration for classification were natural/artificial, temporary/permanent, shady/lighted, vegetation, movement and turbidity. Breeding habitats such as streams and rock holes were the richest habitats shared by 18 mosquito species followed by seepage pools harboring 16 species of mosquitoes. The lowest species diversity (6 species) was recorded from shallow pits. Generally, all the collected species were found in natural habitats in quiet/stagnant conditions at a depth of 0.1–0.5 m. Generally, the maximum number of species preferred partially shady and temporary water habitats. Moderate vegetation and clear water habitats also had a diversity of mosquito species. *Culex mimeticus* Noe and *Anopheles maculatus* Theobald had the highest association coefficient (0.941) followed by *Anopheles stephensi* Liston and *Anopheles vagus* Donitz (0.884). The highest negative association (–0.30) was found between the species of *Culex vishnui* Theobald and *Culex brevipalpis* (Giles). There were a few species of mosquitoes for which only immatures were collected. Phytogeographically, the zones of lower elevation shared higher species abundance than the higher elevation.

Keywords: immature, Culicines, Anophelines, breeding habitat similarity, cluster analysis
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Received: 6 June 2006 | **Accepted:** 10 November 2006 | **Published:** 16 May 2007
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ISSN: 1536-2442 | Volume 7, Number 32

Cite this paper as:
Devi N, Jauhari RK. 2007. Mosquito species associated within some western Himalayas phytogeographic zones in the Garhwal region of India. 10pp. *Journal of Insect Science* 7:32, available online: insectscience.org/7.32

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Introduction

Species never exist alone but always assemble together with other organisms to form a community in the same area or habitat. The co-existence of more than one species in a habitat at a given time indicates that species share habitat requirements. For example, different species of immature stages of mosquitoes occupy the same habitat and are, therefore, part of a guild. Understanding the relationship between habitats, environmental factors and occurrence of immature mosquitoes is essential for an efficient application of mosquito control methods. The majority of mosquito species preferred to breed in permanent breeding sites, especially natural sites in urban, semiurban and periurban areas, while some species are more abundant in temporary breeding places. Hence, the association between species of mosquitoes can provide clues to an understanding their biology and their role in the transmission of pathogens.

Senior White (1926) grouped the mosquitoes based on their preference of breeding habitats, which emphasized the ability of different species to select breeding habitats. Contributions made by earlier workers regarding breeding of different species under field conditions are entirely based on frequency of co-occurrence of the immature and have not been analysed statistically to know the strength of association or repulsion between them (Cole 1949; Bhat 1975a,b; Malhotra et al. 1987 and Bhatt et al. 1990). A number of studies have been carried out on Anopheline mosquito breeding in various habitats (Iyengar 1932; Russell and Rao 1940; Rahman et al.1973; Rajagopalan et al. 1979; Sahu et al. 1990; Bhatt et al. 1993). The studies of Reisen et al. 1981, Savage *et al.* 1993, Almiron and Brewer (1996) and Rajnikant et al. 1998 demonstrate interspecific associations among mosquitoes and a correlation with physicochemical and biological composition of mosquito breeding waters. Further, Robert et al. 1998 studied the ecology of larval mosquitoes with special reference to *Anopheles arabiensis* Patton in market-garden wells in urban Dakar, Senegal. Subsequently, Minakawa et al. 1999 and Edillo et al. 2002 conducted studies on spatial distribution and habitat characterization of Anopheline mosquito larvae in western Kenya and West Africa respectively and discussed factors that influence their distribution patterns. Later on, Sattler et al. (2005) undertook studies on habitat characterization of *Anopheles* mosquito larvae in Dar es Salaam, Tanzania, and noted the turbidity and location of breeding habitats as key factors influencing the larval diversity. Rueda et al. 2005, 2006 described habitats and distribution patterns of *Anopheles sinensis* Wiedemann and the *An. hyrcanus* group. Recently, Aditya et al. 2006 conducted studies on larval habitats and temporal variations in mosquito diversity in the hill town of Darjeeling Himalayas, India, for a qualitative and quantitative assessment of mosquito distribution.

Some related mosquito faunal studies from the Garhwal region in the state of Uttaranchal, India, were made by Mahesh and Jauhari (2000a, 2003) and Pemola and Jauhari (2004 a, b), while studies on interspecific associations and the index of association among immature of Anophelines from the same region have been worked out by Jauhari et al. 1995, Mahesh et al. 1995 and Mahesh and Jauhari (2000 b).

During field surveys of mosquito breeding sites in the Garhwal region in the state of Uttaranchal, India, several environmental factors that could be quantified were found to be promising as predictors of mosquito occurrence (Pemola and Jauhari 2005). One of the most important factors was the vegetation that favors larval propagation and is correlated with adult densities. Moreover, habitat and climate has also been found to exhibit a correlation with the mosquito species that are present in an area.

Given that a thorough knowledge of physicochemical and biological parameters of the breeding habitats is essential, since each habitat produces specific mosquito species and shows a seasonal progression, we surveyed possible mosquito breeding sites in all three phytogeographic zones of Garhwal and grouped mosquito species associations according to the similarity of their chosen habitats. The present study is the first attempt to understand mosquito associations in different breeding habitats in the Garhwal region of India.

Materials and Methods

Study area

The survey was made between November 2000 to October 2002 from fixed localities across three phytogeographic zones in the Garhwal region: tropical (300–1000 m), sub tropical (1000–2000 m) and temperate (2000–3000 m). The study covered a major part of the 5 districts including Dehra Dun, Pauri, New Tehri, Chamoli and

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Table 1. Distribution of Mosquitoes across the three different Phytogeographic zone in Garhwal region of Uttaranchal (India) during November 2000 to October 2002.

Phytogeographic zones / Name of Species	Tropical (300–1000m)	Subtropical (1000–2000m)	Temperate (2000–3000m)
Genus – *Aedes* Meigen, 1818			
Subgenus – *Christophersiomyia* Barraud, 1923			
Ae. thomsoni Theobald, 1905	✓*	-	-
Subgenus – *Finlaya* Theobald, 1903			
Ae. albolateralis Theobald, 1908	✓*	✓*	✓*
Ae.aureostriatus greeni, Theobald, 1903	✓	-	-
Ae. dissimilis Leicester, 1908	✓*	-	-
Ae. pulchriventer Giles, 1901	-	✓	✓
Ae. suffusus Edwards, 1922	✓	-	-
Subgenus – *Stegomyia* Theobald, 1901			
Ae. aegypti Linnaeus, 1762	✓	-	-
Ae. albopictus Skuse, 1894	✓*	✓	-
Ae. subalbopictus Barraud, 1931	-	✓*	✓*
Ae. unilineatus Theobald, 1906	✓	-	-
Genus – *Anopheles* Meigen, 1818			
Subgenus – *Anopheles* Meigen, 1818			
An. gigas Giles, 1901	✓*	✓*	✓*
An. lindesayi Giles, 1900	✓*	✓*	✓
An. nigerrimus Giles, 1901	✓*	-	-
Subgenus – *Cellia* Theobald, 1902			
An. aconitus Donitz, 1902	✓	-	-
An. annularis Van der Wulp, 1884	✓*	-	-
An. culicifacies Giles, 1901	✓*	-	-
An. fluviatilis James, 1902	✓*	-	-
An. maculatus Theobald, 1901	✓*	✓*	✓*
An. minimus Theobald, 1901	✓	-	-
An. splendidus Koidzumi, 1920	✓*	-	-
An. stephensi Liston, 1901	✓*	-	-
An. subpictus Grassi, 1899	✓*	✓*	✓
An. theobaldi Giles, 1901	✓	✓	✓
An. vagus Donitz, 1902	✓*	✓	-
Genus – *Armigeres* Theobald, 1901			
Subgenus – *Armigeres* Theobald, 1901			
Ar. durhami Edwards, 1917	✓	✓	-
Genus – *Culex* Linnaeus, 1758			
Subgenus – *Culex* Linnaeus, 1758			
Cx. barraudi Edwards, 1922	✓	✓*	✓*
Cx. mimeticus Neo, 1899	✓*	✓*	✓*
Cx. quinquefasciatus Say, 1828	✓*	✓*	✓
Cx. vagans Weideman, 1828	✓*	✓*	✓*
Cx. vishnui Theobald, 1901	✓*	-	-
Subgenus – *Culiciomyia* Theobald, 1907			
Cx. pallidothorax Theobald, 1905	✓	-	-
Cx. viridiventer Giles, 1901	✓*	✓*	✓*
Subgenus – *Neoculex* Dyar, 1905			
Cx. brevipalpis Giles, 1902	✓*	-	-
Genus – *Uranotaenia* Lynch Arribalzaga, 1891			
Ur. nivipleura Leicester, 1908	✓	✓	-

✓ - presence of adult specimens;
* - presence of immature forms

Uttarkashi located between 29°26´N to 31°26´N latitude and 77°39´E to 80°03´E longitude. As per earlier records, the western part of the Himalayas has been found to be extremely rich in plant life. Among the phytogeographic zones, the tropical zone is mainly covered by deciduous forest while sub-Himalayan region consists of sub-tropical forest type including pine forest and mixed oak and rhododendron vegetation. The third zone of temperate forest is composed of conifers, oak and rhododendrons. Details of the selected area such as longitude, latitude and altitude were computed using the global positioning system (GPS) for accurate location of sampling stations and the areas of interest. A portable altimeter was also used for measuring altitude of the mosquito's habitat.

Mosquito sampling

Adult mosquitoes were collected using aspirator and flash light from both indoor and outdoor resting habitats during morning hours (06:00–08:00) every two weeks. Collection of immature mosquitoes was also made on the same

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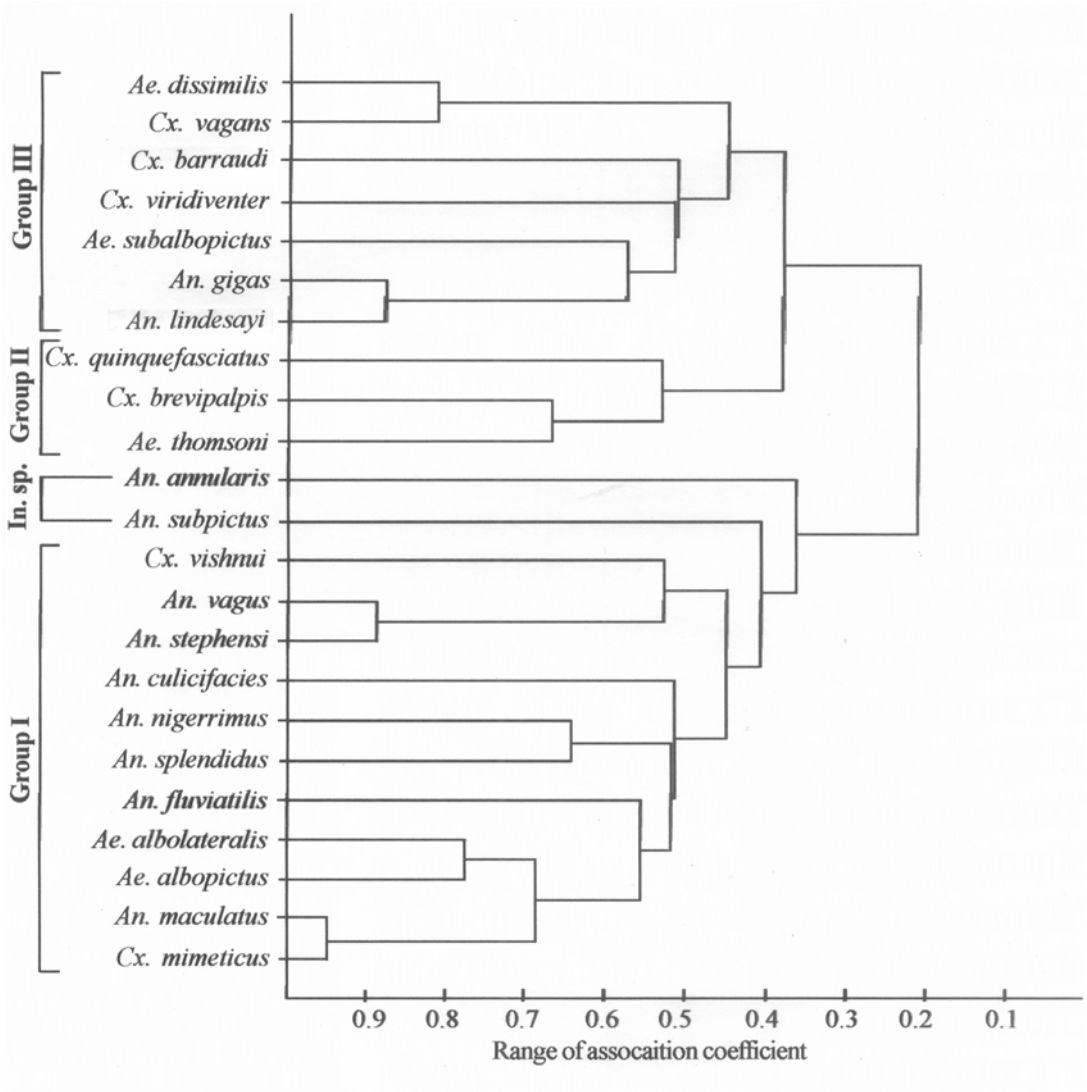

Figure 1. Phenogram of 23 OUT's resulting from Cluster analysis (based on Table 2).

day by dipping and netting methods as per WHO (1975) guidelines. Identification is based on adult characters using standard taxonomic keys and catalogues (Christophers 1933; Barraud 1934; Wattal and Kalra 1961; Knight and Stone 1977; Das et al. 1990; Darsie and Pradhan 1990; Nagpal and Sharma 1995). Species were confirmed from adults that emerged in the laboratory from collected immatures. In each locality, the collection spots were fixed in different directions. In addition, random collection was done from every possible habitat. Information on co-existing biotic community and breeding characters was recorded at the time of mosquito sampling. Identified mosquito specimens are deposited in the insect collection records at Zoological Survey of India, Kolkata.

Data analysis

The collected data with respect of adult and immature mosquitoes were analyzed using the following steps - i) listing of operative taxonomic units, ii) development of basic matrix of data and iii) calculation of similarity for each pair of mosquito species. Since the main purpose was to group mosquito species with similar breeding features, the operative taxonomic units chosen were the mosquito species collected. The recorded breeding habitats and physical characters of breeding grounds were analyzed to identify common patterns of immature stage habitats where different mosquito species were collected. Both quantitative (water depth) and qualitative (natural / artificial, permanent / temporary, shady / lighted, water movement, vegetational condition and turbidity) characters were codified as 1/0 (= presence/absence).

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Table 2. Similarity matrix for the operative taxonomic units calculated using coefficient of association.

	ann	*cul*	*flu*	*gig*	*nig*	*lin*	*mac*	*spl*	*ste*	*sub*	*vag*	*abl*	*abp*	*dis*	*sba*	*tho*	*bar*	*bre*	*mi*	*qui*	*van*	*vir*	*vis*
ann	1																						
cul	0.22	1																					
flu	0.35	0.45	1																				
gig	0.26	0.39	0.39	1																			
nig	0.33	0.34	0.34	0.33	1																		
lin	0.14	0.39	0.39	0.88	0.33	1																	
mac	0.33	0.47	0.47	0.45	0.39	0.45	1																
spl	0.36	0.52	0.52	0.35	0.64	0.35	0.52	1															
ste	0.31	0.43	0.17	−0	0.27	−0	0.39	0.3	1														
sub	0.01	0.24	0.24	−0	0.09	−0..21	0.27	0.3	0.32	1													
vag	0.21	0.34	0.21	−0	0.27	−0	0.39	0.4	0.88	0.3	1												
abl	0.01	0.26	0.26	0.51	0.16	0.51	0.09	−0	−0.3	−0	−0.3	1											
abp	−0	0.18	0.18	0.26	−0	0.26	0.69	0.2	−0.2	−0.1	−0.2	0.8	1										
dis	0.04	0.04	0.3	0.15	0.09	0.03	−0	−0	−0.1	0.1	−0.3	0.3	0	1									
sba	0.21	0.34	0.34	0.58	0.27	0.58	0.27	0.4	−0.1	−0.1	0.03	0.3	0.1	0.3	1								
tho	0.09	0.05	0.05	0.39	−0.2	0.26	−0	−0	0.17	0.2	0.09	0.5	0.3	0	0.2	1							
bar	0.09	0.21	0.21	0.45	0.27	0.45	0.03	0.3	−0.3	−0.1	−0.2	0.5	0.2	0.5	0.5	0.1	1						
bre	0.16	−0.1	−0.1	0.2	−0.1	0.07	−0.1	−0	−0	0.2	−0.1	0.3	0.1	0.2	0.3	0.7	0.1	1					
mi	0.29	0.56	0.56	0.4	0.46	0.4	0.94	0.6	0.46	0.4	0.46	0	0	0	0.2	−0	0.1	−0	1				
qui	0.04	−0.1	−0.1	0.12	0.09	0.12	0.09	0	−0.1	0.2	−0.2	0.3	0.3	0.1	0.4	0.3	0.4	0.5	0.1	1			
van	0.09	0.09	0.34	0.33	0.27	0.21	0.03	0.2	−0.1	0.1	0.03	0.2	−0	0.8	0.5	0.2	0.5	0.1	0.1	0.1	1		
vir	−0.1	0.3	0.3	0.32	0.27	0.45	0.15	0.3	0.01	−0.2	0.03	0.3	0.3	−0	0.5	0.2	0	0.1	0.1	0	0.1	1	
vis	0.04	0.13	0.27	0.07	0.4	0.07	0.28	0.6	0.37	0.2	0.53	−0	−0.1	−0	−0	−0	0.1	−0	0.4	−0	0	−0	1

abl = albolateralis, abp = albopictus, ann = annularis, bar = barraudi, bre = brevipalpis
cul = culicifacies, dis = dissimilis, flu = fluviatilis, gig = gigas, lin = lindesayi,
mac = maculatus, mi = mimeticus, qui = quinquefasciatus, sba = subalbopictus
spl = splendidus, ste = stephensi, sub = subpictus, tho = thomsoni, vag = vagus
van = vagans, vir = viridiventer, vis = vishnui

A basic matrix of data was developed in tabular form on the basis of codified data, consisting of rows for mosquito species and columns for positive breeding habitats and characters. Values within the cells represent 1 or 0 if each character was recorded for each species or not, respectively. These data were used to analyze and calculate the similarity for all possible pairs of operative taxonomic units. The similarity for all possible combinations of mosquito species pairs (operative taxonomic units) was calculated using the coefficient of association and thereafter the similarity matrix was developed. Operative taxonomic units were grouped on the basis of similarity using cluster analysis (SAS Institute, 1987).

Results

Distribution of mosquito species

Altogether 34 species of mosquitoes within the following 5 genera, *Aedes, Anopheles, Armigeres, Culex* and *Uranotaenia*, were collected (Table 1). Among these, 23 species were immatures. Adults and immatures, 32 and 21 species respectively, were collected in the tropical zone at an elevation between 300–1000 m. 17 species of adults and 11 species of immatures were recovered from the subtropical zone, while from the temperate zone 13 and 8 species were found as adults and immatures respectively. There were a few species of mosquitoes for which only immatures were collected from a particular zone. Phytogeographically, the zones of lower elevation shared higher species abundance than the higher elevation.

Grouping of immature mosquitoes

While compiling the data with respect of occurrence of immature vs. breeding characters, groups I, II and III were distinguished in the phenogram in addition to two individual species (Figure 1) according to the coefficient of association obtained (Table 2).

Group I included 11 species: *Culex mimeticus* Noe, *Anopheles maculatus* Theobald, *Aedes albopictus* Skuse, *Aedes albolateralis* Theobald, *Anopheles fluviatilis* James, *Anopheles splendidus* Koidzumi, *Anopheles nigerrimus* Giles, *Anopheles culicifacies* Giles, *Anopheles stephensi* Liston, *Anopheles vagus* Donitz, and *Culex vishnui* Theobald.

Group II included 3 species: *Aedes thomsoni* Theobald, *Culex brevipalpis* (Giles) and *Culex quinquefasciatus* Say.

Group III included 7 species: *Anopheles lindesayi* Giles, *Anopheles gigas* Giles, *Aedes subalbopictus* Barraud, *Culex viridiventer* Giles, *Culex barraudi* Edwards, *Culex vagans* Wiedemann and *Aedes dissimilis* Leicester.

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Table 3. Showing mosquito breeding habitats/characters in respect of different groups of mosquitoes in Garhwal region of Uttaranchal (India) during November 2000 to October 2002.

Groups	Individual species		Group I											Group II			Group III						
Variables of breeding habitats	***sub***	***ann***	***mi***	***mac***	***abp***	***abl***	***flu***	***spl***	***nig***	***cul***	***ste***	***vag***	***vis***	***tho***	***bre***	***qui***	***lin***	***gig***	***sba***	***vir***	***bar***	***van***	***dis***
Seepage pool	x	x	x	x	x	x	x		x	x	x			x	x	x	x	x		x			
Riverbeds	x	x								x	x			x	x	x							
Rice fields	x	x	x		x	x	x	x	x	x			x			x	x	x			x		
Tanks	x			x	x	x	x		x	x	x	x		x						x		x	x
Forest pools	x				x	x	x	x	x	x				x	x	x	x	x	x	x	x		
Ditches		x			x	x							x	x	x	x	x	x	x	x			
Streams	x	x	x	x			x	x	x	x	x	x	x			x	x	x	x		x	x	x
Rock holes	x		x	x	x	x	x			x	x	x		x	x	x	x	x	x	x		x	x
Tree holes	x			x	x	x	x			x			x	x	x	x					x	x	x
Intradomestic containers	x								x		x	x		x	x	x							
Swallow pits	x		x		x		x		x							x							
Natural	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Artificial	x								x		x	x		x	x	x							
Permanent	x			x	x	x	x			x				x	x	x	x	x	x	x	x	x	x
Temporary	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Shady		x		x	x	x	x						x	x	x	x	x	x	x	x	x	x	x
Partially Shady	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Sun lighted	x		x		x			x	x	x	x	x				x				x			
Quite/stagnant	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Slow flowing	x	x	x	x			x	x	x	x	x	x	x			x			x		x	x	x
Clear	x	x	x		x	x	x	x	x	x	x	x	x	x			x	x					
Slightly turbid	x	x		x			x	x					x		x	x			x	x		x	x
Turbid					x	x				x						x	x		x	x	x		
Vegetation-Thick				x					x								x	x			x	x	x
Moderate	x		x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x
Thin	x	x	x				x			x	x	x	x		x								x
Negligible	x	x			x				x		x	x	x	x	x	x							
Depth- 0.01 – 0.05 m	x			x	x	x								x	x	x					x	x	x
0.05 – 0.1 m	x	x		x	x	x				x			x	x	x	x		x	x		x	x	x
0.1 – 0.5 m	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0.5 – 1.0 m	x	x	x	x			x	x	x	x	x	x	x	x			x	x	x	x		x	
1.0 – 1.5 m		x			x		x	x	x	x	x	x	x							x			
1.5 – 2.0 m	x																			x			

abl = albolateralis, abp = albopictus, ann = annularis, bar = barraudi, bre = brevipalpis
cul = culicifacies, dis = dissimilis, flu = fluviatilis, gig = gigas, lin = lindesayi
mac = maculatus, mi = mimeticus, qui = quinquefasciatus, sba = subalbopictus
spl = splendidus, ste = stephensi, sub = subpictus, tho = thomsoni, vag = vagus
van = vagans, vir = viridiventer, vis = vishnui

Two species, *Anopheles annularis* Van der Wulp and *Anopheles subpictus* Grassi had unique preferences of habitat and association.

Cx. mimeticus and *An. maculatus* showed the highest association coefficient (0.941) followed by *An. stephensi* and *An. vagus* (0.884). There was a high positive association among the following mosquito associates: *An. gigas* with *An. lindesayi* (0.877) and *Ae. dissimilis* with *Cx. vagans* (0.819). Since the lowest coefficient of association (0.004) was found between *Cx. quinquefasciatus* and *Cx. viridiventer,* they were separated into groups II and III respectively. The highest negative association (–0.30) was found between *Cx. vishnui* and *Cx. brevipalpis* in groups I and II respectively (Table 2). Both *An. subpictus* and *An. annularis* showed close association with the species of group I but their coefficient of association was lower. The two species of *Aedes*, *Ae. albopictus* and *Ae. albolateralis*, had similar breeding preferences as compared to most of the Anopheline species. Among the *Culex* species, *Cx. mimeticus* and *Cx. vishnui* also showed similarity of habitat requirements with Anopheline species while in group III, *An. gigas* and *An. lindesayi* were found associated with Culicines (*Aedes* and *Culex* sp.) showing different habitat preference from other Anopheline species.

Characters of breeding habitats

The positive breeding habitats, and their quantitative characters (water depth) and qualitative characters (natural/artificial, permanent/temporary, shady/lighted, water movement, vegetation condition and turbidity), are listed with regard to presence or absence of different mosquitoes species in Table 3. The breeding habitats of mosquitoes found in the present study were seepage pools, riverbeds, rice fields, tanks, forest pools, ditches, streams, rock holes, tree holes, intradomestic containers and

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shallow pits. Breeding habitats such as streams and rock holes were the richest habitats sharing 18 mosquito species followed by seepage pools harboring 16 species of mosquitoes. The lowest species diversity (6 species) was recorded from shallow pits. Generally, all the collected species were found in natural habitats in quiet/stagnant conditions at a depth of 0.1–0.5 m. In general, the maximum number of species preferred partially shady and temporary water habitats. Moderate vegetation and clear water habitats also had higher mosquito species diversity.

Mosquito species under Group I were mainly restricted to seepage pool, rice fields, tanks, stream and rock holes. Partially shady habitats, either slow flowing or quiet and clear to slightly turbid, were the main characters of the habitats. Moreover, the mosquito species mostly preferred the habitats located in the surroundings with moderate to thin vegetation. Immatures were also found in tree holes in which the water depth varied from 0.01–1.5 m. Seepage pool, riverbeds, forest pools, ditches, rock holes, tree holes and intradomestic containers were the common breeding habitats of the species of Group II. Shady to partially shady and quiet/stagnant habitats with moderate to negligible vegetation at a water depth of 0.1–0.5 m. were the main characters of the habitats preferred by Group II species. Group III species mostly preferred breeding habitats such as forest pools, streams and rock holes. All the species preferred natural breeding habitats of permanent conditions with shady, quiet/stagnant, moderate vegetation also at a water depth of 0.1–0.5 m. Temporary habitats with thick vegetation also harbored large numbers of species. The larvae of *An. subpictus* were found to breed in all of the above stated habitats except the ditches. The immature of *An. annularis* were found in seepage pools, riverbeds, rice fields, ditches, streams and tree holes. However, the natural habitats of temporary conditions with shady to partially shady habitats were the main characteristics of the habitats of this species.

Discussion

Both quantitative and qualitative characters of the mosquito breeding habitats have contributed to understanding the similarity of habitat requirements of different species. Almiron and Brewer (1996) pointed out that different types of habitats, both natural and artificial, nature of vegetation, water movement and water depth are the main characters that explain the observed variations among mosquito species. Based on habitat similarity by means of cluster analysis, four groups of species have been associated but in the present study only 3 groups are recorded. The phenogram proposed by Almiron and Brewer (1996) with 19 operative taxonomic units, is different from that found in the present study that has 23 operative taxonomic units.

Bhat (1975a,b) studied the frequency of association of immatures of mosquitoes collected from the Himalayan range of India and recorded the highest association of *An. maculatus* with *Cx. mimeticus* which is similar to the present observation. Others, who have made related studies from parts of Garhwal are Pemola and Jauhari (2004b, 2005). Although there is some resemblance, their studies are based on distribution of mosquitoes in macro level features such as vegetation, altitudes and land use patterns. The findings of Bhatt et al. (1990, 1993) concentrated on the association among Anopheline immatures in different breeding habitats, that only slightly resembles the present study.

The present study has some similarities to the habitat requirements of most of the recorded mosquito species, especially *An. culicifacies* and *An. annularis* but from a different region (Sahu et al. 1990). There is little similarity with Gunasekaran et al. (1993) and Mahesh and Jauhari (2000b) as they recorded a positive association between *An. culicifacies* and *An. annularis*, however in the present study a positive correlation between *An. culicifacies, An. aconitus* Donitz, *An. stephensi* and *An. subpictus* has been recorded. On other hand, Jauhari et al. 1995 observed associations of *An. culicifacies* and *An. fluviatilis* with *Aedes aegypti* (Linnaeus) and *Cx. quinquefasciatus* in the forested areas of Doon Valley, but in our findings the association was not the same as *An. culicifacies* and *An. fluviatilis* showed negative association with *Cx. quinquefasciatus* (i.e. –0.05) and larvae of *Ae. aegypti* were rarely found and hence not considered.

There are a number of papers on the relationship between vegetation and immature stages by several authors (Savage et al. 1990; Rajmankova et al. 1991, 1992; Rodriguez et al. 1993; Rajnikant et al. 1996) and almost all of them reported that larval abundance is related to the presence of a particular kind of vegetation. Their results get support from Aditya et al. 2006 who found cemented temporary pools containing maximum

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food resources, in term of detritus, vegetation and algae allowing the maximum number of species of different guilds to coexist.

In the present study, mosquito immatures found in turbid water were almost always Culicines, which is similar to the findings of Sattler et al. (2005). The preference of the immatures of Anophelines to breed in clear to slightly turbid water is similar to the findings of Bates (1994) and Robert et al. 1998. However, Gimning et al. 2001 found increasing *An. gambiae* s.l. larval densities with increasing turbidity. Further, the results of the present findings are contrary to those of Minakawa et al. (1999) and Edillo et al. 2002 in having different mosquito species as well as fluctuating ecological conditions prevailing in the area.

Considering the results of the present study in comparison to earlier findings, it has been found that positive associations between mosquito species may result from a common preference for a particular habitat, while negative associations may cause variation in preference for a particular habitat. Moreover, on the basis of associations observed between Anophelines in different habitats, it is also possible to group them as a distinct community. Maximum immature associations, as recorded in the habitats such as streams, rockholes and seepage pools, suggest high survival rate, ovipositional preferences and favorable physicochemical characteristics of these habitats. It was also noticed that prolonged water logging with fast changing ecological conditions and extensive surface area of habitats offer favorable breeding conditions to a number of mosquito species including disease vectors. The co-existence of more than one species in a habitat at a given time indicates that mosquito species of the same nature and preference interact with each other. In order to better elucidate the association between larval occurrence and abundance and environmental variables, further research should be made to examine more variables, including a detailed analysis of water chemistry and the ecology of mosquito predators.

Acknowledgements

The authors are thankful to anonymous reviewers and colleagues for useful suggestions and allowing us to use unpublished materials. This research was funded by the Department of Science and Technology, Govt. of India, New Delhi.

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