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The Mosquito Fauna (Culicidae: Diptera) in the Surface Water of Hapen Creek, Ilan, Taiwan
【Research report】

台灣宜蘭哈盆溪表層蚊相（雙翅目：蚊科）【研究報告】

Hwa-Jen Teng, Meng-Hau Hsue and Yen-Li Wu How-Jing Lee*
鄧華真、徐孟豪、吳艷儷 李後晶*

*通訊作者E-mail : m480@ccms.ntu.edu.tw

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Abstract

A 1-year survey was conducted to understand the mosquito fauna and seasonal abundance of the dominant species in Hapen Creek in the Fushen Botanical Garden, northern Taiwan. Anopheles bengalensis Puri was found to be the most abundant species in terms of the total number collected and its wide distribution at all sampling sites. Culex hayashii Yamada was next and was collected at three out of four sites. Five mosquito groups at Hapen Creek were recognized. Anopheles bengalensis and Cx. hayashii comprised one group, which was dominant in this survey. The average number of An. bengalensis larvae collected per dip increased from April to a peak in June, and then decreased sharply in July. Another peak was found in November and December. For C. hayashii, the first peak was found in October and another in July. The remaining four groups consisted of Cx. nigropunctatus with Cx. halifaxii; Cx. memeticus with An. gigas baileyi; An. lindesayi lindesayi; and Uranotaenia macferlanei. Anopheles lindesayi lindesayi larvae were collected only from February to June in this survey. Water temperature was significantly associated with the number of C. hayashii larvae collected, while total precipitation was associated with the numbers of An. lindesayi lindesayi and An. gigas baileyi collected. From the species correlation analysis of the community to mosquitoes, hemipteran bugs, copepods, and shells were significantly associated with four species of mosquitoes, while shrimp, naucorids, haliplids, dipteran larvae, and water striders were significantly correlated with three species of mosquitoes. Damselflies and stoneflies were positively correlated with two species of mosquitoes. These positive associations with mosquitoes may imply that the species are important natural enemies of mosquitoes or species which coexist with them.

摘要

本調查為期一年以了解宜蘭哈盆溪的蚊相及其主要種類的季節消長。就所採集到的隻數及分布範圍，褐色蚊 Anopheles bengalensis 為優勢種，而林氏家蚊 Culex hayashii 排名第二。哈盆溪蚊種有五群，其中褐色蚊及林氏家蚊是此次調查中最常見。每杓所採集到之褐色蚊幼蟲數四月份開始增加至六月份達到高峰，七月份驟減，另一個高峰在十一月及十二月間。林氏家蚊有兩個高峰，分別在七月份及十月份。另外四個群為黑點家蚊 Culex nigropunctatus 與海氏家蚊 C. halifaxii，斑翅家蚊 C. memeticus 與巨大蚊 Anopheles gigas baileyi，深山蚊 An. lindesayi lindesayi 與麥氏小蚊 Uranotaenia macferlanei。在此次調查中，僅於二月至六月發現深山蚊幼蟲。水溫與林氏家蚊幼蟲的數目有顯著性相關，而降雨量與深山蚊及巨大蚊族群密度有顯著性相關。從群落種類與蚊蟲相關性分析得知半翅目，橈足類及蝸牛與四種蚊蟲發生有顯著正相關，而蝦、潛水（naucorids），小頭水（haliplids），雙翅目幼蟲、與水黽的分布則與三種蚊蟲有顯著正相關。豆娘與石蠅與兩種蚊蟲有顯著正相關。這些正相關可能意味著這些種類可能是蚊蟲的天敵或共生者。

Key words: Anopheles bengalensis, Culex hayashii, stream, seasonal fluctuation
關鍵詞: 褐色蚊、林氏家蚊、溪流、季節消長

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Hwa-Jen Teng, Meng-Hau Hsue and Yen-Li Wu

Medical Entomological Laboratory, Research and Development Center, Center for Disease Control, Department of Health, Taipei, Taiwan 115, R.O.C.

How-Jing Lee* Department of Entomology, National Taiwan University, Taipei, Taiwan 106, R.O.C.

ABSTRACT

A 1-year survey was conducted to understand the mosquito fauna and seasonal abundance of the dominant species in Hapen Creek in the Fushen Botanical Garden, northern Taiwan. *Anopheles bengalensis* Puri was found to be the most abundant species in terms of the total number collected and its wide distribution at all sampling sites. *Culex hayashii* Yamada was next and was collected at three out of four sites. Five mosquito groups at Hapen Creek were recognized. *Anopheles bengalensis* and *Cx. hayashii* comprised one group, which was dominant in this survey. The average number of *An. bengalensis* larvae collected per dip increased from April to a peak in June, and then decreased sharply in July. Another peak was found in November and December. For *C. hayashii*, the first peak was found in October and another in July. The remaining four groups consisted of *Cx. nigropunctatus* with *Cx. halifaxii*; *Cx. memeticu*s with *An. gigas baileyi*; *An. lindesayi lindesayi*; and *Uranotaenia macferlanei*. *Anopheles lindesayi lindesayi* larvae were collected only from February to June in this survey. Water temperature was significantly associated with the number of *C. hayashii* larvae collected, while total precipitation was associated with the numbers of *An. lindesayi lindesayi* and *An. gigas baileyi* collected. From the species correlation analysis of the community to mosquitoes, hemipteran bugs, copepods, and shells were significantly associated with four species of mosquitoes, while shrimp, naucorids, haliplids, dipteran larvae, and water striders were significantly correlated with three species of mosquitoes. Damselflies and stoneflies were positively correlated with two species of mosquitoes. These positive associations with mosquitoes may imply that the species are important natural enemies of mosquitoes or species which coexist with them.

Key words: *Anopheles bengalensis*, *Culex hayashii*, stream, seasonal fluctuation

*Correspondence address
e-mail: m480@ccms.ntu.edu.tw

Introduction

The mosquito fauna plays a major role in the decomposition process of organic debris and serves as food for consumers of higher trophic levels in aquatic ecosystems. Predation by mosquito larvae affects the population dynamics and community structure of freshwater planktonic and bacterial communities (Carpenter and Kitchell, 1984; Carpenter *et al.*, 1985; Elser and Carpenter, 1988; Cochran-Stafira and von Ende, 1998). Many mosquitoes breed in flowing streams, which vary in water velocity, water depth, the coverage of plant species and floating plants, water-bed types, and water quality (Rejmankova *et al.*, 1992, 1993, 1998; Almiron, 1996). These factors determine the species composition of the mosquito fauna in each stream. Laird (1988) described species in the same community and their possible interactions in various aquatic habitats used by mosquitoes. However, flowing-stream studies were limited to highly polluted and stable drainage ditches.

Efficient natural enemies of mosquito larvae in the laboratory are larvivorous fish (Nelson and Keenan, 1992), damselfly naiads (Miura and Takahashi, 1988), hemipteran bugs (*Diplonychus* spp.) (Venkatesan *et al.*, 1986), hydrometrids (Palmer *et al.*, 1998), notonedtid bugs (Wattal *et al.*, 1996), copepods (Nasci *et al.*, 1987), and freshwater prawns (Collins, 1998). Other natural enemies have also been recognized, such as tadpoles, dragonfly naiads, *Culex fuscanus* Widdemann, and *C. halifaxii* Theobald (Laird, 1988).

The Hapen Creek of northern Taiwan is highly protected from anthropogenic influences but is frequently affected by flooding and drought. During the drought months we studied (October-December in 1997, and April, July, and August in 1998), water flowed underground in some places and some microhabitats of mosquitoes became temporary pools or dried out. So, a variety of microhabitats are found in this creek. The objectives of our study were to understand the mosquito fauna and the seasonal abundance of the dominant species in Hapen Creek. The environmental impacts of some available factors such as water velocities, natural enemies, and precipitation, on this community were analyzed and are discussed.

Materials and Methods

Sampling Sites. The headwaters of Hapen Creek are located in the Fushan Botanical Garden at 400~1400 m in elevation. The area of this garden is 1097.9 ha which it is divided into three areas: water source reserve, the botanical garden, and the Hapen Nature Preserve. Annually air temperatures range from 4 to 28 ℃ with an average of 20 ℃. Average annual precipitation is 2900 mm of which 70% occurs in the summer months. The rainy season occurs in winter, while typhoons bring most of the precipitation in summer. Sampling sites were in the area of the Hapen Nature Preserve, in which no tourists are allowed to enter. Four sections of the creek in three types of habitats (ponded, blocked, and flowing streams) were chosen according to the sampling results of the first month of this survey. The characteristics of these four sampling sites are described in Table 1.

Larval Sampling. A 14-cm-diameter dipper was used to collect larvae. The dipper was held at an angle of 60° and 0.6 m from the stream bank. Eighty samples were taken in each section of the stream for a total of 320 dips per month (from September 1997 to August 1998), if conditions permitted. Occasionally, no samples were taken because of drought at a sampling site. Larvae were identified on site to species under 400X microscopes

Table 1. Characteristics of the sampling sites in Hapen Creek, Ilan, Taiwan from September 1997 to August 1998

Habitat characteristics	Ponded[1] stream	Blocked stream	Flowing stream I	Flowing stream II
Water depth (cm)	7.5-99	8-37	9-40	6-35
Water velocity (cm/s)	0-9.5	0	0-22	0-21.4
Drought month	8	8	10-12, 4, 7-8	10-12, 4, 7-8
Overhead vegetation coverage	Half open	Dense vegetation	Half open	Dense vegetation
Streambed	Mud+sand	Mud+sand	Rocks	Rocks

[1]Blocked stream was a side stream of a ponded stream; Flowing stream I was located 10~20 m uptream of Flowing stream II.

and released back at the sampling points except during for the last 2 months. Pupae were brought back to the laboratory and reared to adults for species identification. At the same time, specimens other than mosquitoes were collected to check the species association with mosquito larvae. In addition, water temperature, water velocity, and water depth were measured at each site. Monthly rainfall data was obtained from the Fushan Weather Station.

Statistical Analysis. Species diversity and species packing can estimate the stability of a habitat (Southwood, 1978). The rank-abundance plot or some other indices can describe species diversity, while associations of species or utilization of resources can be used to estimate species packing. Diversity indices were calculated for each habitat type using the Shannon-Wiener information index:

$$H' = -\sum(p_i)\log(p_i);$$

where p_i is the proportion of the ith species in the total sample (Shannon 1948).

In this study, cluster analysis on the basis of correlation coefficients was used to group similar mosquito species, because no assumption is needed in this analysis concerning the number of groups or the group structure (Johnson and Wichern, 1988). In addition, correlation analysis was also used to check if the number of larvae collected per dip was associated with any of the physical environmental factors examined (water temperature, water velocity, water depth, or monthly rainfall). The population density of mosquitoes is hard to quantify with the number of natural enemies in the dip data, because most natural enemies do not necessarily come to the water surface to breathe. Therefore, only the absence or presence of dip data were analyzed by Spearman's rank correlation analysis to show the association of these species to mosquito larvae. Spearman's coefficient of rank correlation applies to data in the form of a rank (in our case, the absence or presence in the dip data).

Results

Species Composition of Mosquito Fauna. In Hapen Creek, *Anopheles bengalensis* Puri was the most abundant species in terms of the total number collected and its wide distribution at all sampling sites (Fig. 1). *Culex hayashii* Yamada was the second most abundant and was found in three out of four sites. Although *An. lindesayi lindesayi* Giles larvae were collected at all sampling sites, the size of the population was relatively small. *Culex nigropunctatus* Edwards, *Cx. halifaxii* Theobald, *Cx. mimeticus* Noe, *Uranotaenia annandalei* Barraud, and *An. gigas baileyi* Edwards were found in small numbers at one or two sampling sites. Among the four sampling sites, seven out of eight species existed in the blocked stream, however, only two or three species were found in

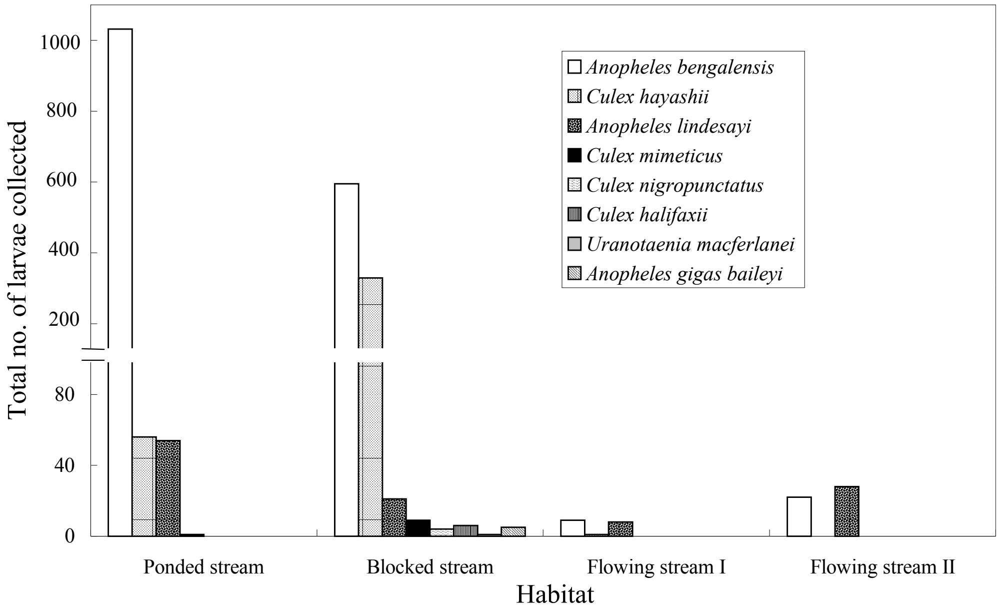


Fig. 1. Species composition of mosquito fauna in Hapen Creek Ilan, Taiwan.

the ponded stream, flowing stream I, and flowing stream II (Fig. 2). A high number of mosquito larvae was collected in habitats of the ponded stream and blocked stream, but only a small population existed in the flowing stream I and flowing stream II. Values of the diversity index (H') for mosquito larvae in the blocked stream, flowing stream I, and II, and the ponded stream were 0.88, 0.87, 0.69, and 0.39, respectively.

Five groups of mosquito fauna in Hapen Creek were recognized by cluster analysis on the basis of species correlation coefficients (Fig. 3). *Culex hayashii* and *An. bengalensis* comprised one group, and they were the dominant species in this survey. The remaining four groups consist of *Cx. nigropunctatus* with *Cx. halifaxii*; *Cx. mimeticu*s with *An. gigas baileyi*; *An. lindesayi lindesayi*; and *U. macferlanei*.

Seasonal Abundance of Dominant Species. The population of *An. bengalensis* larvae increased from April to a peak in June, and then decreased sharply in July (Fig. 4). Another peak was found in November and December. For *C. hayashii*, two peaks were found in October and July. The results indicated bivotinism for *An. bengalensis* and *Cx. hayashii*, although the November population of *An. bengalensis* was much smaller than that in June. *Anopheles lindesayi lindesayi* larvae were only found from February to June with small populations in this survey. From the environmental factor analysis, the population dynamics of *An. bengalensis*, *An. lindesayi lindesayi* and *Cx. hayashii* were independent of water velocity (r = -0.19, 0.17, and 0.03; df = 34; $p > 0.05$) and water depth (r = 0.13, 0.31, and -0.15; df = 34; $p > 0.05$). The population of *C. hayashii* was significantly affected by water temperature (r = 0.37; df = 34; $p < 0.05$) while *An. bengalensis* and *An. lindesayi lindesayi* were independent of it

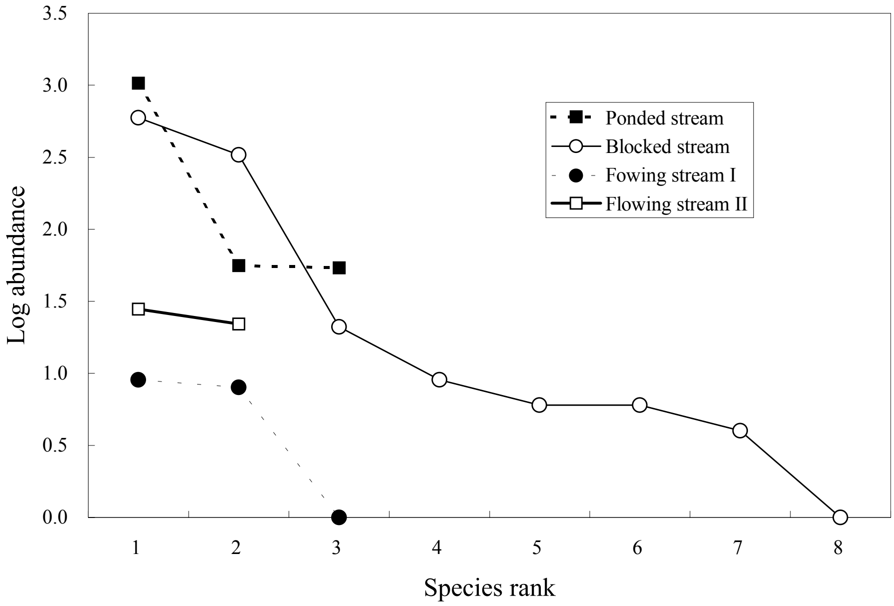


Fig. 2. Species rank-abundance (or dominance-diversity curves) of mosquito fauna for four different habitats in Hapen Creek, Ilan, Taiwan.

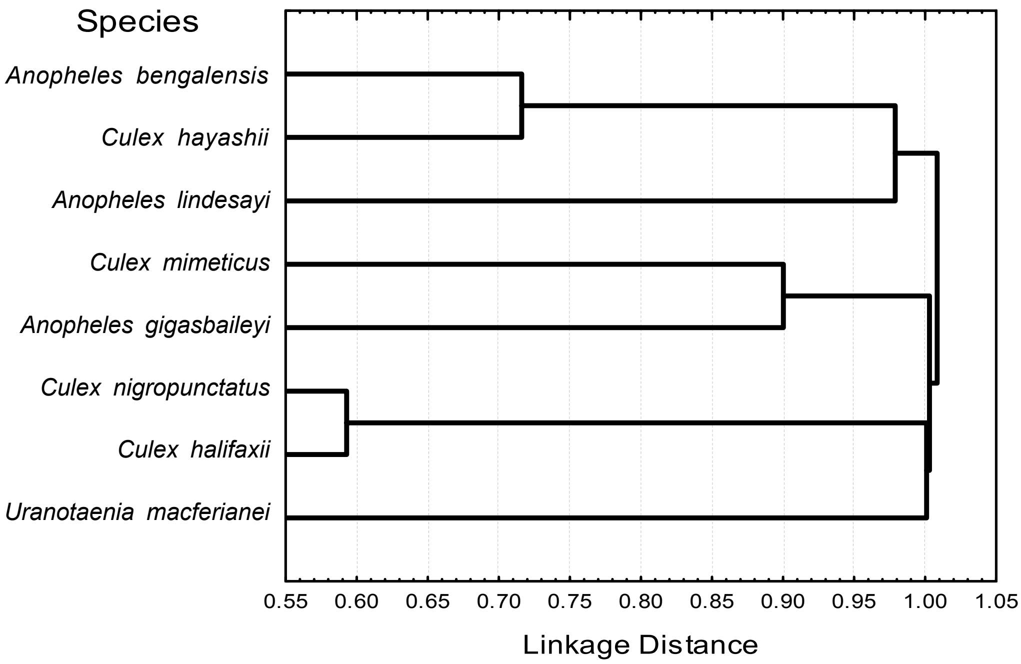
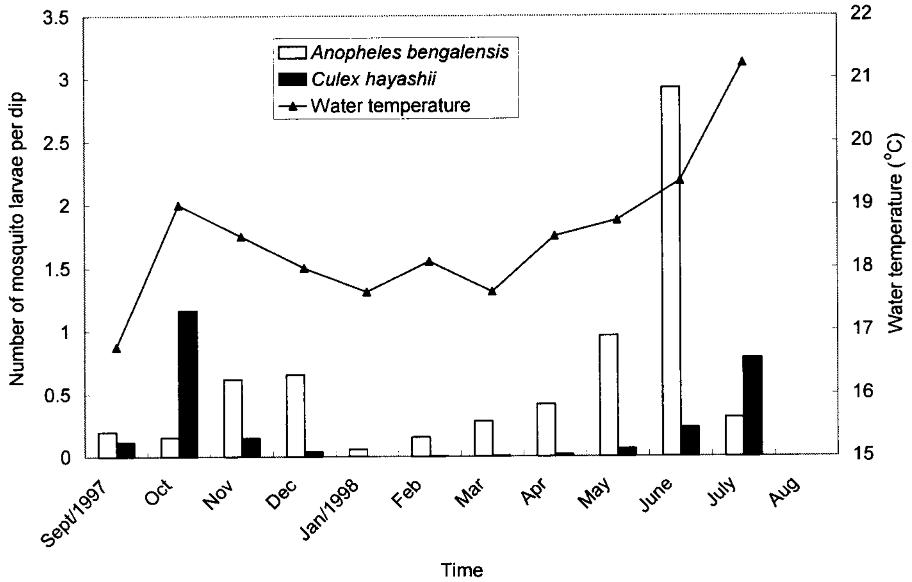


Fig. 3. Tree diagram for mosquito fauna in Hapen Creek, Ilan, Taiwan, by cluster analysis on the basis of correlation coefficients with complete linkages. Species from the same branch of the tree diagram represent close lineages of species, and these serve as recognized groups of mosquito fauna.

A.



B.

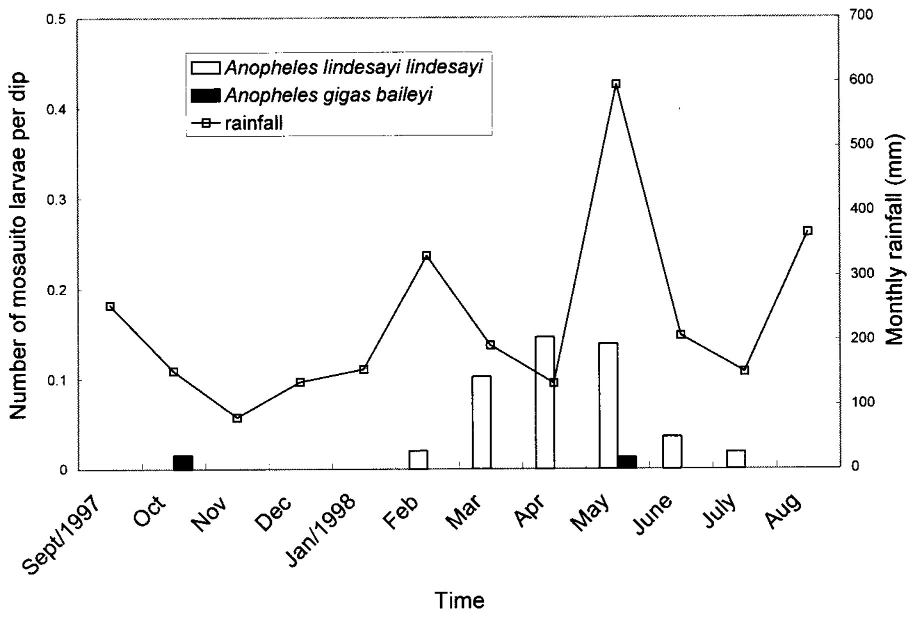


Fig. 4. Monthly abundance of mosquito larvae with water temperature (A) and rainfall (B) in Hapen Creek, Ilan, Taiwan (*n* = 320)

Table 2. Association of mosquito larvae with aquatic animals in Hapen Creek, Ilan, Taiwan by Spearman's rank correlation analysis (n = 2030)

Species[1]	AB	CH	CM	CHA	AL	AGB
Hemiptera	0.292***	0.273***	0.104***	0.037	0.135***	0.043
Copepod	0.250***	0.331***	-0.008	-0.007	0.187***	0.087***
Shell	0.050*	0.151***	0.110***	0.136***	0.027	-0.005
Shrimp	0.202***	0.096***	-0.016	-0.013	0.095***	0.036
Naucoridae	0.062***	0.048*	-0.011	-0.009	0.027	-0.015
Haliplidae	0.068***	0.050*	-0.004	-0.003	-0.019	0.091***
Diptera	0.109***	0.049*	0.117***	-0.003	0.006	-0.005
Strider	0.060***	0.004	0.047*	-0.008	0.066***	-0.012
Damselfly	0.057*	0.101***	-0.004	-0.003	0.035	-0.005
Stonefly	0.080***	0.0003	-0.004	-0.003	0.080***	-0.005
Caddisfly	0.050*	-0.015	-0.003	-0.002	-0.014	-0.004
Fish	-0.020	-0.018	-0.003	-0.003	0.079***	0.004
Mayfly	0.043	0.009	0.059***	-0.006	0.018	0.041
Dragonfly	-0.012	0.019	-0.003	-0.002	-0.014	-0.004
Water mite	-0.022	-0.011	-0.002	-0.002	-0.010	-0.003
Tadpole	0.001	0.002	-0.004	-0.003	0.007	-0.005
Neuroptera	-0.009	-0.005	-0.001	-0.001	-0.004	-0.001

* $p < 0.05$; *** $p < 0.01$.

[1]AB, *Anopheles bengalensis*; CH, *Culex hayashii*; CM, *Culux memeticus*; CHA, *Culex halifaxii*; AL, *Anopheles lindesayi lindesayi*, AGB: *Anopheles gigas baileyi.*

(r = 0.22, and 0.02; df = 34; $p > 0.05$). Total monthly rainfall positively affected the numbers of *An. lindesayi lindesayi* (r = 0.66; df = 11; $p < 0.05$) and *An. gagas baileyi* (r = 0.75; df = 11; $p < 0.01$).

In total, 2639 aquatic organisms were collected. Among them, hemipteran bugs, copepods, and shells were significantly associated with four of six species of mosquitoes while shrimp, naucorids, haliplids, dipteran larvae, and water striders were found to be significantly correlated with three species of mosquitoes (Table 2). Damselflies and stoneflies were positively correlated with two species of mosquitoes, while caddisfly larvae, mayflies, and fish were significantly correlated with only one species. In contrast, dragonflies, water mites, tadpoles, and Neuroptera showed no significant association with the presence of mosquito larvae.

Discussion

In this survey, seven mosquito species were found in the blocked stream while only three species were found at most of the other locations in Hapen Creek. This indicates that blocked portions of the stream serve as reservoirs for mosquito species, while both blocked and ponded portions of the stream support high densities of mosquito larvae. A unique characteristic of Hapen Creek is that its microhabitats are unstable because flood and drought conditions may occur at any time of the year. In our survey period, drought was found in October-December, April, and July-August. Five recognized groups of mosquitoes in Hapen Creek represent different adaptabilities to various microhabitats. The dominant group, *An. bengalensis* and *Cx. hayashii*, were capable of adapting to various microhabitats and survived in both flowing and stagnant water (Tanaka *et al*., 1979).

Seasonal fluctuations of mosquito populations in Hapen Creek differed for the different species studied. The number of *An. bengalensis* was found to be highest in June, while the peak for *Cx. hayashii* was in October and that for *An. lindesayi lindesayi* occurred between March and May. These differences may be due to the nature of these species adapting to various habitats as well to physical environment factors. Our preliminary results showed that water temperature positively affected numbers of *Cx. hayashi*, while rainfall affected populations of *An. lindesayi lindesayi* and *An. gigas baileyi*. The positive relation with monthly rainfall implies that these two species are highly oxygen-demanding species. This factor might render these species inferior to *An. bengalensis*. It is interesting that the lowest water temperature (16.75 ℃) was recorded in September 1997. A possible explanation was the lag effect of heavy rainfall in the previous month and weather conditions on the collecting date.

In our survey, the damselfly was significantly associated with two mosquito species while the dragonfly was independent of all of them. This implies that the damselfly tends to prey closer to the surface of the water where most of the mosquito larvae aggregate (Laird, 1956). Three species of dipteran larvae were also found to be positively associated with mosquito larvae in Hapen Creek. Among them, Dixid larvae, which live on the water surface, might represent another competitor with mosquito larvae. Dragonflies, mayflies, mites, tadpoles, and neuropterans that do not share the same niche with mosquito larvae were temporary members of this community. However, the role of dragonflies and tadpoles is not clear since they may be important benthic feeders. Data presented here are descriptive only; they do not indicate which insect group caused the greatest impact on mosquito populations. More research is needed to understand the interactions within this food web.

Many general predators showed positive associations with mosquito larvae in our study. Because the "natural enemies" hypothesis suggests that predators are more effective in complex environments (Sheehan, 1986), these predators might not have sufficient time to build up relatively stable populations in this unstable creek. Overall, such abiotic factors as drought and flash floods may regulate populations much of the time in Hapen Creek, while biotic interactions such as competition and predation may come into play as the stream surface volume shrinks during periods of drying out. From a species analysis of the mosquito community, Hapen Creek was shown to have less-complex trophic levels and relatively low species diversity (H'), probably because this creek provides many unpredictable and unstable microhabitats (Polis, 1998).

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台灣宜蘭哈盆溪表層蚊相(雙翅目：蚊科)

鄧華眞　徐孟豪　吳艷儷　疾病管制局研究檢驗中心病媒昆蟲實驗室　台北市昆陽街 161 號
李後晶*　國立台灣大學昆蟲系　台北市羅斯福路四段 1 號

摘　　要

本調查爲期一年以了解宜蘭哈盆溪的蚊相及其主要種類的季節消長。就所採集到的隻數及分布範圍，褐色瘧蚊 *Anopheles bengalensis* 爲優勢種，而林氏家蚊 *Culex hayashii* 排名第二。哈盆溪蚊種有五群，其中褐色瘧蚊及林氏家蚊是此次調查中最常見。每杓所採集到之褐色瘧蚊幼蟲數四月份開始增加至六月份達到高峰，七月份驟減，另一個高峰在十一月及十二月間。林氏家蚊有兩個高峰，分別在七月份及十月份。另外四個群爲黑點家蚊 *Culex nigropunctatus* 與海氏家蚊 *C. halifaxii*，斑翅家蚊 *C. memeticus* 與巨大瘧蚊 *Anopheles gigas baileyi*，深山瘧蚊 *An. lindesayi lindesayi* 與麥氏小蚊 *Uranotaenia macferlanei*。在此次調查中，僅於二月至六月發現深山瘧蚊幼蟲。水溫與林氏家蚊幼蟲的數目有顯著性相關，而降雨量與深山瘧蚊及巨大瘧蚊族群密度有顯著性相關。從群落種類與蚊蟲相關性分析得知半翅目，橈足類及蝸牛與四種蚊蟲發生有顯著正相關，而蝦、潛水蝽 (naucorids)，小頭水蜱 (haliplids)，雙翅目幼蟲、與水黽的分布則與三種蚊蟲有顯著正相關。豆娘與石蠅與兩種蚊蟲有顯著正相關。這些正相關可能意味著這些種類可能是蚊蟲的天敵或共生者。

關鍵詞：褐色瘧蚊，林氏家蚊，溪流，季節消長