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Population dynamics of anthropophilic mosquitoes during the northeast monsoon season in the malaria epidemic zone of Sri Lanka

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Abstract. Mosquito-borne diseases are a major health problem in Sri Lanka. Human biting mosquitoes were collected during the night (18.00–06.00 hours) at Nikawehera village, in the malaria endemic intermediate rainfall zone of the country. Collections were made at monthly intervals in the period October 1991 to April 1992, which included the main rainy season due to the northeast monsoon (October–January). Thirteen *Anopheles*, eleven *Culex*, three *Aedes*, three *Mansonia* and one *Armigeres* species were identified, including known vectors of malaria, Bancroftian filariasis, Japanese encephalitis and dengue fever. Mosquito human-biting rates were highest in December. The main malaria vector *Anopheles culicifacies* showed peak biting between 18.00 and 23.00 hours whereas the predominant culicines *Culex fuscocephala* and *Cx quinquefasciatus* preferred to bite after midnight. In 1991–92 the prevalence of some species of anophelines at Nikawehera differed markedly from that observed in 1990–91 and the possible reasons are discussed.

Key words. *Anopheles culicifacies*, arboviruses, *Culex*, dengue fever, filariasis, human-biting rates, Japanese encephalitis, malaria, mosquitoes, Sri Lanka, vectors.

Introduction

Arboviral and parasitic diseases transmitted by mosquitoes are a major health problem in Sri Lanka. Malaria, caused by *Plasmodium vivax* Grassi and *P.falciparum* Welch, is transmitted by anopheline mosquitoes (Diptera: Culicidae), of which *Anopheles culicifacies* Giles is the most important established vector in the country (Samarasinghe, 1990). *Culex quinquefasciatus* Say is the urban vector of *Wuchereria bancrofti* (Cobbold) (Nematoda: Onchocercidae), the causative agent of lymphatic filariasis in Sri Lanka (Abdulcader, 1967). Arboviruses of current medical importance in the country are Japanese encephalitis transmitted by *Cx tritaeniorhynchus* Giles, and dengue transmitted by *Aedes aegyti* Linnaeus and *Ae.albopictus* Skuse (Vitarana *et al.*, 1986).

Sri Lanka has two rainy seasons, the northeast monsoon falling usually in November–January and the southwest monsoon in May–July, with scattered showers in the other months. From the type of precipitation, the island can be divided into the dry zone (annual rainfall <2000 mm falling predominantly during the northeast monsoon), wet zone (annual rainfall >2500 mm occurring during both monsoons) and an intermediate zone with mixed characteristics (Fig. 1). Because of favourable climatic, geographical and other factors, the intermediate rainfall zone is regarded as the source of malaria epidemics in Sri Lanka (Shakoor, 1990). Mosquito abundance and the incidence of mosquito-borne diseases in Sri Lanka can be related to rainfall and other climatic parameters, peak transmission being associated with the monsoons (Shakoor, 1990; Peiris *et al.*, 1992). Seasonal increases of mosquito adult populations depend on the availability of larval habitats during and immediately after the monsoons in Sri Lanka and other countries, for example Brazil (Klein & Lima, 1990) and Thailand (Rosenberg *et al.*, 1990). Irrigated rice fields, marshes and other permanent ground water habitats, natural and artificial containers of water,

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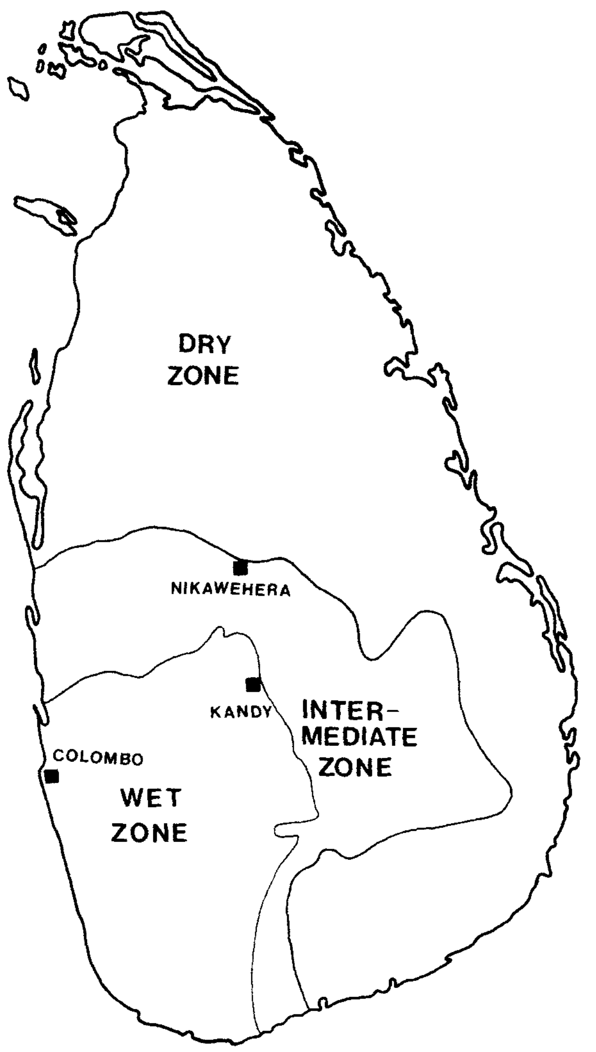

Fig. 1. Map of Sri Lanka showing three rainfall zones and location of the study site at Nikawehera.

provide breeding grounds for mosquitoes between the monsoons. Recent irrigation development and other ecological changes, increase in human population density and urbanization, environmental degradation, the development of insecticide resistance in several vectors (Hemingway *et al.*, 1986; Herath *et al.*, 1988; Peiris & Hemingway, 1990) have had a profound influence on the transmission of mosquito-borne diseases in Sri Lanka. New malaria vectors have emerged (Amerasinghe *et al.*, 1991, 1992; Ramasamy *et al.*, 1992a), and the incidence of malaria has been high, >250,000 cases annually since 1986 with an epidemic in 1986–88. Lymphatic filariasis has increased in both incidence and the extent of the country affected (Dissanaike, 1991). Unprecedented epidemics of Japanese encephalitis (Peiris *et al.*, 1992) and dengue fever (Vitarana *et al.*, 1986) have also been experienced in recent years.

Malaria control in Sri Lanka involves regularly spraying houses in endemic areas with residual insecticides. Increased knowledge of the vector behaviour, biting habits, breeding sites and other factors could help to improve spraying strategies and to develop other methods of reducing vectorial capacity. This study was carried out between October 1991 and April 1992 in an established farming village, Nikawehera, located in the intermediate rainfall zone (Ramasamy *et al.*, 1992b) of Sri Lanka. The monthly pattern of anthropophilic night biting mosquitoes collected during and after the northeast monsoon season is related to rainfall, the incidence of malaria and the potential for transmitting other mosquito-borne diseases.

Materials and Methods

Study area. Nikawehera village (latitude 7°75′N, longitude 80°06′E), with a population of approximately one thousand, lies in the intermediate rainfall zone and near the dry zone (Fig. 1). It is a prosperous farming community, where capsicum, rice and tobacco are cultivated as the main crops. Fields are irrigated by canals leading from an ancient reservoir. Cattle and pig farming are practised extensively. Housing in the village is mainly of brick and concrete with both tiled and thatched roofing. Houses in Nikawehera were treated with malathion by the Anti-Malaria Campaign, Ministry of Health, in October 1991, and January and March 1992 during the period of study, following standard anti-malaria spraying procedures (Pampana, 1969). An interval of at least 7 days elapsed after spraying before mosquito collections were made at Nikawehera. Malaria incidence, clinical features of the population and entomological inoculation rates were reported by Ramasamy *et al.* (1992b) for the period October 1990 to September 1991, showing that malaria was hyperendemic at Nikawehera, peak transmission occurring during the northeast monsoon season.

Mosquito collections. Human-biting mosquito collections were made on two consecutive nights at two sites in each of two houses at 4–5-week intervals during the peak malaria transmission season of 1991–92. Nightly collections were made between 18.00 and 06.00 hours by two pairs of collectors working in 6 h shifts, inside the hallway (with the entrance door open) of each house and at a site 2–8 m outside each house. Mosquitoes landing on exposed limbs of the collectors were gathered by aspiration. All biting mosquitoes were caught; hourly collections were held in plastic cups and provided with glucose for 6–12 h

Table 1. Human biting mosquitoes collected at Nikawehera, November 1991 to April 1992.

Mosquitoes	No.	%
Anopheles spp.	513	18.8
Culex spp.	2022	74.0
Aedes spp.	97	3.6
Mansonia spp.	81	3.0
Armigeres spp.	18	0.6
Total	2731	100

after the catch. The female mosquitoes were then etherized and placed in coded vials at 4°C. The mosquitoes were stored at −20°C in the laboratory until identification. Mosquito species identification was done according to Mahadevan & Cheong (1974), Sirivanakarn (1976) and Amerassinghe (1990).

Rainfall and malaria incidence data. The monthly rainfall data was obtained from an agriculture/livestock centre

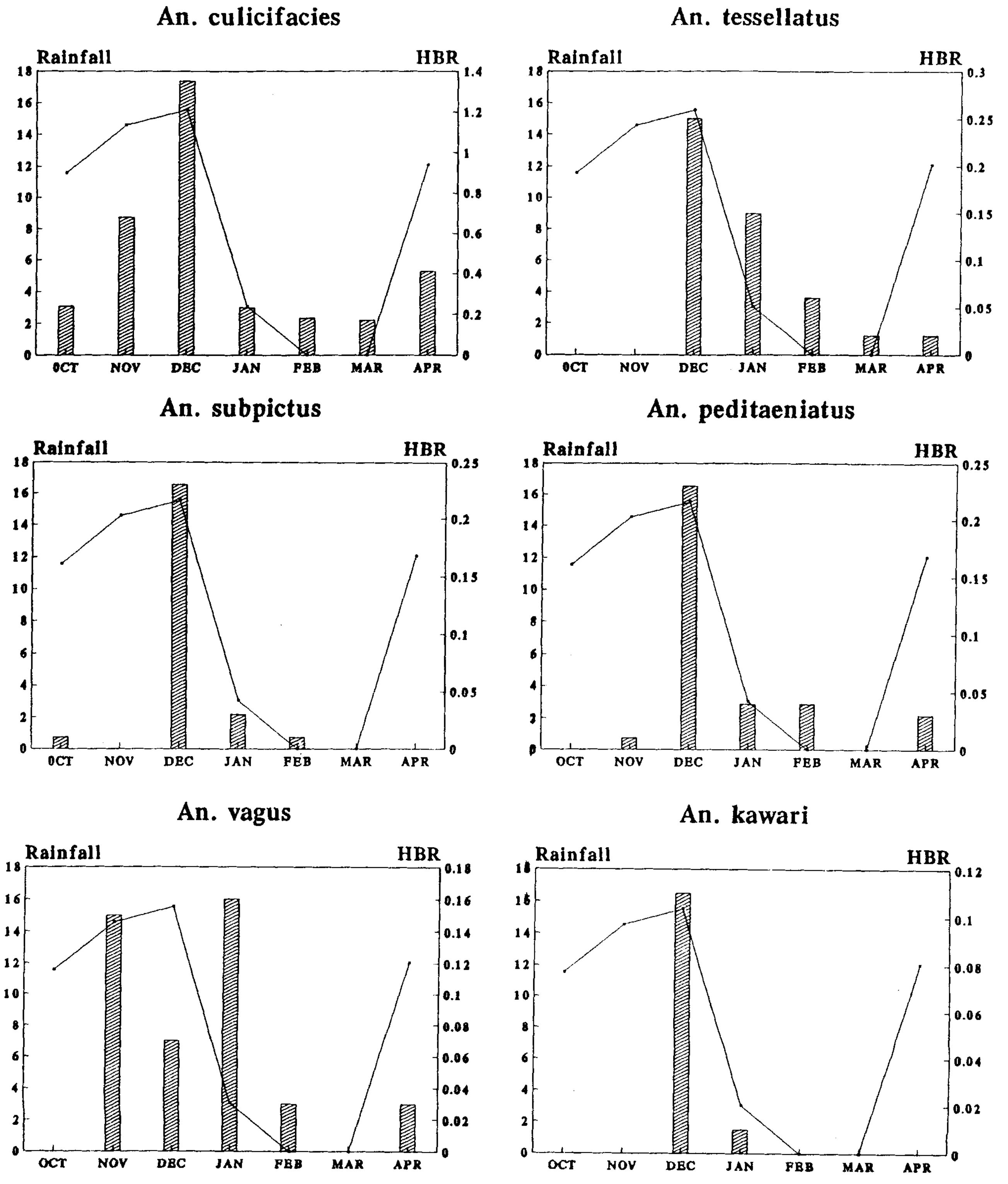

Fig. 2. Prevalence of thirteen species of *Anopheles* in relation to monthly rainfall cm (line). HBR (human biting rate): number of bites per man-hour (column).

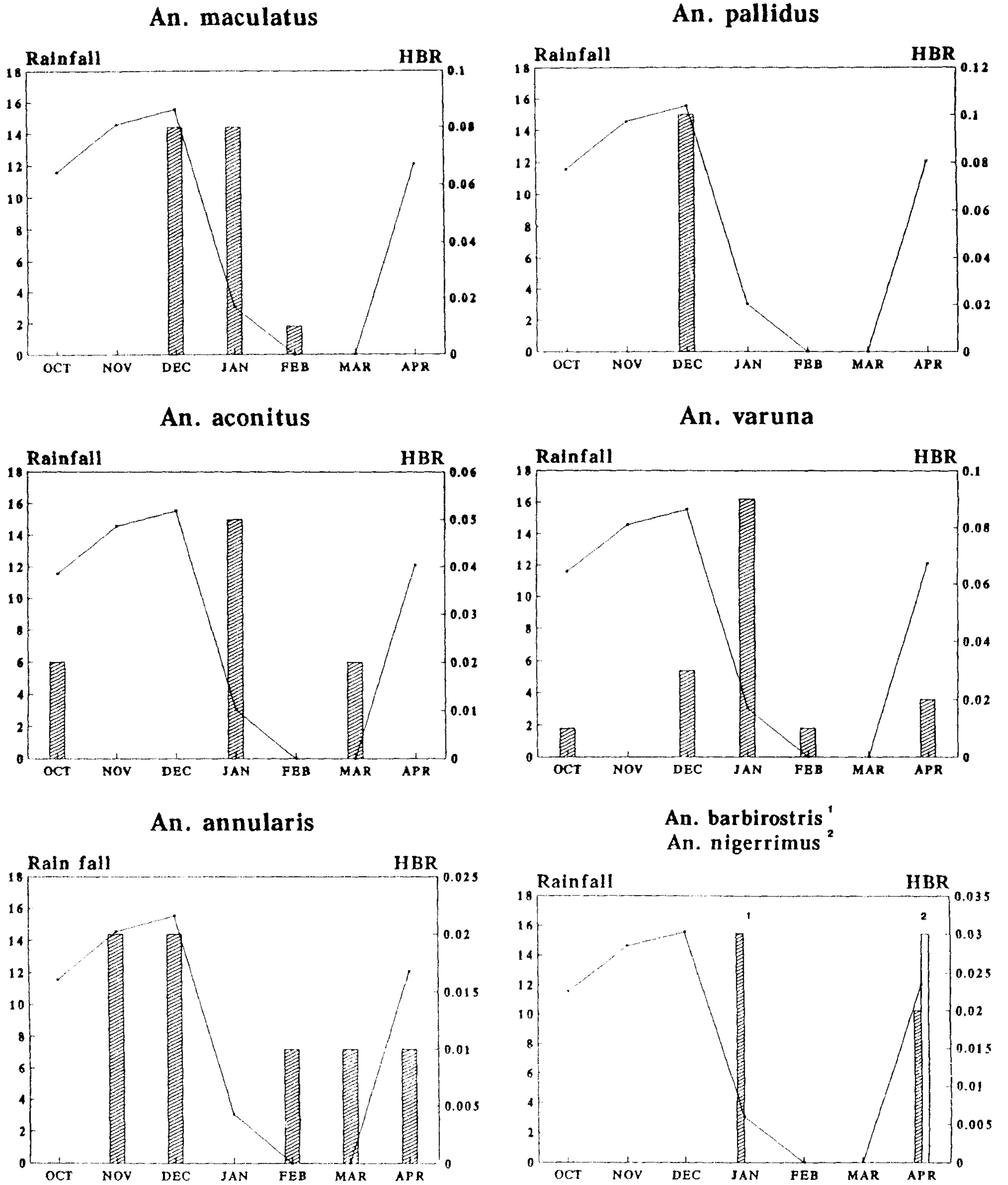

Fig. 2. *(Continued)*

located 5 km from Nikawehera. The incidence of malaria was determined from the examination of thick blood films of fever patients at the nearby Galewela (5 km) and Dambulla (10 km) government hospitals.

Results

The rainfall patterns recorded for the northeast monsoons of 1990–91 and 1991–92 were similar. The monsoon began

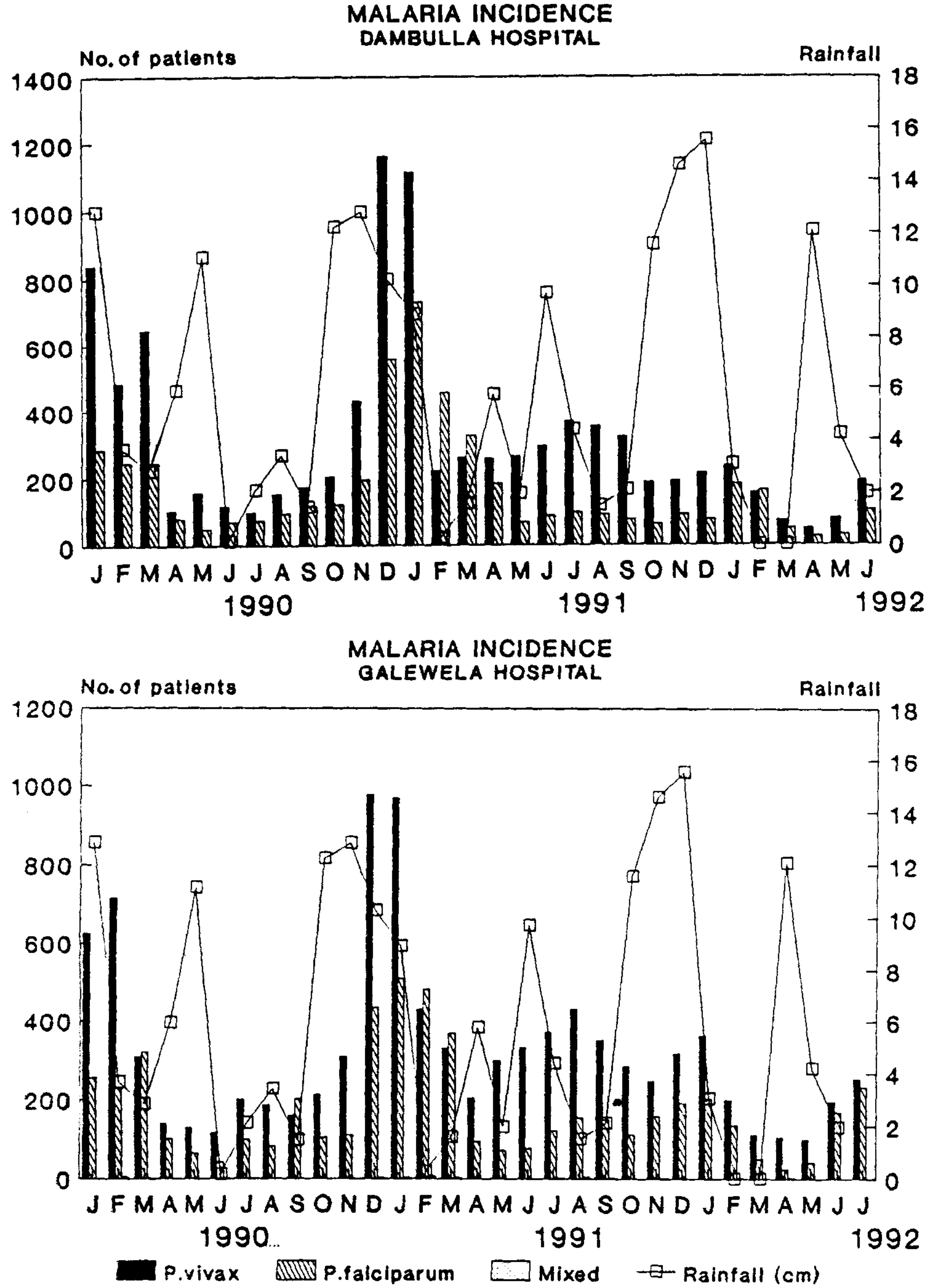

Fig. 3. Number of malaria patients seeking treatment at government hospitals in (a) Galewela, and (b) Dambulla, related to rainfall, January 1990 to June 1992.

in October during both seasons. A maximum monthly rainfall of 16 cm was recorded during the study period in December 1991, followed by drought in February–March 1992 and relatively high rainfall in April 1992. Anophelines were most abundant at Nikawehera in December 1991, with numbers then decreasing rapidly during the period January–March and increasing in April 1992. *An.culicifacies* was present in collections throughout the period and the human-biting rate (HBR, i.e. number of bites per man per hour) reached a maximum of 1.35 in December (Fig. 2). Biting activity of *An.culicifacies* occurred throughout the night, mostly before midnight, with a peak at 20.00 hours (Fig. 5).

A total of 2731 mosquitoes were collected at Nikawehera during 7 months (October 1991 to April 1992), of which 513 (18.8%) were identified as anophelines and 2218 (81.2%) as culicines (Table 1). Among thirteen species of anophelines obtained, *An.culicifacies* predominated (57.2%). The other twelve species of anophelines collected and their prevalence were: *An.tessellatus* Theobald (8.9%), *An.vagus* Doenitz (7.8%), *An.peditaeniatus* Leicester (6.3%), *An.subpictus* Grassi (5.0%), *An.maculatus* Theobald (3.2%), *An.varuna* Iyengar (3.0%), *An.kawari* James (2.2%), *An.pallidus* Theobald (1.9%), *An.aconitus* Doenitz (1.7%), *An.annularis* Van der Wulp (1.3%), *An.barbirostris* Van ber Wulp (0.9%) and *An.nigerrimus* Giles (0.6%).

In February 52% of the anopheline females were nulli-

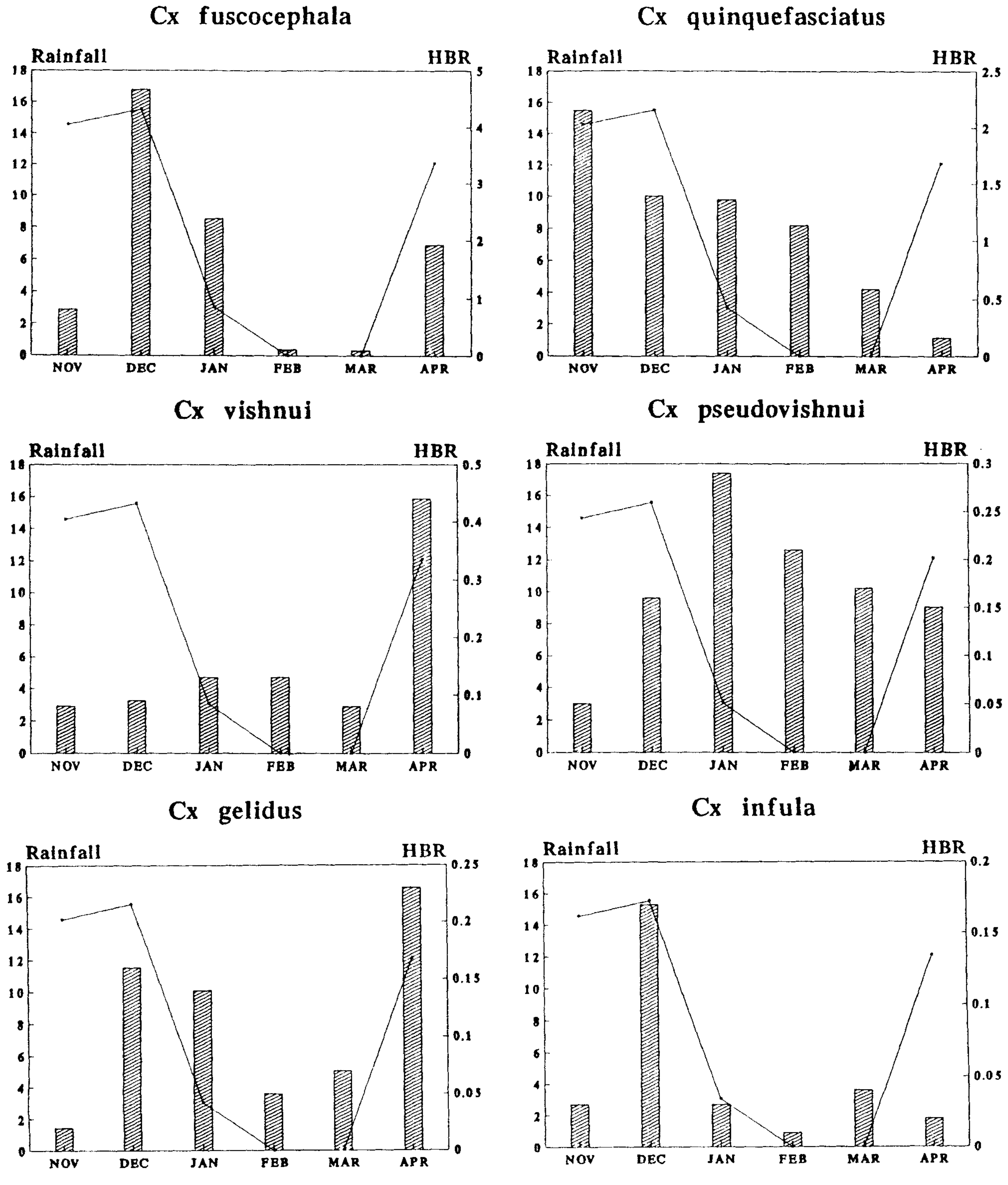

Fig. 4. Prevalence of eleven species of *Culex* in relation to monthly rainfall cm (line). HBR (human biting rate): number of bites per man-hour (column).

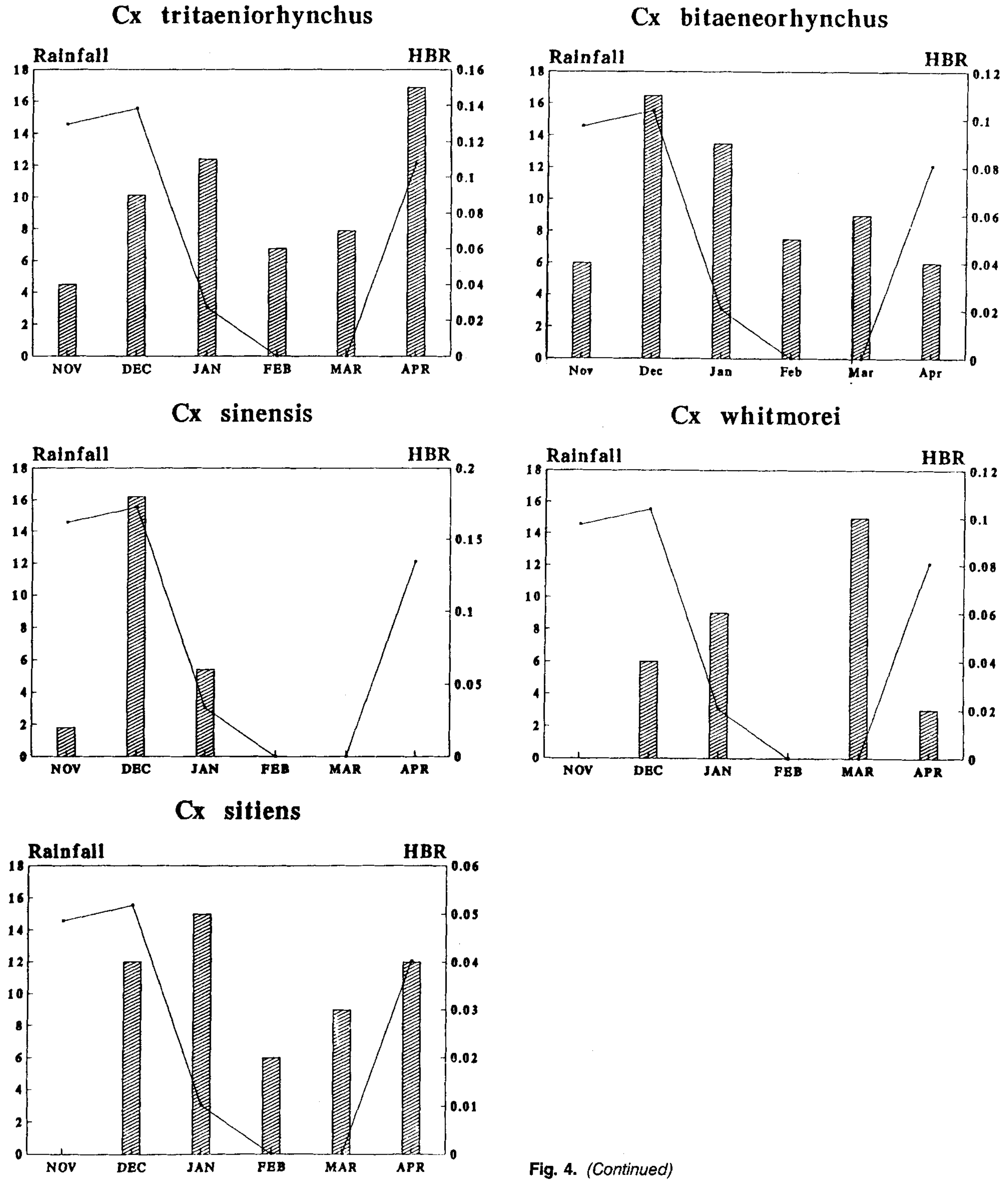

Fig. 4. *(Continued)*

parous (41% parous-1 and 7% parous-2) and the corresponding figures for March were 75% (65% and 10%).

HBR peaks for *An.tessellatus* (0.25) and *An.subpictus* (0.23), *An.kawari* (0.11) and *An.peditaeniatus* (0.23) were also recorded in December. Other anophelines recorded maximum HBR in either November or January. *An.maculatus* had a HBR of 0.08 in December and January, being absent in collections of October–November. The highest HBR for *An.varuna* (0.09) and *An.aconitus* (0.05) were recorded in January.

Monthly malaria incidence peaked in December–January with 150 + 566 cases at Galewela Hospital and

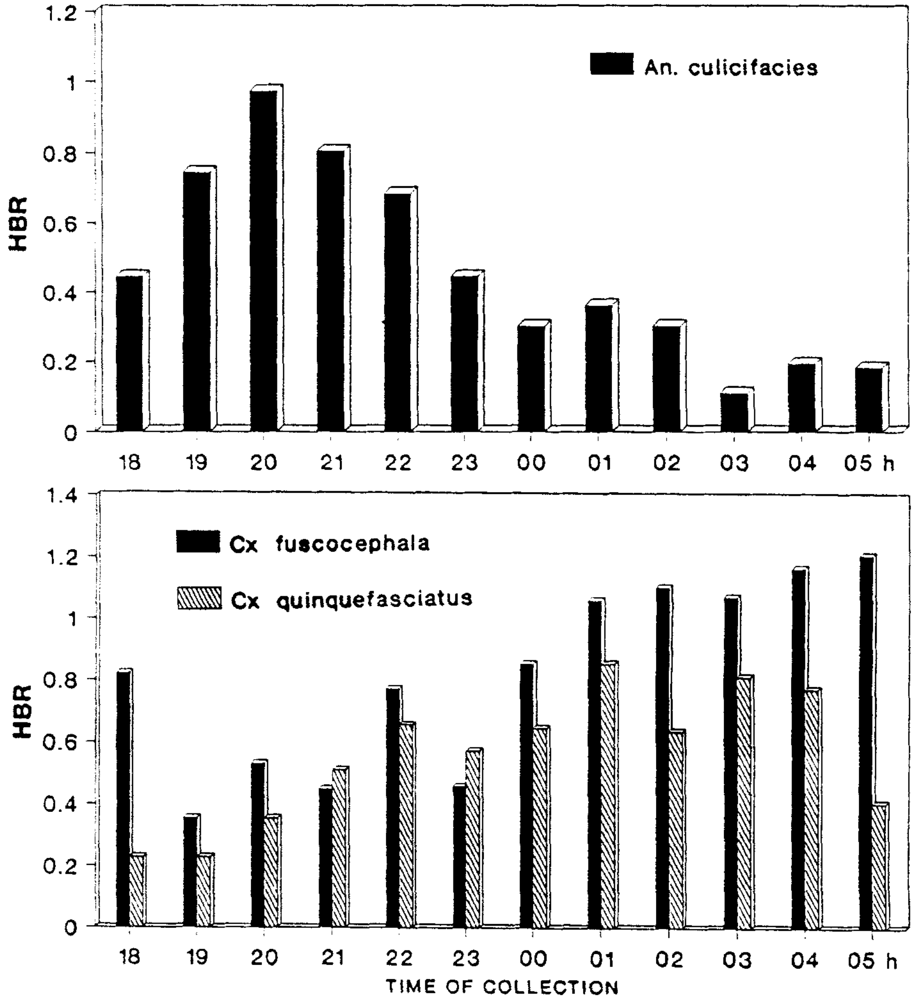

Fig. 5. The nocturnal biting cycles of *An.culicifacies*, *Cx fuscocephala* and *Cx quinquefasciatus*, October 1991 to April 1992 (HBR, human biting rate: mean no. of bites per man-hour) at Nikawehera.

287 + 414 cases at Dambulla Hospital (Fig. 3), overall prevalence of *P.falciparum* being about half that of *P.vivax* malaria.

Sporozoites were not detected in the salivary glands of any anophelines collected when ELISAs to detect *P.falciparum* and *P.vivax* circumsporozoite proteins were carried out as previously described (Ramasamy *et al.*, 1992b). However, *P.vivax* and *P.falciparum* infections were detected by examination of blood films from the residents of Nikawehera during October 1991, January and May 1992 (K. Nagendran, pers. comm.).

The 2218 culicine mosquitoes collected at Nikawehera comprised eighteen species belonging to four genera: *Aedes vittatus* Bigot, *Ae.aegypti*, *Ae.albopictus*, *Mansonia uniformis* Theobald, *Ma.indiana* Edwards, *Ma.annulifera* Theobald and *Armigeres subalbatus* Coquillett, and eleven *Culex* species: *Cx fuscocephala* Theobald (47.1%), *Cx quinquefasciatus* Say (31.8%), *Cx pseudovishnui* Colless (4.8%), *Cx vishnui* Theobald (4.5%), *Cx gelidus* Theobald (3.2%), *Cx tritaeniorhynchus* Giles (2.5%), *Cx bitaeniorhynchus* Giles (1.9%), *Cx infula* Theobald (1.4%), *Cx sinensis* Theobald (1.2%), *Cx sitiens* Wiedmann (0.9%) and *Cx whitmorei* Giles (0.6%). Collectively the peak HBR of *Culex* was recorded in December (Fig. 4). *Cx fuscocephala* and *Cx quinquefasciatus* predominated throughout the study period. An increase of *Cx quinquefasciatus* over *Cx fuscocephala* was observed in the drought months of February and March 1992. *Cx sinensis* was not collected from February to April, *Cx sitiens* was not collected in November 1991. *Cx whitmorei* was absent from the collections of November 1991 and February 1992. *Cx fuscocephala* and *Cx quinquefasciatus* exhibited similar biting cycles throughout the night. Their biting rates increased markedly after midnight and remained high until 06.00 hours (Fig. 5).

Discussion

An.culicifacies was the major vector of malaria collected at Nikawehera during the main malaria transmission season of 1990–91 (Ramasamy *et al.*, 1992b) and the present study shows that this mosquito continued to be the most prevalent anopheline at the site throughout the next major transmission season and until April 1992. The HBR for *An.culicifacies* recorded during the peak of the transmission season of 1990–91 averaged 2.53 bites per man-hour in November and 3.00 in December (Ramasamy *et al.*, 1992b), more than double the corresponding figures of 0.68 and 1.35 observed in the present study. It is noteworthy that only species B of the *An.culicifacies* complex has been reported from Sri Lanka (Green & Miles, 1980; P. A. Abhayawardana, pers. comm.), whereas species A, B, C and D have been reported from India (Subbarao, 1988), with species B being a poor vector of malaria in India. *An.tessellatus*, a malaria vector in southern Sri Lanka (Mendis *et al.*, 1990), which had not been detected at Nikawehera until May and September 1991 (Ramasamy *et al.*, 1992b), comprised 8.9% of the anophelines collected during the present study, with greatest abundance being recorded in December. *An.subpictus*, implicated as a vector of malaria in this area during the previous northeast monsoon season (Ramasamy *et al.*, 1992b) and at a different site in the irrigated dry zone (Amerasinghe *et al.*, 1992), reached its peak HBR at Nikawehera in December 1991. *An.annularis*, a vector at a newly irrigated agricultural site 70 km from the study area (Ramasamy *et al.*, 1992a), was not found at Nikawehera during October 1990 to September 1991 (Ramasamy *et al.*, 1992b), but was first collected at Nikawehera in November 1991 and continued to occur in low numbers throughout the remaining period of study. Likewise *An.peditaeniatus* was identified in collections made in November 1991 and continued its presence throughout the period of study. Whereas the malaria vector competence of *An.peditaeniatus* has not been demonstrated (Rao, 1984), many of the other *Anopheles* spp. collected in Nikawehera have been implicated as vectors of malaria (Subramaniam, 1982; Amerasinghe *et al.*, 1991, 1992; Mendis *et al.*, 1990; Ramasamy *et al.*, 1992a, b). This may be due to rapidly changing mosquito breeding conditions in the environs of Nikawehera and to incursions by species that have become established in the vicinity (e.g. *An.annularis*).

The 1990–91 malaria transmission season coincided with the northeast monsoon season, when the highest incidence of malaria was recorded at Galewela and Dambulla hospitals. The incidence of malaria reported was much lower during the corresponding monsoon period in 1991–92. These observations are consistent with the detection of sporozoite-positive anthropophagic anophelines in November 1990 to February 1991 at Nikawehera (Ramasamy *et al.*, 1992b), but not during the corresponding period in 1991–92 when young mosquitoes (nulliparous and parous-1) predominated. The density of *Anopheles* fell drastically during the drought months of February and March 1991, but increased in April, following high rainfall. Reduction in the *Culex* population was less profound during the drought months of February and March 1992 than in the *Anopheles* population for the same period. This was apparent with the numbers of *Cx quinquefasciatus* collected in February and March, and can be attributed to the continued availability of breeding sites for *Culex* species (e.g. ponds, drains and flooded latrines) after the monsoon when typical *Anopheles* breeding sites (e.g. flooded fields, rainwater pools, and sandy pools in the drying beds of streams) tend to disappear. Peak malaria transmission rates lagged behind increases in the densities of the major anopheline vectors by approximately 1 month in the 1990–91 and 1991–92 northeast monsoon seasons. Conversely, mosquito populations peaked about 1 month after the onset of the monsoon in both years.

This study demonstrates that there were significant differences in malaria transmission patterns and vector populations between the 1990–91 (Ramasamy *et al.*, 1992b) and 1991–92 northeast monsoon seasons. Thus malaria transmission in the area may be termed unstable and changes in vector populations may be an important cause of this.

As *An.culicifacies* and *An.subpictus* are indoor-resting species, bednets could be employed to reduce the human exposure to these vectors. Moreover, insecticide-treated nets are also regarded as an efficient way of reducing the numbers of other anthropophilic mosquitoes. However, much of the human biting by *An.culicifacies*, as observed in our study, occurred between 18.00 and 22.00 hours, during which time many villagers are likely to be outdoors, not in bed. Under these conditions the usefulness of untreated bednets for malaria control will be reduced. Based on the preferred biting times of some of the culicine vectors, the use of bednets in Nikawehera may be expected to decrease the incidence of filariasis and arboviral diseases, if they occur locally. The abundance of *Cx quinquefasciatus* raises the possibility of Bancroftian filariasis transmission in the environs of Nikawehera, but no filariasis surveillance is presently carried out in this rural community. *Cx tritaeniorhynchus* and *Cx gelidus* are vectors of Japanese encephalitis and, in Sri Lanka, this virus has also been isolated from *Cx fuscocephala*, *Cx whitmorei* and *M.uniformis* (Peiris *et al.*, 1992), species collected at Nikawehera in the present study. *Ae.aegypti* and *Ae.albopictus*, the established vectors of dengue in Sri Lanka (Vitarana *et al.*, 1986), were also found plentifully at Nikawehera, raising the need for an integrated mosquito control programme to be devised and implemented (Laird & Miles, 1983, 1985; Curtis, 1990).

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References

Abdulcader, M.H.M. (1967) The significance of the *Culex pipiens fatigans* Weidman problem in Ceylon. *Bulletin of the World Health Organization*, **37**, 245–249.

Amerasinghe, F.P. (1990) A guide to the identification of the anopheline mosquitoes (Diptera: Culicidae) of Sri Lanka. 1. Adult females. *Ceylon Journal of Science*, **21**, 1–16.

Amerasinghe, F.P., Amerasinghe, P.H., Peiris, J.S.M. & Wirtz, R.A. (1991) Anopheline ecology and malaria infection during the irrigation development of an area of the Mahaweli project, Sri Lanka. *American Journal of Tropical Medicine and Hygiene*, **45**, 226–235.

Amerasinghe, P.H., Amerasinghe, F.P., Wirtz, R.A., Indrajith, M.G., Somapala, W., Pereira, L.R. & Rathnayake, A.M.S. (1992) Malaria transmission by *Anopheles subpictus* (Diptera: Culicidae) in a new irrigation project in Sri Lanka. *Journal of Medical Entomology*, **29**, 577–581.

Curtis, C.F. (ed.) (1990) *Appropriate Technology in Vector Control*. CRC Press, Boca Raton, Florida.

Dissanaike, A.S. (1991) Filariasis in Ceylon then (1961) and in Sri Lanka now (1990, 30 years on). *Annals of Tropical Medicine and Parasitology*, **85**, 123–129.

Green, C.A. & Miles, S.J. (1980) Chromosomal evidence for sibling species of the malaria vector *Anopheles culicifacies* Giles. *Journal of Tropical Medicine and Hygiene*, **83**, 75–78.

Hemingway, J., Smith, C., Jayawardena, K.G.I. & Herath, P.R.J. (1986) Field and labortory detection of the altered acetylcholinesterase genes which confer organophosphate and carbamate resistance in mosquitoes. *Bulletin of Entomological Research*, **76**, 559–565.

Herath, P.R.J., Hemingway, J., Harris, J. & Jayawardena, K.G.I. (1988) DDT resistance in *Anopheles culicifacies* and *An.subpictus* from Sri Lanka: a field study on the mechanisms and changes in gene frequency after cessation of DDT spraying. *Bulletin of Entomological Research*, **78**, 717–723.

Klein, T.A. & Lima, J.B. (1990) Seasonal distribution and biting patterns of *Anopheles* mosquitoes in Costa Marques, Rhondonia, Brazil. *Journal of the American Mosquito Control Association*, **6**, 700–707.

Laird, M. & Miles, J.W. (1983, 1985) *Integrated Mosquito Control Methodologies*, Vols 1 and 2. Academic Press, London.

Mahadevan, S. & Cheong, W.H. (1974) Chart to the identification of *Aedes* (*Stegomyia*) group and pictorial key to *Mansonia* (Mansonoides). Institute of Medical Research, Kuala Lumpur.

Mendis, C., Gamage-Mendis, A.C., de Zoysa, A.P.K., Abhayawardena, P.A., Carter, R., Herath, P.R.J. & Mendis, K. (1990) Characteristics of malaria transmission in Kataragama, Sri Lanka: a focus for immuno-epidemiological studies. *American Journal of Tropical Medicine and Hygiene*, **42**, 293–308.

Pampana, E.J. (1969) *A Textbook of Malaria Eradication*, 2nd edn. Oxford University Press.

Peiris, H.T.R. & Hemingway, J. (1990) Temephos resistance and the associated cross-resistance spectrum in a strain of *Culex quinquefasciatus* from Peliyagoda, Sri Lanka. *Bulletin of Entomological Research*, **80**, 49–55.

Peiris, J.S.M., Amerasinghe, F.P., Amerasinghe, P.H., Ratnayake, C.B., Karunaratne, S.H.P.P. & Tsai, T.F. (1992) Japanese encephalitis in Sri Lanka – the study of an epidemic vector; incrimination, porcine infection and human disease. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **86**, 307–313.

Ramasamy, R., de Alwis, R., Wijesundera, D.A. & Ramasamy, M.S. (1992a) Malaria transmission in a new irrigation scheme in Sri Lanka: the emergence of *Anopheles annularis* as a major vector. *American Journal of Tropical Medicine and Hygiene*, **47**, 547–553.

Ramasamy, R., Ramasamy, M.S., Wijesundera, D.A., Wijesundera, A.P. de S., Dewitt, I., Ranasinghe, C., Srikrishnaraj, K.A. & Wickramaratne, C. (1992b) High seasonal malaria transmission rates in the intermediate rainfall zone of Sri Lanka. *Annals of Tropical Medicine and Parasitology*, **86**, 591–600.

Rao, T.R. (1984) *The Anophelines of India*. Malaria Research Centre, Indian Council of Medical Research.

Rosenberg, R., Andre, R.G. & Sochit, L. (1990) Highly efficient dry season transmission of malaria in Thailand. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **84**, 22–28.

Samarasinghe, L. (1990) A situation analysis of malaria in Sri Lanka. *Current Status of Malaria Research in Sri Lanka* (ed. by R. Ramasamy), pp. 1–8. Institute of Fundamental Studies, Sri Lanka.

Shakoor, W.K.T.M. (1990) Environmental factors determining recurrent malaria epidemics in Sri Lanka. *Current Status of Malaria Research in Sri Lanka* (ed. by R. Ramasamy), pp. 85–90. Institute of Fundamental Studies, Kandy.

Sirivanakarn, S. (1976) *A Revision of the Subgenus Culex in the Oriental Region (Diptera: Culicidae)*. Contributions of the American Entomological Institute, Volume 12. Medical Entomology Studies III.

Subbarao, S.K. (1989) The *Anopheles culicifacies* complex and control of malaria. *Parasitology Today*, **4**, 72–75.

Subramaniam, K. (1982) *Anti-Malaria Campaign Report*. Ministry of Health, Colombo.

Vitarana, T.U., Herath, P., Kalpage, K., Jayasekera, N., Wickremasinghe, M. & Gunatilaka, V. (1976) Study of mosquito-borne diseases in some new irrigation schemes in Sri Lanka with particular reference to filariasis and arboviral diseases. *Proceedings of a Joint WHO/FAO/UNEP Workshop on Irrigation ad Vector-borne Disease Transmission*. International Irrigation Management Institute, Colombo.

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