CLIMATIC FACTORS ASSOCIATED WITH EPIDEMIC DENGUE IN PALEMBANG, INDONESIA: IMPLICATIONS OF SHORT-TERM METEOROLOGICAL EVENTS ON VIRUS TRANSMISSION

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Abstract. An extensive outbreak of dengue fever and dengue hemorhagic fever occurred in the city of Palembang, South Sumatra, Indonesia from late 1997 through March/April 1998. All surveyed administrative areas (*kelurahan*) in Palembang were found to be 'permissive' for dengue virus transmission; and all areas that had *Aedes* (subgenus *Stegomyia*) larval mosquitoes in abundance experienced increased cases of DHF during the epidemic. The *Aedes* House Index (HI) for combined *Aedes aegypti* and *Aedes albopictus* was recorded every 3 months before, during, and after the epidemic. Ten surveyed sentinel sites (October-December 1997) immediately preceding the epidemic peak had a combined HI of 25% (range 10-50.8%). Entomological surveys during the peak epidemic period (January-April) showed a combined HI of 23.7% (range: 7.6-43.8%). Kelurahans with the highest numbers of reported dengue cases had an HI exceeding 25%; however, there was no discernable relationship between elevated HI and increased risk of DHF incidence. Despite the unusual climatic conditions during late 1997 created throughout the region by the El Niño Southern Oscillation (ENSO), the house indices during both wet and dry months remained above 23% for the 4 quarterly (3-month) periods surveyed in the second half of 1997 and first half of 1998. Rainfall returned to near normal monthly levels shortly before the reported increase in human cases. However, mean ambient air temperatures continued above normal (+0.6 to 1.2ºC) and were sustained over the months leading up to and during the epidemic. Evidence suggests that an ENSO-driven increase in ambient temperature had a marked influence on increased virus transmission by the vector population. We explore the apparent associations of entomological and climatic effects that precipitated the epidemic before the influx of reported human cases.

INTRODUCTION

The incidence and distribution of dengue-related illness have grown dramatically in recent decades (Gubler, 1998; Clark, 2002) and are responsible for the most significant mosquito-borne viral disease syndromes globally. An estimated 2.5 billion people are at risk of contracting dengue fever (DF) and dengue hemorrhagic fever (DHF), many of whom live in the Southeast Asian region (WHO, 2002). In Southeast Asia, DHF cases have been increasing from an annual rate of <10,000 in the 1960s to >200,000 in the 1990s (Gibbons and Vaughn, 2002). Dengue fever and DHF remain serious health risks in urban and rural popu-

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lations of Indonesia, and are leading causes of excess mortality and hospitalization among children in the country. In 1998, Indonesia witnessed the largest epidemic on record, with 72,133 reported cases (IR 34.2/100,000) of DF/DHF and 1,414 dengue-attributable deaths (Suroso, 2001; WHO, 2004). By comparison, the disease incidence during recent preceding inter-epidemic years fluctuated between 10,000 and 25,000 cases countrywide (Department of Health, Indonesia, unpublished). Beginning in early 1998, the city of Palembang, a large, congested urban center in southern Sumatra, experienced a dramatic outbreak of DF/DHF resulting in large numbers of acute care hospitalizations (Corwin *et al*, 2001). Similar high levels of DF/DHF cases were reported elsewhere in Indonesia and throughout many countries and urban centers in Southeast Asia during the same 1997-1998 time period compared to previous decade (unpublished proceedings of International Conference on Dengue and Dengue Haemorrhagic Fever, Chiang Mai, Thailand, 20-24 November 2000; Do *et al*, 2000; WHO, 2002; Nagao *et al*, 2003).

The majority of the outbreak investigation activities in Palembang took place after the epidemic began to wane in April 1998 (Corwin *et al*, 2001). Multi-year trend analysis of hospital admissions for dengue-associated illness and a community-based, cross sectional study identified a steep rise in dengue cases beginning January 1997 and ending in April 1998 (Fig 1). The distribution (attack rates) of reported cases indicated clustering patterns of disease in the city, but was complicated by possible case collection bias from the 2 primary referral hospitals that may have substantially underestimated or misclassified the true disease burden and distribution in the population (Fig 2). As is often the case, most entomological parameters were poorly documented before, during and after the epidemic, resulting in a substantial investigative deficiency linking concurrent vector dynamics and

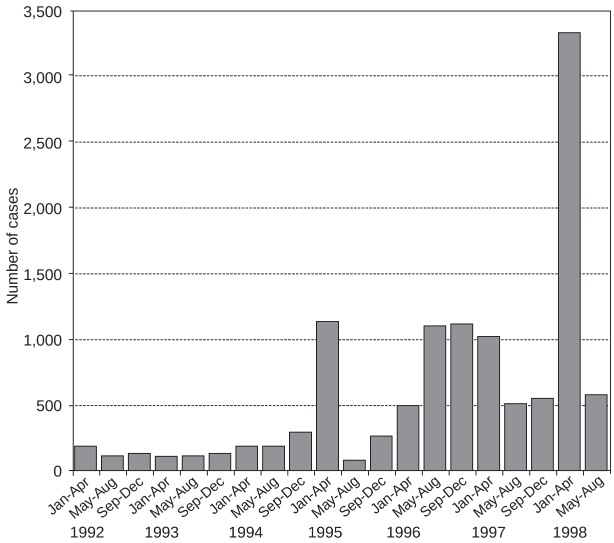
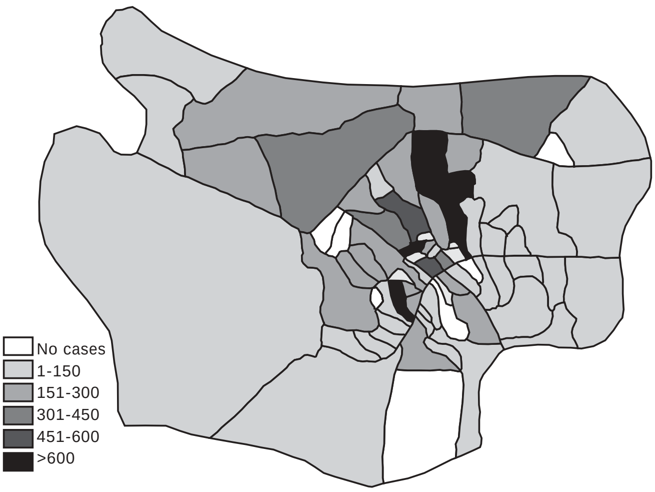


Fig 1–Epidemic curve of clinically diagnosed cases of DF/DHF/DSS from Charitas and M Hoesin Hospitals in Palembang, Sumatra, January 1992-August 1998.



Based on hospital (clinically) recognized cases match with February 1998 census data by Kelurahan

Fig 2–Attack rates of dengue cases per 100,000 population in 74 kelurahans in Palembang, Sumatra from January-April 1998.

precipitating events that may have contributed to increased virus transmission. However, prevailing climatic conditions before and during the outbreak showed profound anomalous rainfall patterns and significantly heightened ambient temperatures compared to normal monthly means. These conditions were attributed to a severe El Niño Southern Oscillation (ENSO), which occurred in the region during the same time period (Glantz, 2001; Kishore *et al*, 2001). We reviewed the climatic and entomological data that was available surrounding the epidemic period and investigated the possible epidemiological influence of these temporary, yet dramatic, climatic events had on dengue transmission in Palembang during late 1997 and early 1998.

MATERIALS AND METHODS

Palembang is a large urban and commercial center located in the Province of South Sumatra (3º 59´ S, 104º 45´ E), the westernmost major island in Indonesia. With an estimated population exceeding 1.5 million people, the city sits in a lowland area (0-25 m above sea level), surrounded primarily by expansive freshwater marshlands. Most areas within the city are densely populated, consisting of congested middle to lower income housing and commercial areas.

Aedes vector surveillance data were provided by the local Palembang Department of Health (DoH) from summarized periodic mosquito vector surveys, premise inspections and vector control activities (DoH 1997-1998, unpublished). Before and during the epidemic period, inspections in and immediately around homes for *Aedes* larvae were conducted approximately once every 3 months in 10 sentinel sites within designated *kelurahans* (administrative units), each representing between 5,000-6,000 houses. The 10 monitored sites represented approximately 10% of available kelurahans within the administrative authority of Palembang. Shortly after the dengue epidemic began, the number of sentinel areas was reduced to 5 kelurahans, with only 2 of the 10 original sites retained from the previous 1997-1998 quarterly survey cycles.

Entomological information was restricted to the *Aedes (Stegomyia)* House Index (HI), a summarized measure of the percentage of inspected houses found infested with *Aedes* mosquito larvae, *ie*, *Aedes (Stegomyia) aegypti* (L.), *Aedes albopictus* (Skuse). Containers were only recorded for presence of *Aedes* larvae and were rarely sampled for species identification on the assumption that most infestations were *Ae. aegypti*. Other standard surveillance measures (Chan, 1985a), including the Container Index (percentage of sampled water-holding containers infested with *Aedes* larvae) and the Breteau Index (number of positive containers per 100 houses inspected) were not routinely recorded. Indoor resting and adult mosquito human-landing collections were not performed during these periods.

Monthly weather data (based on maximum, minimum, and average daily temperatures, relative humidity, and precipitation) were compiled from government statistics for the months immediately before, during and after the dengue epidemic and compared to previous years' records (1984-1996 for temperature and 1952-1996 for rainfall).

RESULTS

Quarterly *Aedes* mosquito surveillance and control activities between April 1997 and September 1998, found variable combined HI measures ranging from 58% (April-June 1997) to 12.9% (July-September 1998) (Fig 3). Generally, less than 50% of houses in any particular survey area were inspected during each quarter. An accurate comparison of house indices between all quarterly surveys was not possible as the number of kelurahans inspected differed between I-IV quarters, April 1997-May 1998 and I-II quarters, April-September 1998. Subsequently, the number of houses surveyed each quarter also varied from 19,071 to 9,535. Peak survey activities occurred during the height of the reported dengue case period (January-March 1998), resulting in a combined 10-locality HI of 23.7% (7.6-43.8%). Kelurahans with the highest number of reported dengue cases had an HI > 25%. The October-December 1997 quarter immediately preceding the epidemic peak had a combined mean HI of 25% (10-50.8%).

Vector control activities during the preceding inter-epidemic period in Palembang were limited to outdoor ground dispersed ultra-low-volume (ULV) insecticide spraying using malathion, or occasionally cyfluthrin, at approximately 6-month intervals. All school grounds were space sprayed once every 6 months and general communities were targeted for ULV applications several months (August-October) before periods of expected increases of dengue cases (October-April). As standard procedure, thermal fogging applications of insecticides occurred within a 200 m radius of all reported DHF index cases (Husni, 1998). Routine larval monitoring activities also included application of temephos (Abate® 1% treated sand granules) or methoprene (Altosid® insect growth regulator) to all larva-positive containers. Temephos was also distributed to households in dengue endemic areas by health department staff or community volunteers with instructions for owners to apply measured amounts to all water storage containers approximately every 3 months. In response to rising cases and public expectations, the frequency and area coverage by ULV and thermal fogging spraying activities increased approximately two-fold (>2 rounds/month) during the epidemic, especially in those areas reporting high numbers of DHF cases.

A distinct period of diminished rainfall was noted from June - November 1997, compared to mean monthly rainfall for the same periods from 1952 through 1996. Above average rainfall occurred in December 1997 through May 1998, compared to the same periods the previous years (Fig 3). The HI dropped from 58% in April-June 1997 to 23.7% in January-April 1998; however, there was no strong association between the HI and rainfall patterns, likely reflecting regular water storage practices in households or insensitive surveillance activities. Despite unusually prolonged drying effects caused by the 1997-1998 ENSO, the quarterly composite house index for wet and dry months remained above 23% for all 4 epidemic quarter periods. The average ambient temperatures were above normal (+0.6-0.9ºC) for the pre-epidemic months of August to November 1997, and remained above normal (+0.7-1.2ºC) from December 1997 to April 1998, compared to the previous 13 years of mean monthly temperatures (Fig 4).

DISCUSSION

An often confounding facet of the dynamics of dengue epidemics is the mosquito vector, its mere presence being simply assumed but infrequently investigated in great detail. *Aedes aegypti* is the primary vector of epidemic DF/DHF worldwide, driven by its strong blood feeding preference and close association with humans (Gubler, 1988). In Indonesia, *Ae. aegypti* has long been implicated in epidemic and inter-epidemic transmission (Nelson *et al*, 1976; Jumali *et al*, 1979; Sumarmo, 1987). Based on vector surveillance data, all surveyed kelurahans in Palembang were found to be highly 'permissive' or receptive areas for dengue transmission. Almost without exception, *Aedes* infested areas had increased DHF activity during the epidemic period. The clustering patterns of DF/DHF cases seen in Palembang was consistent with other findings in Asia and the Americas (Halstead *et al*, 1969; Waterman *et al*, 1985; Gubler, 1988; Getis *et al*, 2003; Tran *et al*, 2004) wherein a normally limited flight range and frequent human blood-feeding behavior of mosquito vectors are often conducive for promoting spatially concentrated virus transmission activity (Scott *et al*, 2000; Van

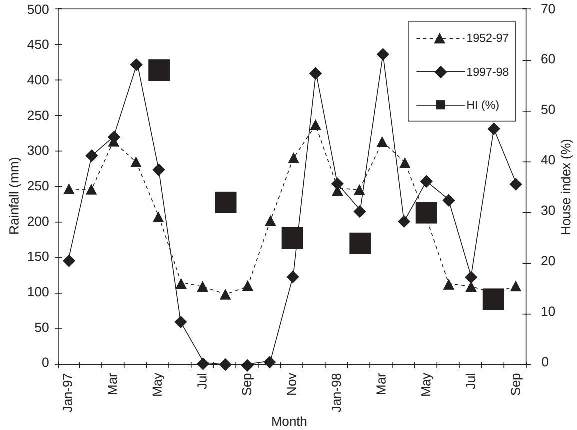


Fig 3- Monthly mean rainfall (mm) from 1952-1997 compared to rainfall for individual months in 1997 and 1998 in relation to *Stegomyia* House Index (% houses infested with *Aedes* larvae) in Palembang, Indonesia.

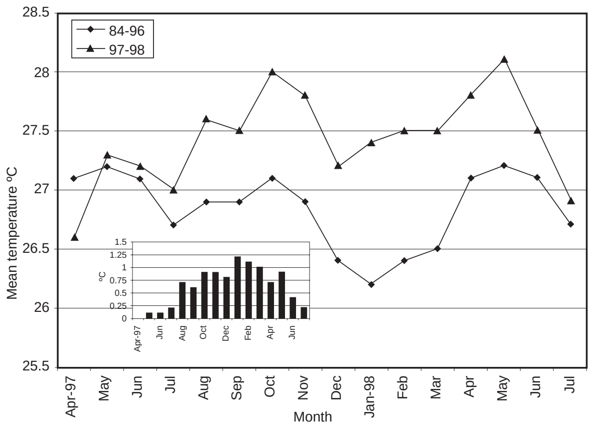


Fig 4- Monthly mean average 24-hour ambient air temperatures from 1984-1996 compared to temperatures for individual months in 1997 and 1998. Insert figure: above normal average temperatures by month for 1997-1998 compared to 13-year average in Palembang, Indonesia.

Benthem *et al*, 2005; Harrington *et al*, 2005; Russell *et al*, 2005).

Increased insecticide spraying activities occurred after the apparent peak of dengue transmission in Palembang. In March 1998, ULV ground spraying occurred at 377 schools located in 3 of the most heavily affected kelurahans in central Palembang, whereas only 4.2% of all localities reporting clinical cases were focally treated with insecticide (Husni, 1998). Previous vector control efforts using ULV ground dispersed insecticides and mass larviciding efforts have been cited as effective in dramatically reducing adult mosquito densities and abating DHF epidemics in Indonesia (Suroso, 1984). A similar strategy was followed in the 1980 DHF epidemic in Palembang, which reportedly reduced vector densities and the number of dengue cases (Suroso, 1981). What contribution, if any, insecticide spraying reduced vector mosquito populations and disease incidence during the 1997-1998 epidemic is not known, but was likely very minimal given the relatively poor and sporadic coverage reported.

Insufficient empirical evidence exists that establish entomological thresholds predicting levels of dengue transmission risk, but by all estimates such parametric thresholds are considered to be very low (Focks *et al*, 1993, 2000; Rieter and Gubler, 1997). Although different container indices exist for the purposes of monitoring vector density in relation to dengue risk, only the *Aedes* HI is routinely reported for mosquito surveillance in Palembang. The HI is considered a crude correlate of dengue transmission risk, providing an estimate of the percentage of houses positive for potential vectors, and thus, a relative percentage of the human population at risk for infection (Tun-Lin *et al*, 1996; Heng *et al*, 1998; Morrison *et al*, 2004). Its primary limitation is that productivity, the number of adult mosquitoes produced over time, is not addressed. The relationship between larval container indices and adult vector density is highly variable, being dependent on particular stressors like container size, degree of larval crowding, and availability of nutrients. However, by many accounts, only when mosquito vector densities appear exceptionally low (*eg*, HI < 5%) does entomologic surveillance appear to provide any predictive value for the potential risk of virus transmission (Chan, 1985a; Gubler, 1989).

The relationship between container indices alone and measures of epidemic risk remains difficult to define. No meaningful correlation could be derived between the HI and increased incidence of DF/DHF in Palembang, as all areas surveyed had indices at or above 23%. Only a few investigations attempting to correlate *Aedes* vectors with dengue virus transmission in Indonesia have been published (Van Peenan *et al*, 1972; Nelson *et al*, 1976; Nalim *et al*, 1978; Jumali *et al*, 1979; Oda *et al*, 1983). The increase of DHF cases in Indonesia is usually greatest during or shortly following the wet season, when *Aedes* populations are believed to increase significantly (Sumarmo, 1987). In line with most investigations, the Palembang outbreak showed no striking correlation between climatic parameters (*ie*, rainfall, temperature) and size of vector population when based solely on larval indices (Sheppard *et al*, 1969; Ho *et al*, 1971; Moore, 1985). Likewise, in Jakarta, no evidence of seasonal fluctuation of adult vector populations has been clearly documented, despite the marked annual wet season that occurs in western Java from October to March (Van Peenan *et al*, 1972; Nelson *et al*, 1976).

The common use of permanent indoor cisterns for domestic needs is considered one of the most important sources of *Ae. aegypti* breeding in Palembang (M Adjad, personel communication). Indoor larval habitats are generally less affected by fluctuations in rainfall compared to outside habitats. Indoor domestic use of water is often derived from permanent sources (*eg*, wells). Despite advances in understanding, there remains no simple relationship (*eg*, critical threshold) that consistently links mosquito density (larval and/or adult) with dengue incidence (Chan, 1985a; Focks *et al*, 1995; Tun-Lin *et al*, 1996). Confounding factors can include climate, seasonal patterns of vector activity and behavior, circulating virus serotypes, host age, degree of population 'herd' immunity, and human activities and movement (Gubler, 1988; Kongsomboon *et al*, 2004; Van Benthem *et al*, 2005).

Mathematical modeling of variations in dengue incidence suggests that climate changes can induce large variations in vector populations, and thus influence dengue transmission (Patz *et al*, 1998; Hopp and Foley, 2001; Jettsen and Focks, 2001). During typical years, Indonesia experiences two distinct seasonal periods: the drier months of April-September and the wet season from October through March. Periodically, prolonged droughts occur in Indonesia, at times affecting the entire archipelago. From 1877 to 1998, 93% of recorded droughts have been linked to contemporaneous ENSO events wherein the onset of the monsoon rains was significantly delayed (Kishore *et al*, 2001). In mid-1997, an El Niño developed rapidly and persisted until April 1998. An El Niño develops as sea surface temperatures (SST) across the central and eastern equatorial Pacific Ocean rapidly become much warmer than normal. As the SST increases, rain-producing cloud mechanisms shift eastward away from the relatively cooler SST prevailing over the western Pacific and Southeast Asia resulting in greatly diminished rainfall throughout much of the region. The western regions of Indonesia (including southern Sumatra) have historically been particularly susceptible to the influence of recurring ENSO cycles and generally more sensitive to such climatic extremes, where the dry season is prolonged before the wet monsoon period resumes. The severe drought reached its peak during the period of September-November 1997, with nearly all areas of the country experiencing rainfall levels far below expectation. After nearly 2 months delay, rainfall returned to near normal levels in Palembang, beginning in December 1997. However, ambient temperatures from May 1997 to July 1998, remained consistently above normal despite the return of precipitation.

The 1997-1998 ENSO had dramatic health and economic consequences throughout most of Indonesia (Kishore *et al*, 2001). Before the Southeast Asian-wide 1997-1998 DF/DHF outbreak, a series of health warnings mounted concerning the potential impact of global warming and periodic ENSO events on vector-borne diseases (Nicholls, 1993; Reeves *et al*, 1994; Bouma and Van der Kaay, 1996; Patz *et al*, 1996; Martens *et al*, 1997; WHO, 1999b; Hunter, 2003). Among the viral agents considered most susceptible to climatic extremes associated with ENSO is dengue (Hales *et al*, 1996, 1999; Sehgel, 1997; Hopp and Foley, 2001, 2003). Certainly, not all dengue epidemics are attributed to such dramatic changes in weather patterns. Although temporal coincidence or biologically relevant factors cannot be entirely ruled out, the apparent overlap between aberrant climate and the record-breaking increase in dengue incidence seen in Palembang and much of the Southeast Asian region is supported by a near simultaneous and sudden drop in cases in almost all affected countries shortly after the cessation of ENSO.

The 1997-1998 ENSO was possibly the most significant worldwide climatic event of the last century (Glantz, 2001; NRC, 2001). It brought tremendous economic loss to the Southeast Asian region, with profound impact on sensitive ecosystems and the welfare of vulnerable human populations. Health-related factors, including extreme shortages in food production and potable water supplies, were exacerbated by a dramatic economic crisis in the Asian region during the same period. Far less understood have been the past linkages between ENSO climate fluctuation and the risk of vector-borne diseases such as malaria and dengue (Nicholls, 1993; Hales *et al*, 1996, 1999; Bouma and Dye, 1997; Gagnon *et al*, 2001; Patz and Kovats, 2002; Hunter, 2003; Hopp and Foley, 2003). The Palembang dengue epidemic is the second recorded account of a large vector-borne disease outbreak in Indonesia associated with the 1997-1998 ENSO (Bangs and Subianto, 2000). There has been an urgent and fundamental need for better understanding of climatic phenomena and anomalies that can impact economic and demographic sectors including agriculture, forestry and health. However, without meaningful disease and vector surveillance programs in place to provide information, debate will continue on the degree of influence ENSO events have on the transmission of dengue and other vector-borne diseases. A better understanding of the relationship between ENSO and disease transmission will provide insights of what future ENSO events may support.

From August through October 1997 there was a dramatic departure from normal rainfall and ambient air temperatures in the region. Although precise influence of the unusually hot-dry period on dengue transmission remains poorly understood, especially during the months immediately preceding the dengue epidemic, we believe the association is beyond mere coincidence. Onset of the Palembang epidemic occurred shortly after the rainy season began in December; however, actual increased levels of transmission likely occurred many weeks or even months earlier (Corwin *et al*, 2001). Although circumstantial, there is compelling evidence to suggest that increased temperature helped precipitate and prolong the epidemic event. Previous dengue epidemics associated with temperature increases have been described in Mexico, Honduras and Singapore (Figueroa *et al*, 1982; Koopman *et al*, 1991; Herrera-Basto *et al*, 1992; Heng *et al*, 1998).

More often, fluctuations in vector life expectancy and population size do not directly correlate with changes in the incidence of dengue infections. Arguably, the same hot-dry conditions before December 1997 could have had detrimental effects on vector survival, behavior and overall mosquito densities attacking humans, yet Sheppard *et al* (1969) found increased vector longevity was negatively correlated with the increased incidence of DHF in Bangkok, Thailand. Furthermore, others have shown a relationship between increased frequency of vector feeding during hot-dry and rainy periods and epidemics of DHF (Yasuno and Tonn, 1970; Pant and Yasuno, 1973).

Temperature directly affects the rate of development of different mosquito life stages, as well as dengue viral replication. Higher ambient temperatures enhance virus replication and shorten the extrinsic incubation period (EIP) in the vector (Watts *et al*, 1987; Reiter, 1988), thereby increasing vectorial efficiency. Mosquito survival is also temperature dependent, which has an influence on the persistence of free water and relative humidity (Christophers, 1960; Rueda *et al*, 1990; Tun-Lin *et al*, 2000; Hopp and Foley, 2001). *Aedes aegypti* is a resilient mosquito, and because of its close adaptation to human households, is more likely to escape hostile environmental extremes detrimental to other, more exophilic species (Macdonald, 1956). Larger body size of female mosquitoes may be considered better physiologically for vectors to acquire viral infections, while also having increased fecundity and greater persistence in blood feeding behavior (Van den Heuvel, 1963; Nasci, 1991; Sumanochitrapon *et al*, 1998). Yet some workers have observed that as a result of higher average temperatures, the shortened gonotrophic cycle and a greater frequency of blood meals in vectors, together with a reduced EIP of the virus, are of greater importance than mosquito size for enhanced dengue virus transmission (Rodhain and Rosen, 1997). The evidence supports that temperature-induced variations in vector efficiency in *Aedes aegypti* are among the most important determinants of temporal variation and incidence of DHF (Scott *et al*. 2000).

The Sriwijaya campus, located in an area with historically high endemicity of DHF (Vector Control Section, 1988) was among the worst affected kelurahans during the 1997-1998 epidemic. *Aedes aegypti* is presumed to account for the vast majority of peridomestic *Aedes* species in the city of Palembang; however, large biting populations of *Aedes albopictus* have been reported in areas surrounding the Sriwijaya University campus in the city center (DoH, unpublished report). The general campus area supports an extensive park-like setting containing numerous trees and natural vegetative cover. *Aedes albopictus* has easily adapted to exploiting human-modified environments, without having acquired the same degree of 'domestication' as *Ae. aegypti* (Hawley, 1988). Anwar *et al* (1995) detected greater indoor *vs* outdoor biting activity for *Ae. aegypti* (ratio 5:1) compared to greater outdoor feeding activity by *Ae. albopictus* (ratio 13:1). The extradomiciliary and exophilic behavior of *Ae. albopictus* populations also demonstrate greater seasonal fluctuation, with population numbers being more dependent on rainfall compared to *Ae. aegypti* (Gould *et al*, 1970; Ho *et al*, 1971; Almeida *et al*, 2005). In the rainy season, a greater number of potential *Ae. albopictus* natural larval habitats become productive, increasing the population density and range of this species (Pant *et al*, 1973; Chan, 1985b; Heng *et al*, 1998). Furthermore, higher temperatures decrease the pre-imago development time to adulthood (Alto and Juliano, 2001), periods often coinciding with the onset of dengue epidemics. Peri-domestic *Ae. albopictus* will feed readily on both humans and other animals, and are more likely to feed out-of-doors compared to *Ae. aegypti* (Pant *et al*, 1973). Nonetheless, because this species can readily exploit a greater variety of both artificial and natural containers, it can also be found in higher adult biting densities, especially during the wet season. Increased population density can also help compensate for generally lower vector capacity compared to *Ae. aegypti*.

As the January-March epidemic peaked during a period of increased precipitation, the possible involvement of *Ae. albopictus* in the epidemic spread of dengue remains a real possibility (Jumali *et al*, 1979). Although apparent clustering of dengue cases was seen in Palembang, the evidence was somewhat weakened given the poor detail in data collection. Those areas that showed less evidence of clustering may have indicated a larger vectorial role by *Ae. albopictus* in epidemic transmission (Heng *et al*, 1998). As *Ae. albopictus* has been found to be a competent laboratory host for dengue viruses (Gubler and Rosen, 1976; Mitchell, 1995) and has been incriminated as a vector in dengue epidemics in Asia (Russell *et al*, 1969; Chan *et al*, 1971; Jumali *et al*, 1979; Ali *et al*, 2003; Almeida *et al*, 2005); more field studies are needed to clarify the involvement of *Ae. albopictus* in the transmission dynamics of dengue in urban areas during both inter-epidemic and epidemic periods (Gratz, 2004). *Aedes albopictus* deserves serious attention in larger urban areas, wherein significant vector populations can exist in more affluent housing communities and park areas that help promote transmission.

Gradual changing climate patterns and short-term climatic anomalies aside, one of the principal factors responsible for the global resurgence of dengue has been the breakdown of effective *Aedes* mosquito surveillance and control in many dengue-endemic countries (Gubler, 1997). Moreover, the emphasis on use of ULV perimeter sprays has been viewed as an ineffective means to prevent or control adult mosquitoes and virus transmission (Newton and Reiter, 1992; Reiter and Gubler, 1997). Recent findings have stressed the preference of assessing vector densities at the household level, involving inspection of all types of water-holding containers and life stages at more frequent intervals (Getis *et al*, 2003; Morrison *et al*, 2004). Although more accurate, it is viewed as not a viable surveillance strategy for many resource-deprived health agencies in dengue endemic countries. A more practical approach to vector control would be to target the immature stages by eliminating only those larval habitats that are the most productive in terms of *Aedes* adult output (Focks *et al*, 2000; Strickman and Kittayapong, 2003). Control measures focusing on only select breeding sites of prime importance would be far less labor intensive and more manageable for routine application, including source reduction (elimination) and the appropriate use of larvicides or biocontrol agents (*eg*, predacious copepods). Unfortunately, budgetary constraints in Indonesia have greatly limited the extent and coverage of a national campaign to promote community-level source reduction against household *Aedes* larval habitats. Ultimately, sustainable vector control through community-based integrated programs (Chan *et al*, 1989; Hoedojo and Suroso, 1990; Gubler and Clark, 1994; WHO 1999a; Nalim *et al*, 2002) including organized source reduction campaigns, routine application of larvicidal agents, and use of mosquito-proof covers placed over containers remains the most practical means available to curtail transmission and prevent explosive epidemics in Indonesia.

We conclude that the combined high *Aedes* indices and elevated temperatures contributed to the 1997-1998 Palembang epidemic. We infer from this investigation that ENSO-induced temporary climate change played a significant role in precipitating the epidemic, based on interpretation of retrospective information from Palembang and the region, and review of research and epidemiological observations on the natural history of dengue viruses and mosquito vectors. Despite the prolonged drought, larval surveys conducted before and during the outbreak found the average HI remained above 25%, a level considered highly receptive for dengue transmission. With other possible contributing factors remaining equal, the most striking observation was the persistent elevated average daily ambient temperature, which remained above normal despite the return of rainfall beginning in late December 1997. With sustained increased temperatures resulting in accelerated viral replication in mosquitoes, together with sufficient adult vector populations, outbreak conditions were greatly heightened. We recognize that temperatures recorded at meteorological stations are not the equivalent of those experienced by immature stages in protected or indoor containers. Therefore, better correlation between ambient temperatures and its influence on natural aquatic habitats, indoor resting behavior of adult vectors and adult survival could help better predict those conditions that best favor larval development and fitness of emerging adults. With better diagnostic and information technology available today, including rapid virus detection assays for mosquitoes (Bangs *et al*, 2001) and sophisticated spatial analysis (Sithiprasasna *et al*, 2004), it is hopeful that increased understanding on vector-virus relationships will serve early warning systems for better prediction and forestalling dengue epidemics.

We hope this discussion promotes further investigation regarding the influence of relevant climatic factors on the fundamental epidemiology of dengue and transmission dynamics.

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