Anthropogenic deforestation, El Niño and the emergence of Nipah virus in Malaysia.

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Abstract

In late 1998, a novel paramyxovirus named Nipah virus, emerged in Malaysia, causing fatal disease in domestic pigs and humans with substantial economic loss to the local pig industry. Pteropid fruitbats have since been identified as a natural reservoir host. Over the last two decades, the forest habitat of these bats in Southeast Asia has been substantially reduced by deforestation for pulpwood and industrial plantation. In 199711998, slash-and-bum deforestation resulted in the formation of a severe haze that blanketed much of Southeast Asia in the months directly preceding the Nipah virus disease outbreak. This was exacerbated by a drought driven by the severe 1997-1998 El Niiio Southern Oscillation (ENSO) event. We present data suggesting that this series of events led to a reduction in the availability of flowering and fruiting forest trees for foraging by fruitbats and culminated in unprecedented encroachment of fruitbats into cultivated fruit orchards in 199711998. These anthropogenic events, coupled with the location of piggeries in orchards and the design of pigsties allowed transmission of a novel paramyxovirus from its reservoir host to the domestic pig and ultimately to the human population.

Key words: Anthropogenic deforestation, El Niiio, Nipah virus emergence.

INTRODUCTION

In September 1998, an outbreak of fatal febrile encephalitis occurred in inhabitants of Ampang village, Kinta district in the northern peninsular Malaysia.' The outbreak was preceded by the occurrence of respiratory illness and encephalitis in pigs in the same district.' By February 1999, similar diseases in pigs and humans were recognized in the central and southern part of peninsular Malaysia, associated with movement of domestic pigs from Kinta district southward. A month later, a cluster of 11 cases of respiratory and encephalitis illness with 1 death was reported among abattoir workers in Singapore who handled pigs from the outbreak regions in Malaysia.[3] A novel paramyxovirus, Nipah virus (NiV), was isolated from the cerebrospinal fluid of an encephalitic patient from Sungai Nipah village and identified as the aetiological agent responsible for the outbreak.[4,5] The outbreak in Singapore ended when the importation of pigs from Malaysia was prohibited and the outbreak in Malaysia ceased with the culling of over a million pigs. A total of 265 cases of encephalitis including 105 deaths associated with the outbreak were recorded by May 1999 in Malaysia.[6]

As with investigations in other emerging zoonotic diseases, the priorities for future prevention and control have involved identification of the natural reservoirs of the aetiological agents, and analysis of the underlying causal factors that resulted in emergence. Nipah virus has a close sequence homology and serological cross-reactivity with Hendra virus, a lethal paramyxovirus of humans and domestic horses that emerged from fruitbat reservoirs in Australia.' In an initial survey of 14 species, neutralizing antibodies to Nipah virus were detected in Malayan flying foxes *(Pteropus vampyrus)* and Island flying foxes *(Pteropus hypomelanus)*.[8] Subsequent work has isolated Nipah virus from two pooled urine samples of *P. hypomelanus* and a swab sample of partially eaten "Jambu air" *(Eugenia aquea)* fruit.' Thus it is likely that *P. hypomelanus* and *P. vampyrus* serve as the natural reservoir hosts of Nipah virus.

Over the last two decades, anthropogenic fire-mediated deforestation has become one of the greatest threats to tropical rainforests in Amazonia,[10,11] Africa," and Southeast Asia." Fire is used for large-scale land clearing, e.g. for

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pulpwood and industrial crop plantations as well as by small-scale farmers to clear land and bum agricultural waste.[13,14] Tropical deforestation by fire occurs on an immense scale in Southeast Asia (S.E.A). In 1982-1983, an estimated 3.5 X 10^6 hectares (ha) was burned in east Kalimantan due to the coincidence of drought and poor land-use management and in 1994 a similar area burned in Borneo and Sumatra.[13,15,16] The impact on wildlife habitat is clear,[9] but the extent of these anthropogenic changes affecting the food supply of highly mobile tropical forest species such as fruitbats is not known.

We sought to investigate the possible link between anthropogenic environmental changes and the emergence of the Nipah virus.

MATERIALS AND METHODS

Forest fires and haze

Satellite image of 199711998 Indonesia's forest fire was sourced from the Meteorological Services Singapore, Ministry of Science and Environment, Singapore (http://www.gov.sg/metsin/). The image was taken by the National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer (NOAA/AVHRR-14) satellite circulating at 870 km from the earth surface. Each hot spot on the image represents at least 1.1 square kilometre area of forest fire.

The data on the haze and air quality affecting peninsular Malaysia was obtained from Alam Sekitar Malaysia Sdn Bhd, Malaysia. Air samples were collected using high-volume air samplers at a flow rate of 1.1-1.5 m^3 min^{-1} and a sampling time of 24 hours. The air pollution index (API) was calculated based on the five pollutants: NO„ SO„ O_3, CO and respirable suspended particulate (PM10). In this study, only the value of suspended particulate matters of 10 micron or less in size (PM10) in terms of mg/m^3 of air was used as the indicator of the severity of haze.

Rainfall and drought

The rainfall data in various parts of peninsular Malaysia were obtained from Malaysian Meteorological Service Department, Ministry of Science, Technology and Environment, Malaysia. Standard rain gauge was used to collect and measure the amount of rainfall daily.

Oil-palm crop output

A 10-acre (4 hectares) size oil palm smallholding in the state of Malacca was selected to demonstrate the climatic (haze and rainfall) changes that affected the crop out-put from 1994 to 2000. This oil palm smallholding was selected for a number of reasons: (1) The palm trees were all uniformly 7 years old in 1994. At 7 years of maturity, the palm trees are known to be entering the peak plateau phase of crop production for the next 15 years.[17] (2) The weeding, pruning and addition of fertilizer were consistent and on a regular basis and managed by the same farmer throughout the period. Thus, any fluctuation in crop out-put could only be due to climatic changes or outbreak of plant diseases.(3) A very good record of the monthly crop out-put in terms of weight (kilogram) of fresh fruit bunches was kept from January 1994 onwards.

Field trips and survey

A number of field trips were made to the initial Nipah virus outbreak area (Ampang) and other pig-farming areas in the Kinta district to survey the existence of wildlife species and the geographical terrain. Information pertaining to the temporary visits of other wildlife species and fruit crops out-put of the areas for the years 1997 to 2000 were gathered by interview with local hunters, orchard and pig farmers. To reduce bias and tendency of local people to withhold sensitive information from government officials, two interviews were carried out, one by the author and the other by personnel from local livestock association.

RESULTS AND DISCUSSION

In the months of August, September and October 1997, fires in Kalimantan and Sumatra destroyed approximately 5 millions ha of forest and with the prevailing southwesterly winds, created the most severe haze ever known in part of S.E.A (Fig. 1).[18] This was particularly severe in the southern part of peninsular Malaysia (Malacca) and the site of initial Nipah virus disease outbreak (Ipoh) was less affected (Fig. 2). Sulphate and organic carbon particles in haze can contribute 73- 92% of total light extinction,[19,20] leading to significant effects on ecosystem function, particularly in tropical rainforests.[21,22,23,24] Here, hygroscopic particles in haze grow in size with increasing relative humidity.[25,26] In tropical rainforests, photosynthetic photon flux density (PFD) is generally a limiting factor of photosynthesis. Tang *et al.* (1996) reported reduced photosynthesis by forest trees during a 1994 haze event in Malaysia, despite the presence

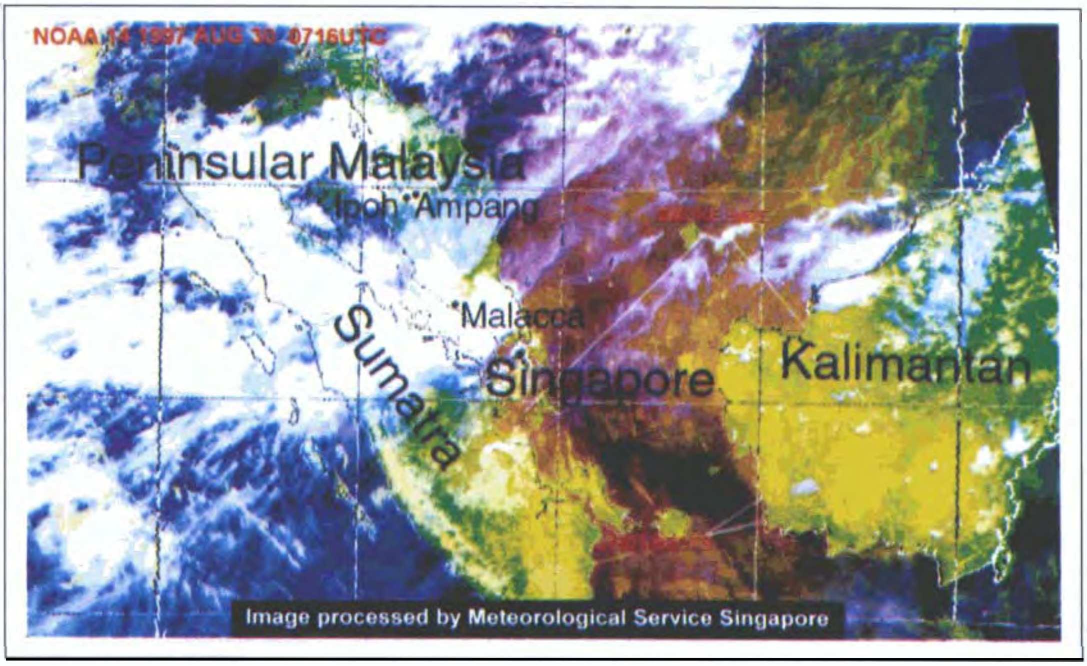

FIG. 1: **A NOAA/AVHRR-14** satellite image taken **in August,** 1997 **(0716UTC)** showing the extent of Indonesia's forest fires (hot spots) in **Kalimantan** and **Sumatra** and the **resultant** haze (brownish discoloration) that blanketed region of Southeast Asia. Each hot spot on the image represents at least 1 square **kilometer** area of forest fire. Source: **Meteorological** Services, Ministry of Science and Environment, Singapore.

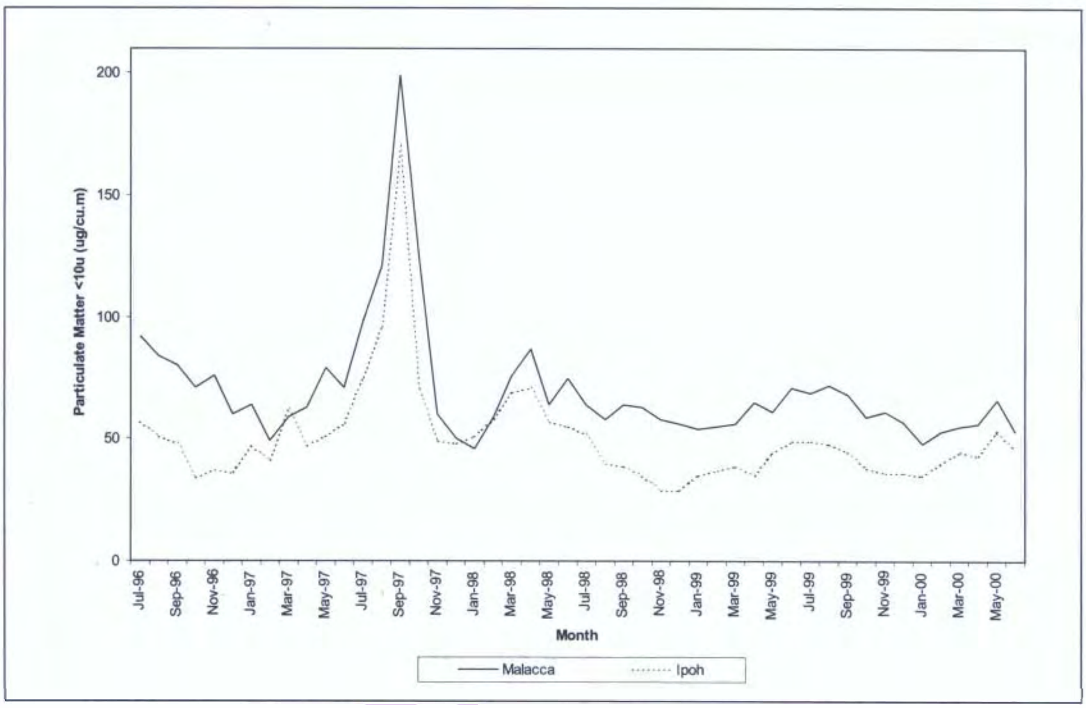

FIG. 2: Monthly air quality **index** of **Ipoh (dotted** line) and **Malacca (continuous** line) **from** 1996 to 1999. The **poor air** quality for **the months** of August, **September and October** 1997 **was** the result of haze **from immense Indonesia's forest** fires in **Kalimantan and** Sumatra. **Malacca was consistently more severely affected than** Ipoh because of the locality of the **fires and direction** of the **northwesterly wind** at that **period.**

of higher level of CO,, and demonstrated that the reduction of PFD within the forest was much higher than that in the open ground.[15]

The effect of 199711998 haze on the flowering and fruiting of tropical rainforest was not fully known. However, the haze substantially reduced flowering and fruiting among orchard fruit trees in southern peninsular Malaysia. Oral histories of orchard farmers in the states of Malacca and Johore reported severe crop failure. Limited studies revealed a 10% reduction in padi yields following the 199711998 haze, even in the northeastern part of peninsular Malaysia (Trengganu) which was less affected by the haze, and a delayed reduction on oil-palm crops in Tawau, Sabah (East Malaysia).[27] Figure 3 shows the 3-monthly output of oil-palm crop in term of fresh fruit bunches (FFB) of a 10-acre size oil-palm smallholding of uniform age in Malacca state entering its peak plateau phase of production from 1994 onwards.[17] The 199711998 haze with the concomitant drought caused a severe reduction in FFB output of oil-palm crop. Furthermore, the decrease in oil-palm crop output was delayed by around 6 months, suggesting the primary impact is failure of flowering (oil palm fruits take 6 months to mature).[28]

Figure 3 also shows the 3-monthly rainfall data in two representative areas in peninsular Malaysia from 1994 to 2000, one in the north (Ipoh – initial site of Nipah virus outbreak) and another in the south (Malacca). Both experienced decreased rainfall corresponding to the severe ENSO but the southern part of peninsular Malaysia was more severely affected. Therefore, the 199711998 ENSO-related drought exacerbated the anthropogenic fires in Indonesia, which may have subsequently aggravated the haze-related flowering and fruiting failure of forest trees. We propose that this loss of foraging habitat for fruitbats, coupled with increasing deforestation, propagated their migration into cultivated orchards. We support this hypothesis by examination of the sites corresponding to the index cases of Nipah virus disease. Figure 4A shows a partially demolished pigsty situated in the midst of durian (Durio zibethinus) and rambutan (Nephelium *lappaceum*) orchards in the Ampang village (approximately 8km from Ipoh city) within the Kinta district in the northern part of peninsular Malaysia. More than 100 hectares of these orchards surround the pig-farming area where the index case of human encephalitis and index cases of pig diseases due

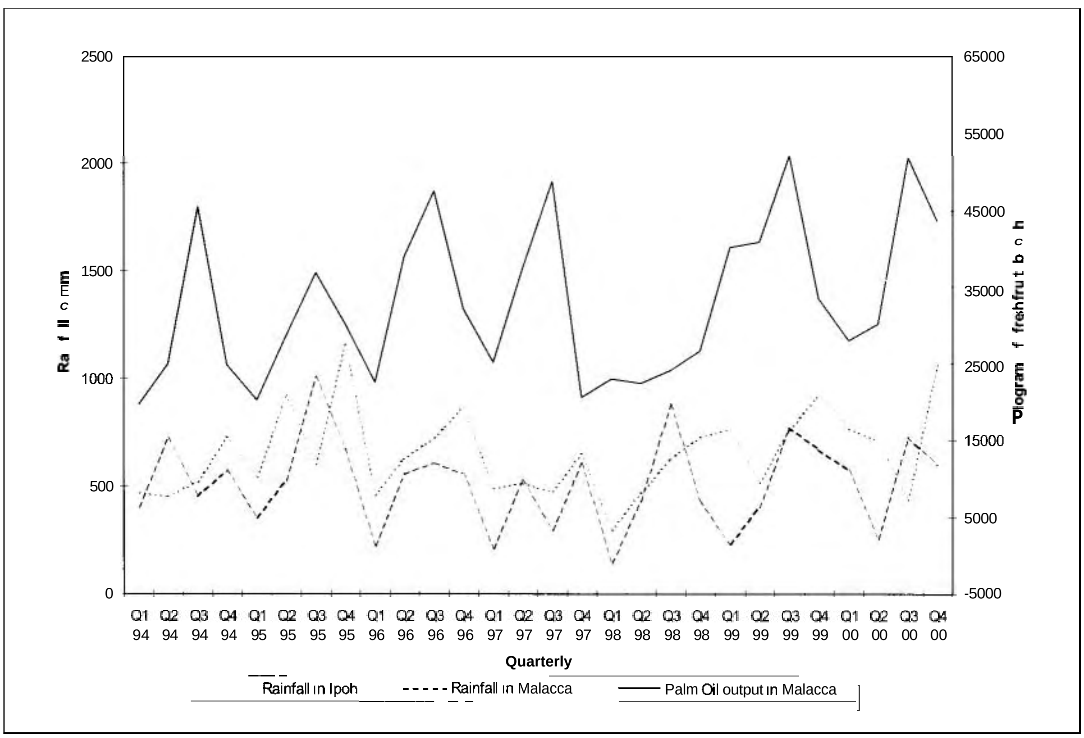

FIG. 3: 3-monthly palm oil crop output in term of kilogram of fresh fruit bunch of a 10-acre smallholding (continuous line) in Malacca in relationship to rainfall in the same period in Malacca (broken line) and Ipoh (dotted line).

to Nipah virus were reported."" Oral histories of local hunters and orchard farmers confirmed that P. *vampyrus* (one of two fruitbat species from which Nipah virus has been identified serologically) is normally absent from this area, but that in 1997 and 1998 (not 1999 and 2000), a colony of P. *vampyrus* roosted in forest about 20 kilometers from Ampang and were noted to visit the orchards surrounding piggeries to forage on durian flower nectar during the night. At the piggeries associated with the index human case of Nipah virus disease (Fig. 4B), pigsties were purposely constructed such that the low concrete walls (black arrow) that confined the pigs extended beyond the edge of the roof (white arrow) to allow rain-water run-off from the roof to collect inside the enclosure for bathing the pigs (Fig. 4C). Partially-eaten fruits were also found within pigsties (Fig. 4D), suggesting a direct mechanism for Nipah virus transmission from fruitbats to pigs. We propose that encroachment of Nipah virus-infected fruitbats throughout late 1997 and early 1998 led to initial transmission of the virus to pigs. The transmission of Nipah virus among pigs led to its amplification and subsequent spread to human population and other domestic animals that were in direct close contact with infected pigs. The transmission of the virus from infected human to human and from infected dogs to human was

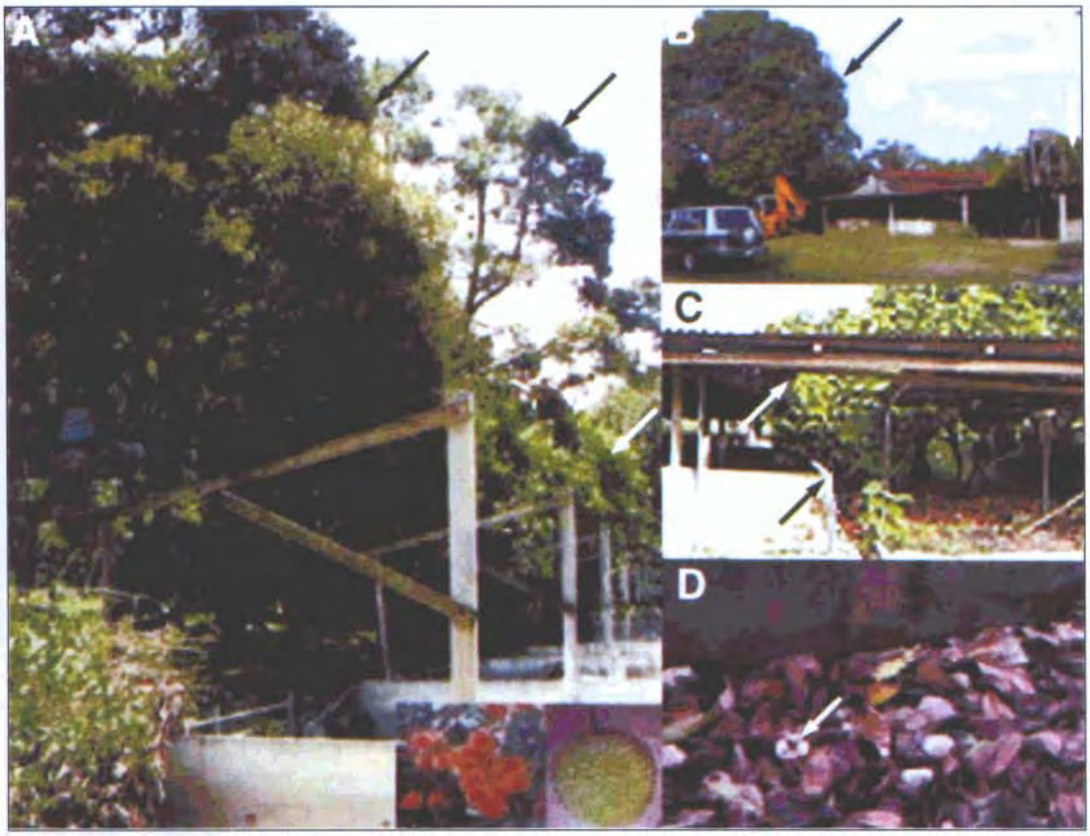

FIG. 4: A collection of photographs showing the close relationship between piggeries and cultivated orchards in the index area of Nipah virus outbreak. (A) A partially demolished pigsty situated in the midst of durian trees (Durio *zibethinus*) (black arrow) and rambutan trees (Nephelium *lappaceum*) (white arrow). The inserts show pictures of the fruits: durian (green) and rambutan (red). (B) Demonstrates the close proximity of fruit trees to pigsty in a farm where the first fatal case of human encephalitis due to Nipah virus was recorded. The tall mango tree (*Mangifera indica*) (black arrow) was not only able to bear fruits to attract the giant fruit bats, also served as a good initial landing place for the bats to go for the fruits in the "jambu air" tree (white arrow). (C) The "jambu air" tree not only grew over the roof of the pigsty, its branches also grew into the enclosure of pigs. Note the low concrete walls (black arrow) that kept the pigs within were built beyond the edge of the roof (white arrow) to allow rainwater collected on the roof to fall inside the enclosure for bathing the pigs. This also allowed any contaminated object or partially eaten fruit (white arrow) to drop into the pig-pan (D).

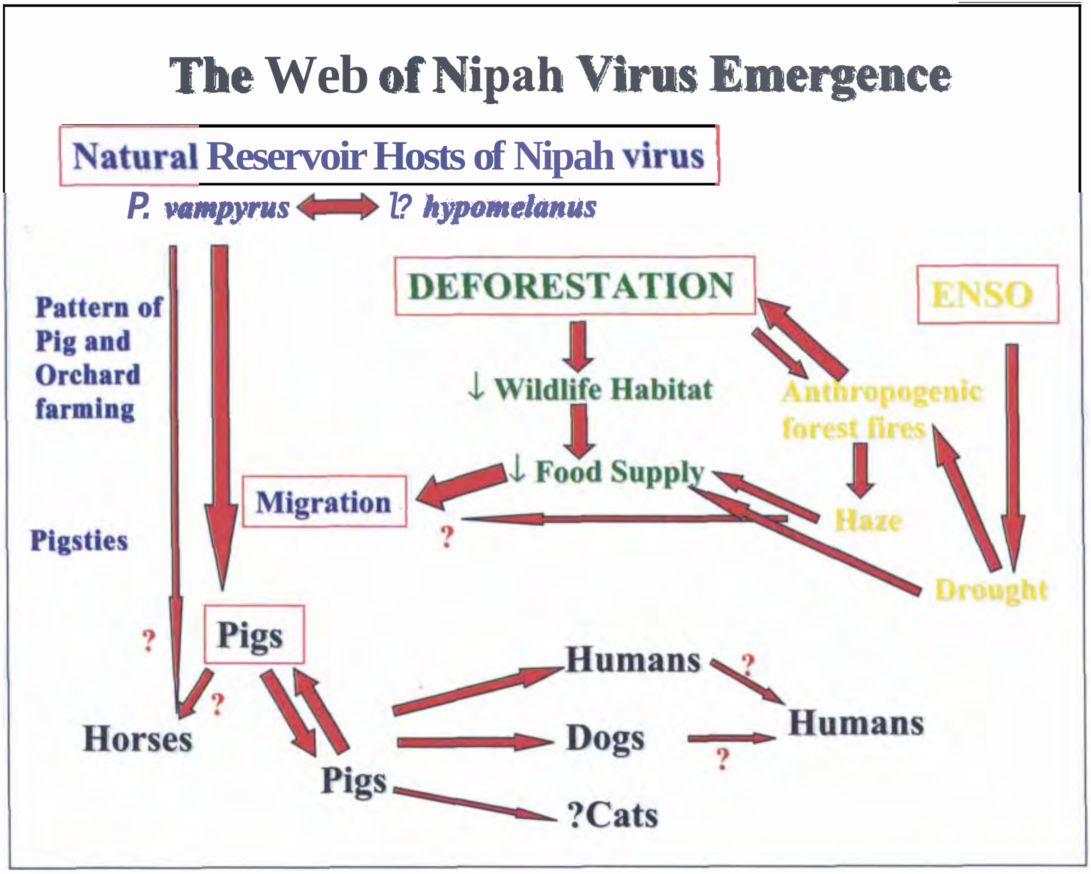

FIG. 5: A flow chart representing the proposed sequence of events leading to the introduction of Nipah virus from its reservoir hosts into the swine population and the transmission to other animal hosts including humans. Letterings in green colour denote anthropogenic deforestation and its consequences. Letterings in golden-brown denote El Niño Southern Oscillation (ENSO) and consequences brought on by the event. Letterings in blue denote the reservoir host of Nipah virus and circumstances in the index farm that led to its introduction into the swine population. Letterings in black denote the infected hosts.

low and had been documented.[29,30] A flow chart summarizing the proposed sequence of events leading to the introduction of Nipah virus from its reservoir hosts into the swine population and subsequent transmission to other animal hosts including humans is shown in Fig. 5. Our analysis provides another example of complex, anthropogenic environmental changes driving zoonotic disease emergence from wildlife reservoirs.[31,32] It also suggests that Nipah virus joined the increasing number of emerging pathogens driven by ENSO events.[33] Increasing severity of these events is likely to hinder efforts to predict and combat future zoonotic emergence.

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