Plague foci in Viet Nam: zoological and parasitological aspects

V.V. Suntsov,¹ Ly Thi Vi Huong,² N.I. Suntsova,¹ & N.G. Gratz³

Reported are the results of studies over the period 1989–94 on host–flea complexes in small mammals and their flea ectoparasites in and around a number of human settlements in Viet Nam in which human cases of plague had been found. Collections were also made in savanna and tropical forest areas within a 10-km radius of the settlements. The greatest numbers of small mammals, for the most part Rattus spp., and of the flea ectoparasite Xenopsylla cheopis were found in inhabited areas. X. cheopis was not found on any feral or sylvan mammal further than 0.6 km from settlements. A possible link between wild and commensal mammals may be provided by the flea Lentistivalius klossi, a specific parasite of squirrels and tree-shrews but also found in very small numbers on commensal rats. No zoonotic foci of plague were found in the immediate vicinity of the villages studied and it is most likely that plague persists in a commensal rat–X. cheopis cycle in and around human settlements in Viet Nam.

Introduction

The sources of human plague outbreaks in Southeast Asia, including Viet Nam, have yet to be completely elucidated. Viet Nam lies in the tropical forest zone, and it is generally held that plague in this ecological area is imported through ports into urban areas and towns, thereafter establishing itself in the local commensal rodent population (I, 2). However, in the Indo-China peninsula and in south China, Yersinia pestis as well as fraction 1 plague antigen and specific antibodies have been identified in a number of small wild mammals, including the squirrels Dremomys rufigenis, Menetes berdmorei, Callosciurus flavimanus, C. erythraeus, and Tamiops macclellandi; the forest rats Berylmys bowersii, Leopoldamys edwardsi, and Rattus sladeni; the mice Mus platythrix and M. cervicolor; the bandicoots Bandicota indica and B. bengalensis; and the predators Herpestes javanicus and Paradoxurus hermaphroditus (3–8). In Viet Nam plague-specific antibodies have previously been found in the tree-shrew, Tupaiia glis, and the black rat, R. rattus, in a boundary area between tropical forest and a coffee plantation in the village of Cu-Zut in Dak Lak Province (9); this has been taken by some workers as confirmation of the existence of natural foci of plague in tropical forests in the region (10–12). Still to be clarified are the identity of the species of fleas that are vectors of plague to the above-mentioned mammals and whether small species of wild mammals maintain plague in natural foci. The present article reports on zoological and parasitological studies carried out in areas of human settlements and in sylvan areas, which provide a biological basis for clarifying the epizootiology of plague in Viet Nam.

Materials and methods

Studies were carried out from 1989 to 1994 in the Tay Nguyen plateau in Dak Lak and Gia Lai–Kon Tum Provinces, in the city of Da Nang and its vicinity (the Sontra peninsula), and in the forest massifs of Mada and Xuyen Mok in Dong Nai Province. Small mammals were trapped alive along a gradient from human settlements to agricultural areas and on into the natural landscapes of the tropical forests or savannas. Eight settlements in which human plague cases were found in 1986–90 or in which there had been plague epizootics among commensal rat populations were selected for study. The most intensive investigations were carried out in the villages of Cu-Zut, Nam-Da Dak-Genh, and Kron-Buk, all in Dak Lak Province. These villages are located 15–55 km west of the town of Buonmathuot in the Tay Nguyen plateau, the area of the highest incidence of plague in Viet Nam (Table 1).

Ten houses were studied in each settlement, including all houses where there had been cases of plague or in which rats had been found dead from plague infection. Three traps were set in each house on three successive nights. For a distance of up to
1 km in the surrounding agricultural areas — rice and corn fields, coffee and manioc plantations, and vegetable gardens — three or four lines of traps were placed for two to three nights. Each line had 20–25 traps set at a distance of 10 metres from one another. Small mammal populations were irregularly distributed in the savanna grasslands, and trap lines were placed on slopes, banks and hillocks. The three to five sites studied in each of the forests were close to the settlements. At each of the forest or savanna sites no less than 100 trap-nights were performed using bait that was a mixture of manioc and sunflower oil.

All the small mammals trapped and their fleas were examined by a microbiologist at a mobile field laboratory for the presence of plague bacilli, fraction 1 capsule antigen, and antibodies to *Y. pestis*. The procedures have been described previously along with the findings of the bacteriological and serological tests (5).

### Results

A total of 2766 small mammals were trapped in settlements, in the agricultural areas surrounding settlements, in grasslands, and in tropical rain forests; 1098 fleas were removed from them (see Tables 2–4).

*Y. pestis* bacilli were observed in 15 specimens of *R. exulans* in Nam-Da, two in Cu-Zut and one in Dak-Minh and in one *R. rattus* from a house in the Sontra peninsula. *Y. pestis* antibodies were detected in three *R. exulans* and four *R. nitidus* in Cu-Zut, from one *R. nitidus* in Do-Ri (a small village) and one in Nam-Da, from one *Bandicota savilei* trapped 200 m from Cu-Zut and from one *T. glis* caught between the secondary forest and a coffee plantation 500 m from the nearest houses in Cu-Zut. Fraction 1 *Y. pestis* antigen was identified only from commensal rodents, including one *R. nitidus* in Cu-Zut and ten *R. exulans* in Nam-Da.

There was no evidence of *Y. pestis* in any small mammal living further than 0.5–0.6 km from the settlements studied. No evidence of *Y. pestis* was detected in any of the fleas tested, including *X. cheopis*, but the sample size was small.

### Small mammals and fleas in settlements

Of the species trapped in this zone (Table 2), *R. nitidus*, *R. norvegicus*, *R. exulans* and *Suncus murinus* are commensals in Viet Nam and are not found in sylvan biotopes. *R. rattus* has been found in all biotopes studied. *B. savilei*, *B. indica* and *M. cervicolor* are all savanna species.

Only two species of fleas were found on the mammals trapped in settlements, i.e. *Xenopsylla cheopis* and *Lentistivalius klossi*. The latter species was represented by only three specimens, while *X. cheopis* parasitized almost all the species of mammals throughout the year, though indices were not very high in the study areas. During the dry season, in May, the mean number of *X. cheopis* on *R.

### Table 1: Number of bubonic plague patients in four districts in Tay Nguyen plateau, Viet Nam, 1986–90

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Cu-Zut</td>
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<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Nam-Da</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Dak-Genh</td>
<td>2</td>
<td>60</td>
<td>8</td>
<td>113</td>
<td>22</td>
</tr>
<tr>
<td>Kron-Buk</td>
<td>53</td>
<td>61</td>
<td>42</td>
<td>18</td>
<td>29</td>
</tr>
</tbody>
</table>

* Data based on clinical diagnosis by local medical services without microbiological confirmation.

### Table 2: Distribution and abundance of small mammals and their fleas in human settlements

<table>
<thead>
<tr>
<th>Mammal species</th>
<th>No. trapped</th>
<th><em>Xenopsylla cheopis</em></th>
<th><em>X. vexabilis</em></th>
<th><em>Lentistivalius klossi</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Rattus exulans</em></td>
<td>801</td>
<td>322</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td><em>R. nitidus</em></td>
<td>260</td>
<td>151</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td><em>R. rattus</em></td>
<td>132</td>
<td>83</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>R. norvegicus</em></td>
<td>20</td>
<td>44</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>R. losea</em></td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Bandicota savilei</em></td>
<td>20</td>
<td>19</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td><em>Mus cervicolor</em></td>
<td>12</td>
<td>1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Suncus murinus</em></td>
<td>13</td>
<td>10</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*a* Mammals caught over a total of 9360 trap-nights.
norvegicus in Da Nang was 1.2, and on R. exulans in Nam-Da it was 1.6 in February–March. In other villages, the index did not exceed 0.5 on commensal rats. During the rainy season, X. cheopis was found only on rats inside houses but not on those trapped outdoors. On 114 R. rattus collected indoors during July–August, the X. cheopis index was 0.49. For the same period, 117 R. rattus were trapped outdoors around the houses and in secondary forest, and no fleas at all were found on them.

The flea L. klossi is normally parasitic on squirrels and tree-shrews. The specimens found had probably been transferred to commensal rodent populations by wild mammals from the forest, i.e. R. rattus and the tree-shrew, T. glis, which was caught both in the rural zone and outdoors in villages.

The human flea, Pulex irritans, and the cat fleas Ctenocephalides felis felis and C. felis orientis were very numerous on cats and dogs in the area and within the houses in the villages but were not found on either commensal rodents or small wild mammals.

Small mammals and fleas in agricultural areas

This zone is inhabited by the savanna rodent species, Mus caroli, M. cervicolor, B. savilei and B. indica as well as by commensal species R. exulans, R. nitidus and R. rattus, and by some species representative of the forest fauna. This latter group includes the rat Berylmys berdmorei, the squirrel M. berdmorei and the tree-shrew T. glis. As shown in Table 3, the total number of small mammals trapped in the fields and plantations was considerably lower than that in the settlements. The wild species found in highest density in the agricultural areas were M. cervicolor and M. caroli. In rice fields and grasslands, the trapping success rate was only 7.0–15.0%.

Again only X. cheopis and L. klossi were found on these small mammals. During the February–March dry season, the density index of X. cheopis on R. nitidus was 2.5. No X. cheopis were found on any small mammals trapped further than 0.5–0.6 km from settlements or buildings. No fleas were found on M. caroli or M. cervicolor, even in areas where these species were present in high densities. In the course of 560 trap-nights during the rainy season, only five R. rattus were caught in the cultivated area and none were parasitized by fleas.

Small mammals and fleas in the savanna grasslands

There are no truly primary savanna areas in Indo-China, which is essentially a region of tropical forests. Primary grasslands have a sporadic distribution, for the most part, where ecological conditions prevent the growth of trees, such as in areas that are seasonally flooded. However, secondary grasslands have replaced forests over wide areas of Viet Nam. In the present studies, grasslands around settlements yielded B. savilei (3 specimens), B. indica (7), M. caroli (114), M. cervicolor (36), R. losea (9) and the ubiquitous R. rattus (25), on none of which were the fleas X. cheopis, X. vexabilis, L. klossi, or a novel Neopsylla species found; one Acropsylla girshami flea was found. The three specimens of the forest rat, B. berdmorei that were trapped, on which five X. vexabilis were found, were undoubtedly migrants into the savanna. Generally, the density of small mammals in the savanna was low and none had any flea ectoparasites either in the rainy or dry season.

Table 3: Distribution and abundance of small mammals and their fleas in agricultural areas

<table>
<thead>
<tr>
<th>Mammal species</th>
<th>No. trapped</th>
<th>Xenopsylla cheopis</th>
<th>X. vexabilis</th>
<th>Lentistivalus klossi</th>
<th>Neopsylla sp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandicota savilei</td>
<td>11</td>
<td>2</td>
<td>—</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>B. indica</td>
<td>7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Mus cervicolor</td>
<td>22</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>M. caroli</td>
<td>21</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Rattus rattus</td>
<td>31</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>R. nitidus</td>
<td>35</td>
<td>35</td>
<td>—</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>R. exulans</td>
<td>5</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Menetes berdmorei</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Berylmys berdmorei</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Tupala glis</td>
<td>7</td>
<td>—</td>
<td>11</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Mammals caught over a period of 2752 trap-nights.*
The mammals were caught over a total of 3379 trap-nights.

Small mammals and fleas in the tropical forest

Only where there are no roads or human settlements are the rain forests in Viet Nam well preserved. All forests close to human settlements have been disturbed by human activity. The small mammals trapped in the forest included the semi-arboreal squirrels *M. berdmorei*, *D. rufigenis*, the tree-shrews *T. glis* and *Dendrogale murina*, the terrestrial rats *Maxomys surifer*, *M. moti*, *B. berdmorei*, and *B. bowersii*, semi-arboreal rats of the genera *Leopoldamys* and *Niviventer*, and *R. rattus*. Excluding *M. surifer* in the Mada and Xuyen Mok forests, the number of small mammals taken in the forests was low (Table 4).

Only three flea species were found on mammals in the forests — *X. vexabilis*, *L. klossi* and a novel *Neopsylla* species. Six fleas of the genus *Pariodontis* were collected from a Malayan porcupine, *Hystrix brachyura*, which had been killed by hunters in the province of Dak Lak. The hunters stated that they had found many fleas on the animal, which lives in large, deep burrows.

The flea *X. vexabilis* is specific to the white-toothed rat, *B. berdmorei* (13, 14). Its infestation indices were as follows: Xuyen-Mok forest, 20.0; Mada forest, 13.0; and on the Tay Nguyen plateau of Dak Lak Province, 5.0. This flea species was not found on any commensal or field rats. In a village adjacent to the forest (Xuyen-Mok), 20 *X. cheopis* were collected from 20 *R. rattus* specimens trapped inside houses. Only 20–50m distant from the house, inside the forest, 19 sylvan rats were caught (*B. berdmorei*, *L. edwardsi*, *M. surifer* and *N. cremoriventer*) from which 59 specimens of *X. vexabilis* were obtained. Though *L. klossi* was found on many small mammals in the forest, the number of fleas was always very small.

Discussion and conclusion

Maintenance of a plague focus in the South-East Asia Region requires high, stable numbers of susceptible mammalian hosts and flea vectors. The humid tropical climate of the Indo-China peninsula is not favourable to the proliferation of large flea populations. Less than 20 native species of fleas have been described from the region (15). Most of the species concerned are rare; these fleas parasitize a few species of endemic animals which are established in stable dry sites. As follows: tree trunks, e.g. fleas of the genera *Macroystophora*, *Medwayella*, *Lentisitivius* and *Stivalius* on squirrels and tree-shrews; within caverns or caves, *Ischnopsyllus* and *Thaumapisylla* spp. on bats; burrows ≥1.5m deep in the water-resistant layer of soil; under termite
mounds or on steep rises, including the genera Ceratophyllus, Xenopsylla, Acropsylla, and Neopsylla on the rats B. berdmorei and B. bowersi; the genus Pariodontis on the porcupines H. brachyura and Atherurus macrourus; and the genus Paraceras on the badgers Melogale personata and M. moschata. None of these animals, each of which is infested with its own particular fleas species, is abundant. A number of other forest and savanna mammal species in Viet Nam which have nesting sites in rainy areas do not have specific species of flea ectoparasites. The diet of larval fleas consists of dry, semi-digested faecal deposits of blood from the adult fleas (16). Olson has suggested that under damp conditions such deposits would be quickly consumed or decomposed by bacteria, fungi and other heterotrophs, leaving the flea larvae within the nests without an adequate food supply (16). Also, the nests of ground-dwelling small mammals which inhabit burrows are often flooded and are, in any event, changed several times a year.

The cosmopolitan species X. cheopis is primarily a parasite of rats of the genus Arvicanthis in the dry, subtropical regions of north-east Africa and has been widely dispersed to most areas of the world by commensal rats. In the damp climate of Viet Nam, X. cheopis populations exist only on indoor, commensal rodents, where they are not adversely affected by rainfall. Even inside houses, however, the indices of X. cheopis on commensal rodents decline precipitously during the rainy season.

In the biotopes studied, only human settlements had high numbers of commensal rats and fleas in the present survey (Table 2). In rural areas, X. cheopis parasitizes commensal rodents during the dry season; this is a zone of seasonal fluctuation for this flea, which is found throughout the year parasitizing small commensal mammals within settlements. The fluctuation arises because some commensal rodents migrate from houses and other buildings into the surrounding agricultural areas during the dry season.

The savanna zones are totally unsuitable for the establishment of plague foci since the mammals living there have virtually no fleas, and the rats, mice and bandicoots dig only shallow burrows, which are readily affected by rainfall.

The most numerous species in the forests, M. surifer, digs shallow burrows no more than 40 cm in depth, which are quickly saturated in the rainy season. There therefore appears to be a lack of specific flea ectoparasites on M. surifer. On the other hand, large numbers of X. vexabilis infest the white-toothed rat, B. berdmorei, which excavates burrows over 1.5 m in depth in water-resistant or well-drained layers of soil. However, the numbers of this rat species in the forest are low and it comprised no more than 1% of the trap catches. L. klossi parasitizes a wide variety of wild and commensal small mammals and may be carried from the forest into cultivated areas or settlements by semi-arboreal squirrels or the black rat, R. rattus. Nevertheless, the numbers of L. klossi on its mammal hosts are quite small and its role in plague transmission is therefore probably negligible.

The distinct differences between the ecological areas affected by human activity and the sylvan or natural complexes of small mammals and their fleas, and the fact that the high densities of rodents and fleas needed to ensure plague transmission occur only in and around human settlements, suggest that plague should only occur in forested areas, though it may occasionally be imported from areas where there are commensal rodents and X. cheopis fleas. Thus, plague foci appear to be restricted to environments in or near human settlements, with the limits of each focus corresponding to those in which X. cheopis may disperse around settlements. The dispersion is greatest in the dry season when some species of savanna and forest small mammals may enter cultivated areas or even settlements where they may acquire Y. pestis by being bitten by infected X. cheopis. When forests are cut down and settlements constructed, the commensal rodents, their fleas and Y. pestis expand their distribution into these new zones. In short, the occurrence of human plague follows human expansion and development activities rather than resulting from the penetration of people into undisturbed plague foci.

Claims about the existence of natural plague foci in Viet Nam are generally based on few data mentioning the finding of Y. pestis and fraction 1 antigen and in wild mammal species (10–12), as noted by Van Peenen et al. (7) and Cavanaugh et al. (17). However, the occurrence of Y. pestis or fraction 1 specific antibodies in wild mammals does not necessarily support the existence of natural or wild foci of plague. It appears, rather, that only isolated, individual, wild small mammals that penetrate into cultivated areas or settlements during the dry season may become infected by Y. pestis through being bitten by X. cheopis (Fig. 1).

Of the plague foci in tropical areas, those in South-east Asia appear to be the simplest. In the drier climates of other tropical regions such as Madagascar, continental Africa and the mountainous regions of South America, the spatial structures of plague foci are more complex. In these regions, many wild, burrowing animals and their flea populations can acquire Y. pestis from commensal rodent populations and their fleas, thereafter establishing secondary natural plague foci.
Résumé

Quelques aspects zoologiques et parasitologiques des études sur les foyers de peste au Viêt Nam

On a étudié les complexes hôte-ectoparasite qui se sont formés entre des puces et de petits mammifères à l'intérieur et aux abords d'établissements humains où l'on a découvert des cas de peste. Des prélèvements ont également été effectués dans la savane et la forêt tropicale, dans un rayon de 10 km autour de ces établissements. C'est dans les zones habitées que l'on a trouvé le plus de petits mammifères, pour la plupart du genre Rattus, ainsi que le nombre le plus élevé d'ectoparasites, des puces de l'espèce Xenopsylla cheopis. On n'a pas observé de puces de l'espèce X. cheopis sur des mammifères sauvages ou sylvestres à plus de 0,6 km des habitations. Il est possible qu'un parasite spécifique de l'écureuil et du toupaye, mais que l'on trouve aussi en très petit nombre sur des rats commensaux, Lentistivalius klossi, constitue le lien entre les mammifères sauvages et les mammifères commensaux. Les données fournies par cette étude montrent qu'il n'y a pas de foyer de peste zoonosique à proximité immédiate des villages examinés et que, selon toute probabilité, la peste se perpétue dans le pays selon un cycle rat-X. cheopis à l'intérieur et aux abords de certains établissements humains.

References

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