THE RELATION OF RAT-FLEAS TO PLAGUE IN SHANGHAI.

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(With 1 Chart.)

From 1900 to November 1908 there was no human plague in Shanghai. Then (S.M.C. 1908) "A case of Plague, confirmed by examination in the laboratory, occurred at Hankow on November 30, 1908, on board a river boat, under conditions which pointed to the disease having been contracted in Shanghai. No human case having been prior to this, either reported or suspected in the Settlement, an examination of rats found dead in the streets and alleys was made in the laboratory. On December 8, the first plague rats were discovered and since then were found almost daily."

After this, plague rats were found every year from 1908 to 1916 and again in 1920, 1924 and 1925, there were also some cases of human plague (see Table I).

Table I. *Plague rats and human cases found in each year from* 1908 *to* 1925.

	1908	1909	1910	1911	1912	1913	1914	1915	1916
Plague infected rats	49	187	249	138	95	122	186	76	6
Human plague cases	0	0	6	0	18	10	26	1	0

	1917	1918	1919	1920	1921	1922	1923	1924	1925
Plague infected rats	0	0	0	2	0	0	0	3	1*
Human plague cases	0	0	0	0	0	0	0	4	0

* Found in January.

There are two remarkable features shown by these figures. First, that plague, having died out after 1916, was not easily re-established, although Shanghai is within two or three days' voyage of several ports in which plague is endemic. Second, that the number of human cases is small compared with the number of infected rats found. For some reason, Shanghai is not very susceptible to the disease; and possibly this is connected with some peculiarity in the rat-fleas.

Fleas of the genus *Xenopsylla* are the chief carriers of plague, but probably not all species are equally efficient. It is known that *X. cheopis* transmits plague from rat to rat, and from rat to man, but it has been shown by Cragg (1921) in India, and Hirst (1923) in Colombo, that it is doubtful whether *X. astia* is equally efficient. If the rats of Shanghai did not harbour fleas of the genus *Xenopsylla*, or if the fleas were *X. astia*, the partial immunity of the town and the relative freedom of human beings might be explained.

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In the spring of 1923, at the request of Dr Norman White, the representative of the Health Committee of the League of Nations, a census was taken of the rat-fleas. Between February 22nd and April 12, 1923, 382 fleas were collected from 129 rats, of which *Xenopsylla* numbered 0·5 per cent. As this period was too short to allow useful conclusions to be drawn, I carried out a further survey between October 1923 and January 1926. 2893 fleas from 1545 rats were examined. The numbers and percentages were as follows:

Xenopsylla cheopis	331	11·4 %
Ceratophyllus fasciatus	1051	36·3 %
Ctenopsylla musculi	1477	51·1 %
Ctenocephalus felis	34	1·2 %

No specimens of *X. astia* or *X. brasiliensis* were found. Of 1511 rats, 72·8 per cent. were *Rattus rattus*, and 27·2 per cent. *R. norvegicus*.

The special local problems of plague are not explained by the absence of an insect carrier, as both *X. cheopis* and *C. fasciatus* have been incriminated, the former in tropical countries, the latter in temperate. Shanghai provides samples of both climates and it will be seen from Table II that each flea varies in numbers according to the changes of the seasons. *X. cheopis* flourishes in the hot moist summer, *C. fasciatus* in the cold winter and spring.

Table II. *Monthly variation in the flea index of three species, with the mean temperature and humidity* (*saturation* = 100) *and the saturation deficiency*[1].

		X. cheopis	*C. fasciatus*	*Ct. musculi*	Mean temperature	Mean humidity	Saturation deficiency in inches
1923	October	0·36	0·44	1·18	63·0	72·1	0·161
	November	0·40	0·36	0·68	53·4	78·0	0·087
	December	0·73	1·14	4·36	42·6	72·6	0·075
1924	January	0·06	0·13	1·19	39·5	75·6	0·059
	February	0·04	0·61	0·57	39·7	80·0	0·049
	March	—	0·98	0·44	43·7	74·4	0·074
	April	—	2·77	1·33	59·0	77·1	0·114
	May	0·03	1·90	1·60	65·0	83·7	0·108
	June	0·12	0·65	1·56	72·4	83·3	0·134
	July	0·19	0·03	0·42	82·4	79·6	0·224
	August	1·85	—	—	81·0	82·1	0·189
	September	0·83	0·37	0·30	73·2	84·7	0·118
	October	0·60	0·57	1·09	64·0	77·9	0·132
	November	0·60	0·50	0·60	48·6	72·3	0·094
	December	0·55	0·45	2·63	42·0	73·9	0·070
1925	January	0·33	0·67	2·83	36·4	79·7	0·043
	February	—	0·60	0·45	37·0	78·2	0·048
	March	—	0·65	0·35	47·4	76·3	0·078
	April	0·01	1·63	1·29	54·0	72·2	0·113
	May	—	1·24	1·53	66·5	81·5	0·118
	June	0·08	0·31	0·74	75·9	79·3	0·185
	July				78·9	86·7	0·130
	August	0·25	—	0·07	79·8	84·9	0·169
	September	0·09	0·34	0·68	71·3	83·5	0·126
	October	0·17	0·66	0·70	62·9	74·0	0·149
	November	0·62	0·36	1·69	55·2	78·5	0·094
	December	0·23	0·93	0·69	40·4	71·2	0·072
1926	January	0·14	0·63	0·80	38·3	74·3	0·060

[1] "By saturation deficiency is meant the difference between the actual tension of aqueous vapour present in the atmosphere at the temperature in question and the tension of aqueous vapour that would be present in a saturated atmosphere at the same temperature" (St John Brooks, 1914). It is therefore an index of the drying capacity of the air.

Table II shows the variation of the "flea index" for each species. Each month it was found by taking the total number of fleas in each species, and dividing it by the total number of rats found in that month. By this method the variation in each species is shown independently of variations in the accompanying species. The table also shows corresponding changes of temperature, humidity and saturation deficiency.

During the months of June and July 1925, owing to the disorganisation of work by the riots and strikes in Shanghai, I was unable to supervise the collection of fleas, so that the fleas for each month were not kept separate.

The meteorological figures show that the climatic conditions are not such as to inhibit plague; for when the temperature is high the atmosphere is moist. St John Brooks (1914) has shown that the disease can flourish with the mean temperature above 80° F. provided that the saturation deficiency is below 0·30 in. Bacot showed that a hot, and especially a dry atmosphere was inimical to the fleas.

X. cheopis is at its minimum from February to May and flourishes from August onwards. It comprised, in August 1924, 100 per cent., and in August 1925, 81·6 per cent. of all fleas taken. A collection made in August 1923 showed 85 per cent. to be *Xenopsylla*. On the other hand *C. fasciatus* has its maximum in April and disappears in August. *Ct. musculi* is variable throughout the year. The figures for *X. cheopis* and *C. fasciatus* cannot be compared with each other on account of the difference in their habits. It is the custom of *X. cheopis* to live on its host more than *C. fasciatus*, which returns after feeding to its host's nest. Consequently *X. cheopis* is more easily caught on trapped rats.

Similarly, the disease itself exhibits a seasonal variation. Table III gives the sum of all plague rats and human cases from 1909 to 1915, arranged under months.

Table III. *Monthly incidence of plague in Shanghai*, 1909–1915.

	Jan.	Feb.	Mar.	Apr.	May	June
Plague infected rats found	142	88	129	114	85	34
Human cases notified	0	0	0	2	0	8

	July	Aug.	Sept.	Oct.	Nov.	Dec.
Plague infected rats found	9	8	23	61	148	217
Human cases notified	0	0	2	12	15	4

Plague is a disease of the cool weather. It begins to revive in September and increases to a maximum in November and December, after which it declines gradually until July and August. This is shown more strikingly in the notification of human cases than in the finding of plague rats. The autumn is the most favourable time for its increase and presumably also for its introduction from abroad; after December it declines slowly and presumably the spring is a less favourable time for its introduction. Therefore if the disease were introduced to the port we might expect that it would not gain a footing

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unless it arrived in the autumn. Actually, when it did appear, it was first recognised in November 1908 and 1924, and in December 1920.

The next question is: When is plague likely to be brought to Shanghai? It is endemic in many ports of China; but for most of these statistics are not available. But Hongkong is a port in frequent communication with Shanghai and one in which plague is endemic; and there are full and reliable statistics. Table IV shows the monthly incidence of plague in Hongkong. It rises sharply to its height in April, May and June, after which it declines equally sharply.

Table IV. *Mean monthly incidence of human plague in Hongkong*, 1908–1922.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5·8	7·8	29·3	99·0	198·2	134·7	50·4	16·7	5·0	2·6	2·7	2·8

Consequently at the time when Hongkong is most likely to transmit infection, Shanghai is in the least suitable condition to receive it, for in April and May an epidemic, which was spreading in the previous autumn, is unable to support itself and is declining rapidly. It is not improbable that conditions in other Chinese ports, such as Canton, Amoy or Foochow, are the same as in Hongkong, but as there are no dependable figures it is impossible to be certain. However, it is probable that Shanghai's relative freedom from plague is at least partly due to the seasonal difference between itself and those ports which would otherwise be most likely to infect it.

Chart 1 shows graphically the relation of rat plague to rat fleas. The curves for *X. cheopis* and *C. fasciatus* are drawn from the flea-index figures given in Table II. Super-imposed on these is a curve showing the incidence of rat plague, calculated from Table III. A study of these suggests the following argument. If plague is to rise from a period of quiescence into an epizootic, there must be a full supply of the insect vectors. Even if these are available in large numbers, the epizootic will not be apparent at first because time must be allowed for the incubation in each case and the infection of new cases. Suppose that when the epizootic is at its height, the number of the vectors declines rapidly, the epizootic will not decline equally rapidly, because, being extensive, it can be carried on at a declining rate by a relatively small number of fleas. The epizootic will "lag" behind the transmitting agent both in starting and stopping. Eventually it will become quiescent, and only be rekindled when the number of fleas increases again.

Chart 1 shows that this is the relationship between the epizootic and *X. cheopis*. But the position is complicated by the presence of *C. fasciatus*, which is known to be a carrier of plague. Yet the epizootic continues to decline and few human cases occur (Table III), while the flea index of *C. fasciatus* is at its maximum.

The variations of *Ct. musculi* are very irregular and bear no relation to the variation of plague. It is of little importance in the epidemiology of plague because it bites man with great reluctance (Chick and Martin, 1911, and

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others). Therefore I suggest that the explanation of Shanghai's comparative freedom from plague lies in this; that *X. cheopis* is the flea mainly responsible for the spread of plague in Shanghai, and that the part of *C. fasciatus* is subsidiary, though it may be responsible for prolonging the declining epidemic into the spring and early summer. Consequently the disease is not likely to take root unless it is introduced during the *Xenopsylla* season in the latter part of the year, as it did in 1908, 1920 and 1924; whereas the time when

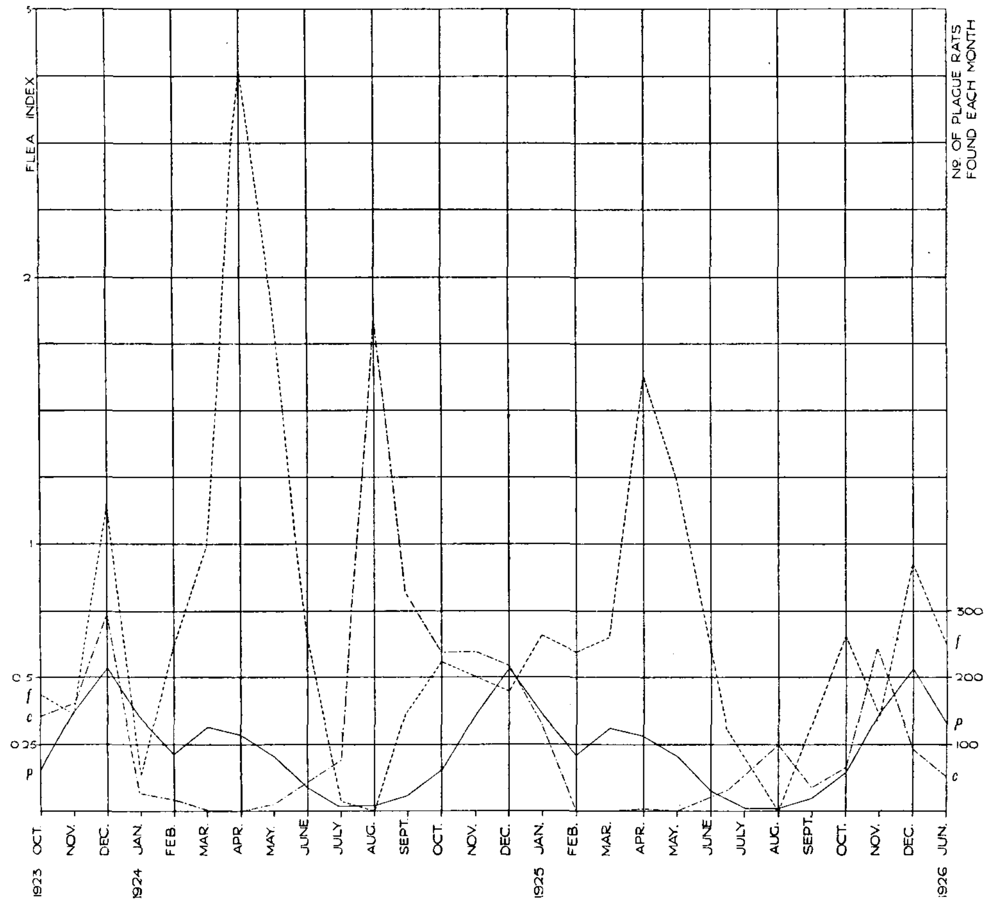

Chart 1. *P* = Plague in rats. *c* = *X cheopis*. *f* = *C. fasciatus*.

infection is most likely to be introduced from China ports—or, at least, from Hongkong—is from April to June.

To return to the question of the efficiency of *C. fasciatus*: it is known that this flea is capable of carrying plague; Chick and Martin (1911) have shown that it will bite man freely, so that it might seem a highly efficient agent. Against this there are several points.

Bacot and Martin (1914) fed fleas having a blocked proventriculus on a series of rats. When the flea used was *X. cheopis*, four out of four rats died;

when the flea was *C. fasciatus*, one out of six died. However, when the experiment was repeated under rather different conditions, the results were not so conclusive.

Again, the difference in the habits of the two fleas must be considered. As *C. fasciatus* does not live and travel on its host, it is likely to have less extensive opportunities of spreading infection; and especially less opportunity of infecting man.

Bacot states that *C. fasciatus* "in view of its more retiring habits is less likely to be the vector of the disease when *Xenopsylla cheopis*...is present in equal numbers."

Tidswell (1909) says that in Sydney the plague season is from January to July, with a maximum in March, April and May. Three species of flea are found, *X. cheopis*, *C. fasciatus* and *Ct. musculi*. *X. cheopis* flourishes chiefly from January to July, corresponding to the plague season, whereas the other two species are at their lowest from April to August. The writer comments on the statement, "This might, if confirmed, constitute an important epidemiological consideration, and would reduce the significance of the fact that *C. fasciatus* bites man so readily." The same paper states that "in Japan, Kitasato (1909) has found that the absolute and relative abundance of *X. cheopis* is much increased during the autumn, *i.e.* during the plague season." Unfortunately I have not been able to consult the original papers of Tidswell and Kitasato.

Hirst (1925) considers that "both experimental and epidemiological evidence point to the conclusion that both *C. fasciatus* and *X. astia* are less efficient as porters of plague from rat to rat than *X. cheopis*."

The above considerations support the view that in Shanghai the flea mainly responsible for carrying plague is *X. cheopis*.

The case of Japan is interesting as it offers a parallel to that of Shanghai. Statistics published by Norman White (1923) show that since 1897 plague has been sporadic and that human cases have been more frequent in the autumn than in the earlier part of the year. Again, I am informed by the Commissioner of Public Health for Japan that a survey of fleas held at Kobe between March 1909 and February 1910, showed that *X. cheopis* flourished in the autumn, while *Ceratophyllus*, which was much more numerous, showed a maximum in the winter and spring, and a minimum in August.

The aim of this paper is to suggest that Shanghai is most susceptible to infection in the *Xenopsylla* season, which is chiefly in the latter part of the year, whereas infection is most likely to reach it in the second quarter of the year. The discrepancy between the number of rat and human cases is less easily explained. It may be due to the habit of *C. fasciatus* of living apart from its host. This restricts its power of infecting rats but far more restricts its chances of biting man. I do not wish to deny that there may be some other factor concerned in the problem. For though plague died out in the spring of 1916, yet it was introduced in the autumns of 1920 and 1924 and failed to spread.

SUMMARY.

1. Though Shanghai is in close communication with ports in which plague is endemic, it has not suffered severely.

2. The number of human cases is small compared with the number of plague-infected rats found.

3. Both *X. cheopis* and *C. fasciatus* are found. Reasons are given for considering that *X. cheopis* is the chief agent in spreading plague, and that infection, being unlikely to reach Shanghai during the season when this flea flourishes, has difficulty in gaining a foothold.

4. The discrepancy between the number of cases of human and rat plague may possibly be explained by the habits of *C. fasciatus*.

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