THE ECOLOGY OF BUBONIC PLAGUE.

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When I entered for the first time the office of the Chief Sanitary Officer of the Isthmian Canal Commission, I saw a large wall chart, the curve of which told exactly how much malaria there was each month on the Canal Zone, expressed as a percentage of the entire working force. This was six years ago. This chart registered the splendid results obtained by the sanitation corps of the I. C. C.; it showed how, although the working force was increased yearly, the malaria rate kept declining yearly. Today malaria is practically exterminated.

This curve showed me more than merely the results of anti-*Anopheles* measures. It showed a definite, seasonal rise and fall in the rate. Malaria was at its lowest from about November or December until April or May, and reached its crest in July. It was the lowest during the dry season, and highest during the wet. Malaria began to shoot upward just after the first heavy rains had fallen. When the dry season approached, the rate fell rapidly. If the dry season was late in coming, then malaria behaved accordingly. The critical factor here is moisture.

The bulk of this malaria is transmitted by *Anopheles albimanus* Wiede., and its racial variety *tarsimaculata* Goeldi. They breed extensively during the wet season. Field inspections show rapid increase in the number of breeding places just as soon as the rains start in. During the dry season it is very difficult to find larvæ of these species. Instead of them, we find plenty of *A. pseudopunctipennis* Theob., a species apparently unimportant in the transmission of malaria on the Isthmus. *Albimanus* is a wet season species; *pseudopunctipennis* is a dry season species. Maximum humidity, maximum malaria and maximum numbers of transmitors of malaria coincide as to time.

In addition to this, it must be noted that the advent of the first heavy rains means also that the workmen get wet, either going to or from their work, or even while working. This means a lowering of their bodily resistance, a factor which is extremely important for the early rise of human malaria.

It appeared to me desirable to learn if such ecological relations could be traced with any of the other diseases directly transmitted by arthropods, especially bubonic plague. World's commerce is becoming so extensive that very soon it will become imperative to open up territories now almost closed to us on account of the presence in them of plague. Quarantine measures are efficacious, but they are also quite expensive because much time is lost. We must fight the plague wherever it occurs. We must get rid of it. This can be done and the cost is relatively low. The study of the ecological relation in plague should reveal to the sanitary officer not merely the kinds of measures he must adopt in order to obtain quick and telling results, but also *when* to employ these measures, and just *where* they must be used in order to obtain maximum efficiency.

I found very valuable data on bubonic plague in the many "Reports on Plague Investigations in India," published in the Journal of Hygiene. During twelve years plague claimed five million victims in India. A trifle over two a minute died during the year 1907! The chart appended to my notes is taken from one of these reports. Other regions where plague is endemic may have a different set of conditions from those in India. These conditions must be well known before the inter-relationships between rat, flea and plague are properly understood and correlated.

A. Plague and Climate.

1. *Bombay City*.—Its climate is hot and dry, the daily mean temperature being from 70° to 80° F. The average diurnal range in only 12.5° F. The S.W. monsoons appear from May to October, and they bring the rains. These rains are heaviest from June to August. The N-E monsoons, which blow from November till April, bring very little or no rain.

The plague epidemic begins in January, rises gradually until it reaches its maximum in March, then declines to a "normal" about the middle of May. Charts which were kept for ten consecutive years show *plague mortality lowest when humidity was highest*, (June to September), and that an almost automatic recession from the maximum takes place as soon as the humidity begins to rise. The mean temperature at the beginning of the rise is from 72° to 75° F., but as soon as it reaches 78°-80° F., mortality drops off. Slight recrudescence may occur during May to October, i. e., when a fall in the mean temperature occurs. It should be borne in mind, however, that the single factor temperature is not the critical one; it is rather the resultant humidity which counts.

2. *Poona City and Cantonments.*—It is 80 miles from Bombay, 2,000 ft. above sea level, and has a daily mean temperature of from 70° to 80° F., with an average diurnal range of 22.5° F. From May to October it is subjected to the S-W monsoons, but the rainfall (March to June) is less than that of Bombay. June is the hottest and dryest month, its daily mean temperature being from 83° to 90° F. In July the daily mean is from 75° to 80° F., with S-W breezes. The winter months have a daily mean of about 70° F., and an average diurnal range of about 30° F.

The plague epidemics occur between August and March. The charts show that *mortality increases rapidly as the humidity recedes from its maximum crest.* The period of high plague mortality is relatively short, dropping off as soon as the humidity rises.

3. *Nagpur City.*—It is in the Central Province and resembles much Poona, excepting that its mean temperature is slightly higher. Its hot season is from March to June, the mean temperature being from 85° to 95° F. During July to September the temperature is a little over 80° F., while during the cold months (November to February) it is from 70° to 75° F. The rainfall occurs from June to September, and ranges from 40 to 60 inches.

Plague epidemics were most favorable from November to March, and the charts again show *plague mortality lowest when humidity was highest.*

4. *Belgaun City.*—This is in the extreme south of Bombay Province, 2,500 ft. above sea level, and 75 miles inland from the West coast of India. The mean temperature from June to February is from 70° to 75° F., with an average diurnal range of 20° F. March to May is the hot period, the daily mean being about 80° F. The rains occur mostly from June to October, and amount to about 40 inches.

Epidemics begin in July or August and reach their maximum in October. The charts show *plague rising rapidly as soon as the humidity retreats from its maximum.*

5. *Lahore City.*—It is 700 ft. above sea level. It is not within the hot mansoon belt. The rainfall is slight, amounting to about 20-25 inches, and occurs chiefly from July to September. Some rain falls at times during January and February. From November till March the daily mean temperature is below 70° F., in January as low as 54° F. The remainder of the year is above 70° F., from May to August as high as 85° F. to 95° F. The average diurnal range is 27.5° F. (April to May it is 32.5°, and October to November it is 35°.)

Plague epidemics occur from March to May. There is a tendency to recrudescence during the winter months. *Plague mortality rises rapidly as the humidity recedes, but as soon as the humidity begins to rise, the epidemic is quickly terminated.*

6. *Rawalpindi City and Cantonments.*—Situated at the base of the Himalayas, 1,700 ft. above sea level, it has an average diurnal range of from 20° to 30° F. Its hot weather comes from May to August, with a mean temperature of from 80° to 92° F. The rainfall, mostly from July to September, amounts to but 30 or 40 inches. About eight inches of rain falls during the winter season, January to April.

The plague epidemic is from September to November, with slight recrudescence practically throughout the year. *The major epidemics rise rapidly as the humidity recedes.*

7. *Summary:* The authors of the several articles from which these notes were taken, draw certain conclusions, which in brief are: That a temperature of 85° to 90° F., or one of 50° or less, are very unfavorable to plague. This holds true for Bombay City, but does not for Poona and other cities. The truth of the matter is that no one factor alone may exert such wide influences, but that it is rather a resultant of several factors—in this case it is *humidity.* When plague mortality and humidity are placed on the same chart, it becomes at once evident that there is a direct relation between the two.

We shall see a little later on, that *the severity of an epidemic of bubonic plague bears a direct ratio to* (*a*) *flea prevalence and* (*b*) *to humidity.*

B. Fleas.

The investigators in India report that a temperature above 80° F. affected the conditions to which the bacillus was subjected in the flea's stomach. At high temperatures the bacillus disappears from the stomach more quickly than at lower temperatures, i. e., 70° to 80° F. They found fleas remained infective for longer periods at lower temperatures. A temperature of 50° or less, may directly influence plague prevalence. Fewer rats were found with developed septicaemia at low temperatures than at higher ones.

From an explanatory standpoint these facts mean that due to heat, frequent evacuations take place in the flea, and as a result of this, the bacillus in the digestive tract of the flea is filtered out with greater frequency.

Another excellent observation was that high temperatures retarded both egg deposition and development, and that low temperatures prolonged the life cycle. This should be humidity because high temperatures in India were associated always with high humidity. Humidity, then, is inimical to the flea. The chart shows fleas at their greatest abundance from February to May, their numbers dropping off rather sharply after May, and the cause of this is the humidity which is on the increase from June to August.

Nearly all reports on plague show that its maximum coincides with the period of maximum numbers of fleas. Kitasato (1909) finds that the absolute and relative abundance of *X. cheopis* is much increased during the autumn, i. e., during the plague season. Tidswell (1910) gives a table of the flea population per month per one thousand rats, the average mean monthly temperature, and the average mean monthly humidity; the flea abundance corresponds with the plague season.

The chart for Bombay shows the fleas on *M. decumanus* increase in numbers from June to August, outnumbering those on the black rat. This period is one of heavy rains, and these drive the brown rat from its subterranean burrows, cellars, etc., and force them into dwellings, i. e., into drier situations. Rat breeding increased at this time, due to the ravages of plague among them during the previous months. This influx of rats into a drier habitat is most favorable to the rapid development of fleas.

Quite naturally, the houses in the barrios which are near wharves, etc., may show slight recrudescences of plague at a time when plague in general had declined.

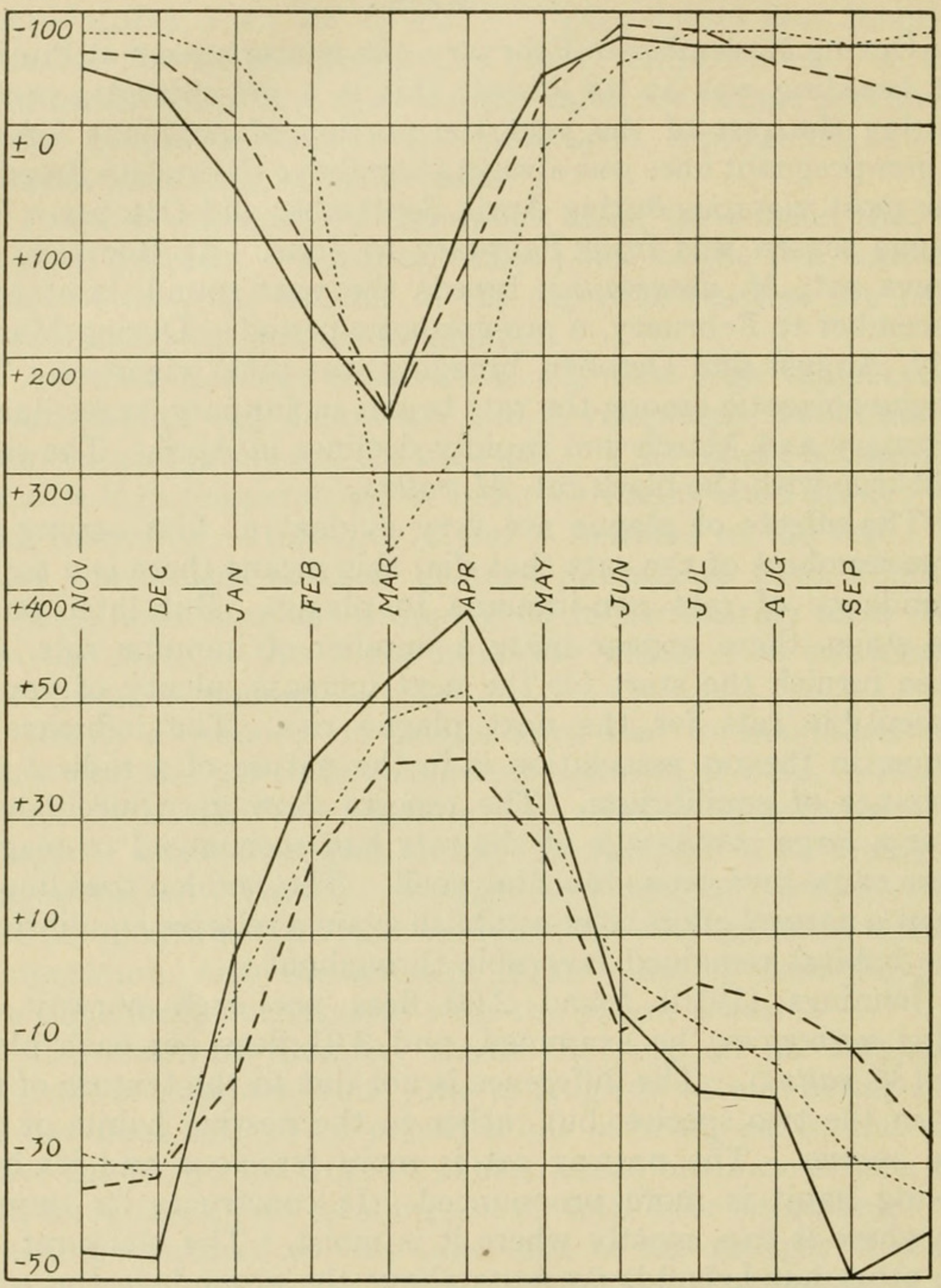
C. Rats..

During November to February, the winter season at Punjab, rat breeding was at its lowest; this is a pre-epizootic period. During the rest of the year the portion of pregnant females to non-pregnant ones was always at or above the mean. Breeding was most vigorous during April, September and October. The plague season was from February to June. At Bombay, the brown rat, *M. decumanus*, breeds the year round, least from December to February, a pre-epizootic period. During March, July, August and October, breeding was most vigorous. The plague epizootic among the rats begins in January, rages during February and March and rapidly declines in April. The same held true with the black rat, *M. rattus*.

The effects of plague are very evident at first among the large numbers of the rats that die; this means there is a super-abundance of rats non-immune to plague. But later on in the stage, there appear quite a number of immune rats, and these furnish the start for the next increase, plenty of young, susceptible rats for the next plague rise. The influence of plague in the rat association is in the nature of a radical disturbance of equilibrium. The reports show very nicely how, after a large percentage of the rats had succumbed to plague, there came a vigorous breeding spell. This sudden breeding-fit is but a natural effort to re-establish again a relative equilibrium. The habitat remained favorable throughout.

Jennings (1910) found 2.20 fleas per each norway rat (*Mus norvegicus*) he examined, and 3.61 fleas per each black rat (*M. rattus*). The difference is not due to the texture of the fur in the two species, but rather to the nesting habits of the two species. The norway rat is more ferocious and its burrowing habit is more pronounced. It constructs its tunnels anywhere it can, mostly where it is moist. The black rat, on the other hand, builds its nests above the ground, in the walls of buildings, etc., consequently in a drier habitat. Moisture is inimical to the flea larva and adult, and therefore the greater number of fleas on the black rat.

Heavy rains affect rats and fleas. They drive them from the wet or submerged burrows into drier situations, and this means closer contact with people as well as increased flea breeding.



PREVALENCE of PLAGUE

—— In M. rattus
– – – " M. decumanus
.... Human

PREVALENCE of FLEAS

—— On M. rattus
– – – " M. decumanus
.... " all rats

FROM "REPORTS ON PLAGUE INVESTIGATIONS IN INDIA."

Gauthier and Raybaud (1903) find that the Indian Plague flea, *X. cheopis*, constituted 25% of the flea population upon ship rats at Marseilles, and that the numbers rapidly became fewer as the distance of a locality from the docks increases. Jennings (1910) found that 97.9% of the fleas on rats examined by him at Panama were the Indian plague flea. We have no plague endemic in the Canal Zone (thanks to efficient quarantine), but we have everything favorable to plague epidemics—the right fleas, plenty of rats, and a wet and dry season.

D. The Plague Association.

The severity of an epidemic of bubonic plague was shown to depend upon flea abundance and upon humidity. Fleas are abundant if rats are abundant, and humidity is the critical factor determining at what time of the year fleas are most abundant. The reports of the plague commission show that at Bombay City rat breeding was at its minimum when humidity was lowest, and vice versa, it was most vigorous when humidity was highest. Plague was highest when humidity was lowest, and large numbers of rats were killed off, leaving only a few immune ones with which to start the next progeny. As plague dropped off, and to readjust the loss of equilibrium in the rat world, there followed a vigorous breeding spell. This is with humidity high. A new colony of non-immune rats resulted. The rat epizootic began in January and declined in April. During this period fleas reached their maximum.

Referring to the chart for a moment: Fleas on all rats were at a maximum in March and April. Plague mortality in rats reached its culmination in March. The fleas which left their dead hosts increased plague among human beings from about plus 20 to plus 360 *within one month!* From May on, plague recedes; this is the period of the S-W monsoons, the rain winds.

The chart shows more fleas on the black rat, *M. rattus*, than on the brown rat. This was found true on the Canal Zone by Jennings. It places the black rat into greater importance with respect to the transmission of human plague. This rat is the common Canal Zone rat; so is *X. cheopis* the common flea, whose natural host is the black rat.

These notes show that *the severity of an epidemic of bubonic plague bears a direct ratio to (a) flea abundance and to (b) humidity.* This holds true for India. No doubt it holds true for other places where bubonic plague is endemic. The same set of conditions may not be duplicated elsewhere, but the ecological relations will in the main part correspond to those of India.

I am indebted to Dr. S. T. Darling, formerly Chief of the Board of Health Laboratory of Ancon Hospital, for the use of his library.

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1909. **Kitasato.** Trans. Bombay Med. Congress, p. 93.
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