A REPORT ON THE OUTBREAK OF THE PLAGUE IN COLOMBO. 1914—1916.

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(With five maps and one chart.)

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I. Introduction.

Although plague broke out in India in 1896, it was not until a period of 18 years had elapsed that it reached Ceylon, notwithstanding the close proximity and the daily intercourse which takes place between the two countries. It is not surprising that this prolonged immunity, coupled with the example of the failure of the disease to thrive in such places as Madras, Singapore and other maritime towns within the tropical belt, should have created in the minds of the public in Colombo a feeling of considerable security as regards invasion by this disease, and that when it was announced that plague had at last broken out, there was the usual scepticism expressed as to the accuracy of the diagnosis. The advent of plague in Ceylon has already been announced by Castellani and Philip (1914).

In order to appreciate the unusual circumstances which attended the appearance of the disease in Colombo it is necessary to briefly describe the measures which were in force for the detection and prevention of plague prior to the arrival of the disease.

When plague first broke out in India the Government of Ceylon appointed a Committee for the purpose of adopting measures for keeping the disease out of the island. The measures adopted included the making of regulations, and the carrying out of a system of inspection and quarantine of immigrants from infected areas. Within the town of Colombo, the municipal authorities instituted a system of rat capture and destruction, whereby some 50,000 to 60,000 rodents

were secured annually. From February 1912, when the municipality first employed a bacteriologist, up till September 1913, a systematic bacteriological examination of rodents for plague was carried out by the junior author, some 2000 animals being thus examined, without, however, the finding of a single case of plague infection. From September 1913 until 7th February 1914, the bacteriological examination of rats had, for unavoidable reasons, to be suspended; but the Public Health Department Staff, being fully alive to the possibility of plague being brought over from India, were constantly on the look out for the usual signs of the presence of an epizootic. The junior author had paid special attention to this question, and had already pointed out, that the climatic conditions in Colombo were not unfavourable to plague during the months of December and January.

The first indication that anything unusual was happening, was contained in an anonymous letter, received on 24th January at the Public Health Office, in which it was stated that the residents of Sea Street were becoming alarmed at the occurrence of a number of sudden deaths, thought to be due to a new and deadly disease. The symptoms were stated to be "Fever in the morning, and death in the evening with a boil." Sea Street is a crowded insanitary quarter, lying adjacent to the harbour, which was moreover the chief centre of the grain trade between India and Ceylon.

As plague was the only new and deadly disease which was likely to appear in Colombo, and as the mention of a "boil" suggested bubos, the matter was at once treated seriously and a house to house inspection made in the locality, particular attention being paid to the search for dead rats. Nothing unusual was however found, not so much as a single dead rat, but it was ascertained that the residents, particularly the Chetties, who are the chief dealers in grain, were genuinely alarmed. An examination of the death returns and the result of interviews with medical practitioners in the locality, disclosed nothing beyond the fact that there had been some ten deaths in this locality during the previous fortnight, which however were ascribed to pneumonia, and other usual causes. It was nevertheless decided to lose no opportunity of detecting plague should it have actually broken out, and accordingly the Medical Registrar of Deaths (Dr Miss Rudd) was requested to withhold the death certificate and to at once communicate with the Public Health Department, should any further sudden death occur.

The very next day, *i.e.* on 25th January, Dr Rudd reported another sudden death in a resident of this same street, the history of which was

as follows. The patient, a well nourished and otherwise healthy young Moorish trader, who had lived in Sea Street for two months, took suddenly ill with "fever" at 10 p.m. on the night of 24th January. Next morning at 7.30 he walked to Dr Rudd's private dispensary—a distance of about half a mile. He had no symptoms at all beyond complaining of having "fever." His temperature was found to be 103° F., and he was given a mixture and walked home again. He died suddenly the same afternoon at 4 p.m. after an illness of only 18 hours. An external examination of the body disclosed nothing to account for death, and there was no trace of enlarged glands. In spite of considerable difficulties a post-mortem was held at midnight, but nothing abnormal was observed beyond a very slight congestion of the vessels of the meninges and a slight enlargement of the spleen. Samples of blood and of the various organs were taken for bacteriological examination by Dr Castellani who, in the absence of the junior author in India, had kindly consented to carry out the bacteriological investigation. Pending the receipt of the bacteriological result, steps as for plague were adopted, the house of the deceased being treated with a mixture of kerosine and cyllin.

The bacteriological examination disclosed the fact that the blood was swarming with *B. pestis*.

Within the next two weeks there was a succession of 19 sudden deaths, all but one of which were proved by bacteriological examination to be due to septicaemic plague. The exception, which was the fourteenth death in order of occurrence, developed an axillary bubo, the patient being a hospital cooly who had apparently been inoculated with the disease while engaged in a post-mortem examination of one of the previous septicaemic cases.

It was at first thought that with the decline from its initial virulence the prevailing type of infection would change from the unusual septicaemic form to the ordinary bubonic form. Reference to Tables 1 and 2 (p. 540) will show, however, that there has been practically no change in this direction in the last two years.

Unusual features of the outbreak of Plague at Colombo.

Plague is responsible for only a small mortality among the human population of Colombo, the total deaths from human plague being 383 in 1914, and 128 in 1915. The following features of this epidemic are however sufficiently remarkable and unusual to render them worthy of careful study.

(*a*) The percentage incidence, both among human beings and rats, is low except amongst the rats at the commencement of the epizootic, yet the virulence of the infection is very great.

(*b*) The clinical signs in the human subject are often very obscure.

(*c*) There is frequently a remarkable absence of distinctive post-mortem signs, not only in the human subject, but in both naturally and artificially infected rodents.

(*d*) The septicaemic type of infection prevails over the bubonic among naturally infected *Epimys rufescens*, the Colombo house rat, as it does in the human subject.

(*e*) The usual method of estimating the incidence of plague among rats by a study of their post-mortem appearances, which has proved so successful in Northern India, would for this epizootic fail to detect a large proportion of the most heavily infected rats.

(*f*) The usual signs of the presence of an epizootic among rats have been conspicuous by their absence both before and since the appearance of plague.

(*g*) The predominant rat flea is a different species from that occurring on rats in most plague infected localities.

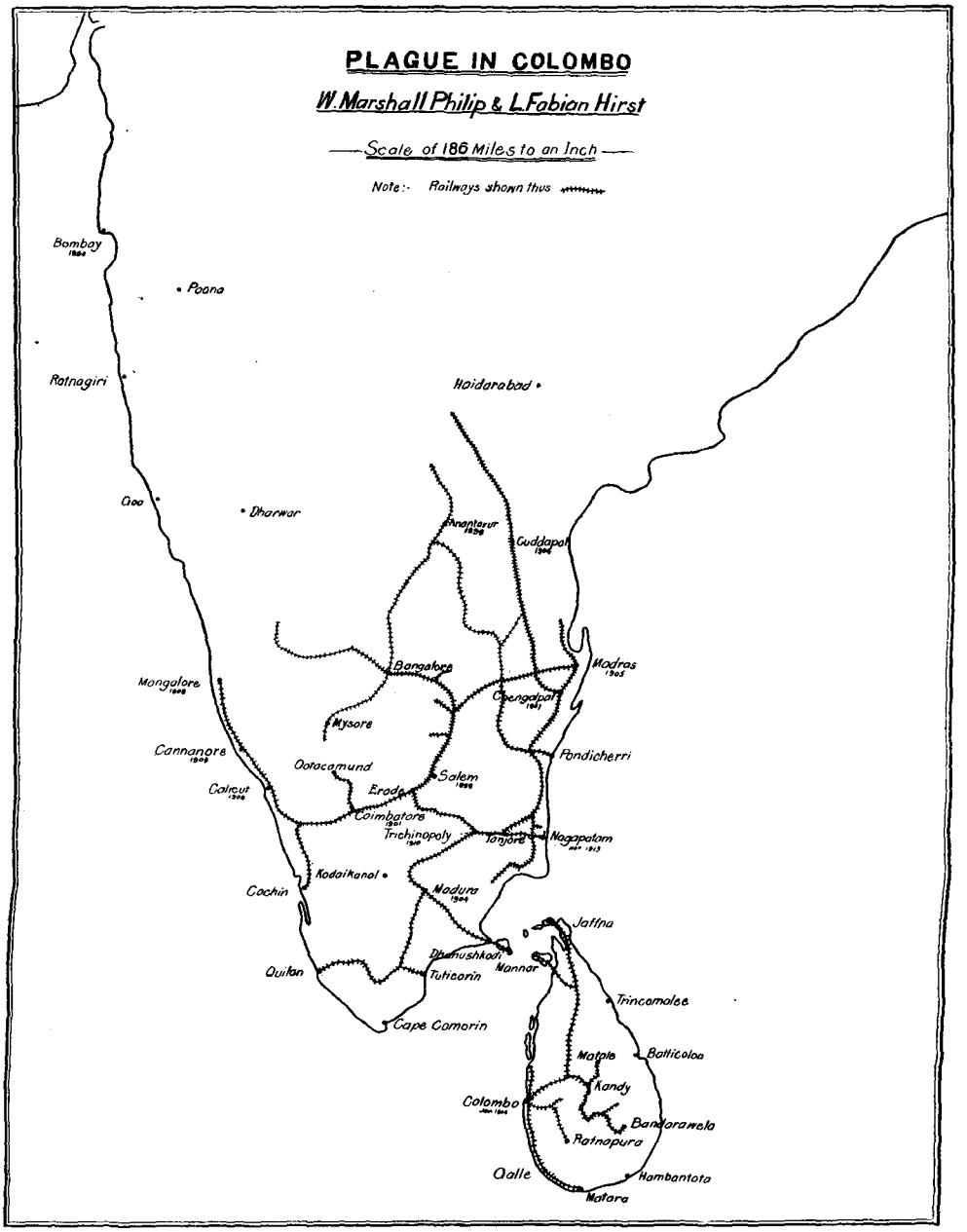
(*h*) There is experimental evidence that the Ceylon strain of plague is peculiar in some respects.

(*i*) Plague as it appeared in Colombo is a disease which might easily escape detection for long periods in localities where an efficient system of inquiry into the cause of deaths is not in operation.

(*j*) The incidence of the human plague has been almost entirely confined to certain insanitary districts of the city.

Source of infection.

A reference to the annexed map of South India (Map I), and Chart indicates that, as the Hon. Mr F. Bowes, C.C.S., C.M.G., Chairman of the Plague Committee, has pointed out in his report for 1914, there can be no reasonable doubt that the infection was brought from Negapatam, where a severe outbreak occurred at the end of November 1913, and reached its maximum in January 1914, in which connection he records that large shipments of rice were received from that port in late December and early January. On the assumption that the disease was conveyed by an infected rat concealed in a bag of rice, the first appearance of the disease in the grain centre at Sea Street would be explained.



Map I

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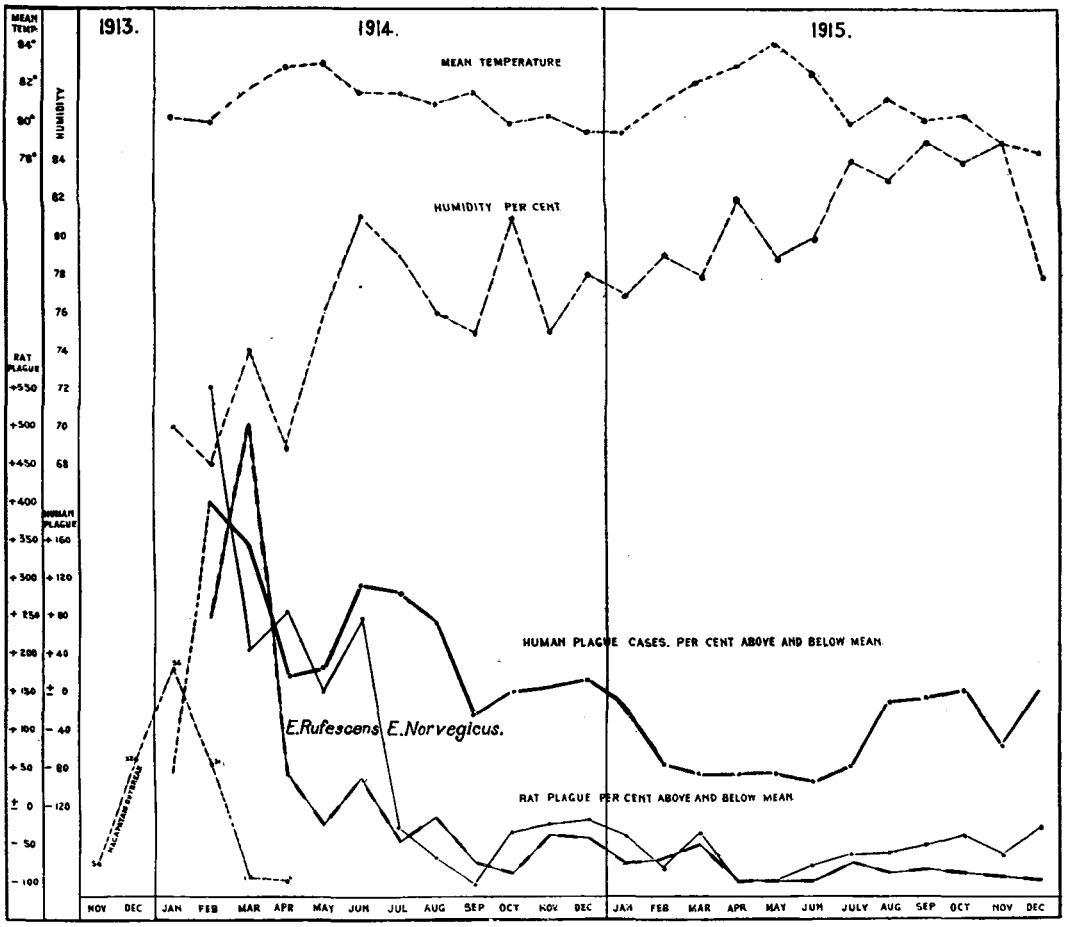

Chart showing seasonal incidence of Plague in Man and Rats.

II. HUMAN PLAGUE IN COLOMBO.

(*a*) *Noteworthy features of Plague in the human subject.*

Bubonic Type. The bubonic cases displayed no unusual features in the clinical picture or in their morbid anatomy. The case mortality is very high, and the disease seems to run an exceptionally rapid course. Bacteriologically the degree of septicaemia was unusually high.

Septicaemic Type. Some authorities contend that it is not correct to speak of a "septicaemic" as opposed to a "pneumonic" and "bubonic" variety of plague for the reason that septicaemia exists in every type

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of plague. "Septicaemic plague" is however a convenient expression to represent a definite clinical and pathological entity quite distinct from the ordinary varieties of plague. It is associated nearly always with the early demise of the patient, probably before the usual inflammatory reactions and necrotic changes in the tissues have time to develop. It may be suggested that the high proportion of septicaemic cases recorded in Colombo is due to a large number of mild non-fatal bubonic cases having escaped detection, but the house-to-house visitations which were carried on in the infected localities were so frequent and so thorough that we feel sure that such an explanation may be rejected. On the other hand it seems not improbable that, on account of the lack of physical signs in this type of disease, rapidly fatal septicaemic cases may sometimes be overlooked in other places, thus giving a fallaciously low case mortality.

In the septicaemic plague, death is frequently very sudden, and as there are usually few indications of the real cause of death, it is the rule for the Coroner to hold an enquiry, and for the Judicial Medical Officer to perform a post-mortem on these cases.

One of us has been present at many of these autopsies, and we are in all cases furnished with notes of the post-mortem appearances.

Plague septicaemia.

In view of the comparative rarity of the purely septicaemic variety of plague it may be advantageous to give a brief description of the morbid anatomy.

As in the first case thus examined there may be a remarkable paucity of noteworthy lesions of any description.

The following are the morbid appearances most commonly noted: Marked congestion and slight oedema of the lungs. Congestion of the mucous membranes of the alimentary canal and bronchi, frequently accompanied by haemorrhagic extravasation between their coats. Marked congestion of the meninges and the cortical vessels of the brain. Petechial haemorrhages in the serous membranes of the pleural, pericardial and peritoneal cavities. Haemorrhagic extravasation into the perirenal tissue and into the pelvis and tubules of the kidney. Slight general enlargement and deep congestion of the lymphatic glands. The degree of enlargement is seldom sufficient to render it possible to easily palpate the subcutaneous lymphatic glands. The liver and spleen are usually somewhat congested, but the spleen is seldom notably

enlarged in this group of cases; *B. pestis* usually swarms in both organs.

In general the post-mortem appearances are strongly suggestive of a haemorrhagic septicaemia, but in many of the cases in which the macroscopic changes were most obscure the tissues swarmed with *B. pestis*. Marked necrotic changes are only seen in the bubonic cases.

It would be impossible to arrive at a definite diagnosis in the septicaemic cases without a bacteriological examination, though signs of haemorrhages in the tissues, the darkly congested lungs and injected mucous membranes usually give a clue to the diagnosis.

It is of interest to note the large numbers of bacilli in the alveolar cavities of the lung and in the urinary tubules. Nevertheless multiple infection among the members of a household is rare. In a few cases of septicaemic plague one lung showed a patch of consolidation but in each case pneumococci were present in large numbers in addition to the plague bacillus. They also accompanied *B. pestis* in the internal organs in smaller number. No instance of true pneumonic plague has yet been discovered in Colombo.

The bodies of persons who have died of septicaemic plague have usually been well nourished and apparently normal in outward appearance.

Material from 374 post-mortems has been examined by us and 202 positive results obtained. Of these 193 were septicaemic.

Included among the septicaemic class are a small group of cases of particular interest. In these only a few plague bacilli are visible microscopically in the tissues, and if many saprophytes are also present it may be impossible to make even a provisional diagnosis with the aid of the microscope, and it is usually necessary to resort to the animal inoculation tests. Though the organisms are so few, marked congestion of the viscera is the rule, and sometimes haemorrhages are found. The striking feature is the rapidity with which death follows the onset of symptoms, which are very indefinite, consisting merely of a slight sensation of fever and a painful feeling of oppression in the chest. The following are the registered numbers of cases which undoubtedly belong to this group and in which we have definite information of the duration of illness prior to death.

No. 17, nine hours ill; No. 122, twenty-four hours; No. 62, seven hours; No. 244, twenty-four hours; No. 590, twenty-four hours; No. 7, seventeen hours; No. 27, ten and half hours; No. 42, one hour.

For the routine examination for suspected human plague a portion of the lung, liver, and notably enlarged lymphatic glands, and the spleen are in all cases forwarded with the least possible delay from the post-mortem room to the laboratory.

In all cases smears are made from the various tissues, fixed in alcohol and stained and examined microscopically for *B. pestis*.

Our routine stain is carbol methylene blue, but if the material is fresh the prettiest preparations are obtained by staining with dilute Giemsa.

The microscopic examination enables a provisionally positive opinion to be given without delay in the great majority of the septicaemic cases.

Cultivations are also made on agar and in broth. When the suspected tissues are reasonably fresh there is seldom any difficulty in isolating the typical bacillus from these cultures. Should the microscopic examination be negative a guinea-pig is inoculated from an emulsion of the suspected tissues. The inoculation is usually subcutaneous, but if the material is much decomposed the cutaneous method is employed in order to avoid the possible pathogenic effects of some of the putrefactive organisms.

Out of twelve cases in which the body was discovered with the viscera in an advanced state of decomposition only one gave a positive result. It is possible that the thermo-precipitin test might have given a positive result in some of these cases. Recently advantage has been taken of a favourable opportunity to test the value of the thermo-precipitin method for the routine diagnosis of plague.

Three splenic punctures were performed on the dead bodies of women of the Mohammedan community. One gave a positive result. This procedure is useful when serious objections are raised to a post-mortem, but it cannot be considered reliable.

Two of the negative human cases were of special interest. In both the lungs were partially consolidated. All the tissues examined were crowded with a bipolar-staining gram-negative bacillus bearing some resemblance to that of plague but more regular in outline and less rounded at the ends. A pure culture of the organism proved very pathogenic to guinea-pigs, rats and rabbits, producing post-mortem appearances somewhat suggestive of plague. The tissues at the site of injection showed marked necrosis, the subcutaneous tissues were oedematous and congested. There was slight enlargement and congestion of the superficial lymphatic glands and as a rule some clear

fluid in the pleural and pericardial cavities. All the tissues swarmed with bacilli similar to those observed in the human tissues. On cultivation, however, the organism was at once distinguishable from *B. pestis*. It produced a dense white shining growth on agar similar to *B. lactis aerogenes* or Friedländer's bacillus. It fermented glucose, mannite, saccharose, lactose and adonite with copious production of acid and gas. It did not ferment dulcite. The bacillus was non-motile, Vosges and Proskauer's reaction was marked, and indol negative.

The characters of this organism correspond most closely to *B. lactis aerogenes*, and it is probably allied to Friedländer's pneumonia bacillus. Similar cases have been described by Hirschbruck and Ziemann (1913).

In these instances neglect to isolate the organism and study its characters in pure culture might have led to a misleading diagnosis.

(*b*) *The clinical signs and symptoms in the septicaemic cases.*

The paucity of signs or symptoms of disease in cases which rapidly prove fatal is one of the most striking features of the septicaemic class of case met with in Colombo. In several instances the onset was so sudden that the patient (who has usually been a young adult) was actually pursuing his ordinary occupation without complaint on the day of his death, and only began to feel ill a few hours before the end. The following is a typical account of an average case running a course of 36 to 48 hours from the time when the patient first began to complain of feeling ill till the time of death.

The onset is always very sudden, the patient feels very ill and complains of fever and a feeling of tightness and oppression in the thorax. The patient is frequently found sitting up, if seen early in the attack, and does not at first sight appear to be very seriously ill. His face has however an anxious look. The eyes are slightly bloodshot, the breathing is hurried, the skin is hot and dry and the pulse is accelerated. Upon taking the temperature it is found to be raised, a usual figure being 103° F., but temperatures as high as 106° and even 107° have been observed. The only subjective symptoms which can as a rule be elicited are a feeling of illness and fever, and of great oppression in the chest, this latter being one of the most constant symptoms of these septicaemic cases. As a rule a question will elicit the fact that there is headache, but this is seldom volun-

tarily complained of. The outstanding complaint, and which always arouses a suspicion of plague, is the feeling of oppression in the chest. Within a few hours restlessness and delirium supervene, and the patient rapidly sinks into a state of collapse and dies.

It is remarkable how often, among the comparatively few septicaemic cases which survived long enough to reach hospital, the temperature chart shows a sharp fall to normal or subnormal about 12 hours before death, with a sharp rise just before that event took place.

As a rule there are no other symptoms than those mentioned above, but in a few cases there has been obstinate vomiting and in others diarrhoea, or both. In a small group of cases, there seems, so far as we have been able to judge by disconnected observations in the patients' homes, to have been little or no febrile reaction, the patient having rapidly reached a condition of profound toxaemia and collapse at a very early stage. Such cases are extremely puzzling, and cannot possibly be diagnosed without a bacteriological examination.

In no case included in the group of septicaemic plague has it been possible to detect by palpation any enlargement or even tenderness of the glands. This is in marked contrast to the bubonic cases where even the slightest degree of perceptible enlargement is as a rule attended with great tenderness and pain.

In no case have cutaneous haemorrhages ever been observed in our cases.

We are indebted to Dr E. R. Loos, the Junior Assistant Medical Officer of Health, and to Dr Iyappen, the Medical Officer in charge of the Infectious Diseases Hospital for particulars in regard to the clinical features of the cases seen by them.

(c) *Incidence in relation to race, class and habits of the people.*

Race has apparently no influence *per se* upon the incidence of plague, but on the other hand "class," *i.e.* social position, has a very marked influence. Nearly all the cases occurred amongst the very poorest class of the population, who by reason of their poverty are compelled to live in the most insanitary parts of the town, where the conditions are most favourable to rat infestation. Although by far the largest number of cases occurred amongst Tamils, Sinhalese, and Moors, while Burghers and Malays had very few cases and

Europeans none at all, this incidence has nothing to do with race, but is merely an index of the low social condition of those affected, as proved by the fact that the wealthier members of the Tamil, Sinhalese and Moorish populations who live under more sanitary conditions were not affected at all.

Closely associated with the incidence of plague in relation to class is the question of the habits of the people. It is notorious all the world over that the poorest people are the most improvident and the most careless in matters of domestic sanitation. The well-to-do man has, it is true, his servants to collect the kitchen waste and put it in the dust bin out of sight and out of reach of rats, whereas the poor man has to do this himself, a task which he but rarely fulfils; he prefers instead to adopt the easier and more insanitary method of throwing it out on the yard. The result is that one sees more waste food-stuffs lying about in the slums than in other parts of the town, and the rat has consequently less difficulty in obtaining his meals in the poorer quarters.

Another habit amongst the poorer classes which favours the spread of plague, and one which is in a measure the direct result of poverty, is their custom of sleeping upon the floor. In the vast majority of instances it was found that the infected person slept upon the earthen floor, within easy reach of the infected rat fleas emerging from the rat holes which are most commonly situated at the junction of the floor with the wall. It not infrequently happened that the person who slept on the earth floor of the rat-riddled back kitchen became infected while the rest of the family who slept in the paved front room—possibly on a raised bed—escaped.

In this connection it is interesting that in Singapore where there has been very little plague compared with Colombo, we understand that practically all the floors even in the poorest quarters are cemented or otherwise paved, while the walls are constructed of bricks set in mortar, and it is comparatively rare to find rat holes in the houses.

(*d*) *Incidence in relation to sex.*

Only 113 females as against 437 males were attacked. A similar disproportion in the incidence amongst males and females is recorded in India, and it has been suggested that there it is due to greater concealment of female cases. This would not however we believe explain the extraordinary disproportion in Colombo, where the

system which is in force of registration of deaths and medical inspection of all bodies prior to the granting of a burial certificate would almost certainly have disclosed any marked tendency towards concealment. A more probable explanation is, we believe, to be found in some difference in the habits of the respective sexes, especially as regards the places where they sleep at night when rats and their fleas are abroad in search of food.

(*e*) *Incidence in relation to age.*

The largest number of cases occurred in persons between the ages of 10 and 25, the very young and the elderly being comparatively slightly affected. A similar incidence was observed in India, and it would appear probable that those at the extremes of life are in reality less susceptible than the full blooded young adult.

TABLE 1. *Human Plague in Colombo.*

Cases and deaths.

	1914	1915
Total cases	412	138
Total deaths	381	128
Septicaemic cases	246	80
Septicaemic deaths	246	80
Bubonic cases	166	58
Bubonic deaths	135	48

TABLE 2.

Race distribution of cases.

	1914	1915
Burghers	2	3
Sinhalese	108	24
Tamils	172	79
Moors	105	29
Malays	10	1
Others	15	2
All races	412	138
Case rate per 1000 population (all races) ...	1·72	0·56
Death rate per 1000 population (all races) ...	1·59	0·52
Percentage of septicaemic cases to total cases ...	59·7	58·0
Percentage of bubonic cases to total cases ...	40·3	42·0

N.B. In 1914 and again in 1915 one case returned as septicaemic plague "recovered," but as the diagnosis was not confirmed bacteriologically each of these has been excluded from the statistics here dealt with.

TABLE 3.

Age and sex distribution of cases.

	1914			1915		
	Persons	*Males*	*Females*	*Persons*	*Males*	*Females*
0 years — 5 years	13	7	6	1	1	—
5 „ — 10 „	22	11	11	5	3	2
10 „ — 15 „	72	49	23	15	14	1
15 „ — 20 „	72	58	14	22	21	1
20 „ — 25 „	63	57	6	26	26	—
25 „ — 30 „	33	26	7	10	7	3
30 „ — 35 „	51	42	9	15	13	2
35 „ — 40 „	25	19	6	15	12	3
40 „ — 50 „	24	20	4	19	16	3
50 „ — 60 „	23	16	7	10	8	2
60 „ and over	14	11	3	—	—	—
All ages ...	412	316	96	138	121	17

TABLE 4.

Distribution of human cases by Wards.

	1914		1915	
Ward	Cases	Deaths	Cases	Deaths
Fort	1	1	0	0
Pettah	29	28	21	19
San Sebastian ...	48	47	15	14
St Paul's	156	148	69	65
Kotahena	12	12	11	8
New Bazaar ...	16	16	8	8
Maradana	112	97	2	2
Slave Island ...	26	22	6	6
Kollupitiya... ...	4	3	2	2
East Extension ...	3	3	3	3
Wellawatte... ...	0	0	0	0
Homeless vagrants	5	4	1	1
Total	412	381	138	128

III. THE EPIZOOTIC.

(*a*) *Work prior to the Epizootic.*

The systematic examination of rodents in the laboratory was begun on a small scale in February 1912. Between the beginning of that month and of September 1913, 1722 rodents were examined.

In general one live rat was sent from each ward daily, together with all dead rats found within the city limits. The rats were examined for plague, trypanosomiasis and the rat leprosy of Stefanski. Collections of the various species of ecto-parasites were forwarded to the British Museum for identification.

All rats exhibiting post-mortem appearances in any way suggestive of plague were very carefully examined with the aid of the microscope, by cultivation from suspected tissues, and by animal inocula-

tion. Watch was also kept for the *B. pestis* in the many hundred slides from normal rats made for the trypanosomiasis examination. The results were entirely negative.

About 20 % of the rats examined in February and March, 1912, were infected with the *Trypanosoma lewisi*. Trypanosomiasis proved to be frequently associated with enlargement and congestion of the subcutaneous lymphatic glands, particularly the submaxillary and inguinal, and of the neighbouring tissues, and with enlargement of the spleen.

During the last quarter of 1914, only twenty rats were examined for plague owing to the extreme pressure on the resources of the laboratory as a consequence of an outbreak of cholera.

(*b*) *The discovery of Rat Plague in Colombo.*

The junior author resumed work at the laboratory on the 7th February 1914, and two days later he reported the discovery of rat plague in two rats from Sea Street. One of the first steps undertaken as the result of this discovery was the reorganisation of the work of rat collection and examination on a much larger scale than hitherto. The work of collection was placed under the direction of Dr A. G. Milne of the Government Sanitation Department who was seconded for the purpose as he had previous experience of plague elsewhere. On Dr Milne's departure from the Colony, this work was taken over by Mr C. W. Pate, the Municipal Veterinary Surgeon, to whom we are indebted for the statistics in regard to rat capture.

The number of rats trapped and found dead during the two years under review was as follows.

TABLE 5. *Rats trapped and found dead.*

	1914	1915
Rats trapped ...	126,394	147,198
Rats found dead ...	430	260
	126,824	147,458

TABLE 6.

Particulars of species received at the Laboratory.

	1914	1915
Epimys rufescens ...	12,833	16,505
Epimys norvegicus ...	4,535	6,338
Mus musculus ...	137	376
Bandicota malabarica	68	134
Gerbillus indicus ...	6	1
	17,579	23,354

Thirty specimens of the Insectivore, *Crocydura coerulea*, the common "musk rat" of Colombo were received in 1914, and 163 in 1915. Classed with *Epimys norvegicus* are a considerable number of *Gunomys gracilis*, possibly as much as 10 % of the total.

Epimys rufescens is the local representative of "*Mus rattus*" and *Epimys norvegicus* of the "*Mus norvegicus*" of many writers on plague. Types of our species have been identified for us by the Mammal Department of the British Museum (Natural History) and by the Bombay Natural History Society. In what follows we shall use the symbol E.R. to represent the former and E.N. for the latter rodent.

IV. General Summary of the Results of the Rodent Examination for Plague Infection.

TABLE 7.

	Epimys rufescens		*Epimys norvegicus*	
	1914	1915	1914	1915
Total number rodents examined for plague	11,183	13,757	3,891	5,129
Total number rodents infected with plague	127	33	106	30
Gross percentage incidence ...	1·13 %	0·23 %	2·72 %	0·58 %
Number rodents trapped alive...	10,996	13,623	3,773	5,009
Number infected with plague...	103	27	90	24
Percentage incidence	0·93 %	0·19 %	2·38 %	0·47 %
Number rodents found dead examined for plague	187	134	118	120
Number rodents found dead infected with plague	24	6	16	6
Percentage incidence	12·83 %	4·47 %	13·56 %	5 %

Plague infection among

	1914	1915
Mus musculus ...	4	0
Bandicota malabarica	3	2
"Crocydura coerulea"*	Nil	Nil

	Epimys rufescens		*Epimys norvegicus*	
	1914	1915	1914	1915
Septicaemic type ...	61	20	22	9
Bubonic type	66	13	84	21
Percentage septicaemic	45·08	60·6	20·75	30

* The capture of *Crocydura coerulea* was subsequently forbidden, and all that entered the traps were liberated.

TABLE 8.

Percentage of infected trapped rodents.

Month	1914						1915					
	Epimys rufescens			*Epimys norvegicus*			*Epimys rufescens*			*Epimys norvegicus*		
	No. of rodents trapped	No. infected	Percentage	No. of rodents trapped	No. infected	Percentage	No. of rodents trapped	No. infected	Percentage	No. of rodents trapped	No. infected	Percentage
January	—	—	—	—	—	—	1237	4	0·32	389	3	0·77
February	87	4	4·59	74	6	8·11	1580	6	0·38	424	1	0·24
March	353	19	7·51	312	12	3·84	1067	7	0·65	374	3	0·80
April	496	9	1·81	361	16	4·43	820	—	—	281	—	—
May	630	6	0·95	317	10	3·15	862	—	—	371	—	—
June	942	16	1·69	348	15	4·31	766	—	—	301	1	0·33
July	1376	9	0·65	345	3	0·87	1016	3	0·29	487	2	0·41
August	1352	14	1·03	428	9	2·10	1550	2	0·13	640	3	0·47
September	1624	5	0·31	395	10	2·53	1015	2	0·19	499	3	0·60
October	1540	2	0·13	370	3	0·81	1273	2	0·15	363	2	0·76
November	1487	11	0·74	326	3	0·92	1355	1	0·07	441	2	0·45
December	1109	8	0·72	297	3	1·01	1082	—	—	439	4	0·91
Total and Average %	10996	103	0·93	3573	90	2·52	13623	27	0·19	5009	24	0·47

The most remarkable feature of the Colombo epizootic is the high proportion of plague infected E.R., showing the septicaemic type of plague, viz. 45·08 % in 1914 and 60·6 % in 1915. The feature is less marked in the case of E.N., but is still very notable, viz. 20·75 % in 1914 and 30 % in 1915. The term "Bubonic Type" is used in this connection somewhat arbitrarily and includes all rats showing not only bubos but any other distinctive post-mortem sign of plague.

Another very remarkable point is the small total number of rats found dead considering the high percentage incidence. The total number for 1914 is 430, and for 1915, 320. The figures in the tables refer to examinable rats. Very large numbers of rats must nevertheless have died of the effects of both plague and rat poison, for out of 2,595,212 poison baits laid in 1914, no less than 467,814 were consumed, the figures for 1915 being 3,913,944 and 734,697 respectively. The "Punjaub vermin exterminator" is used.

It is noteworthy that the spectacle of plague-infected rats wandering in the open in an obviously moribund condition, so frequently observed in India, has so far not been observed in Colombo. Rat carcases are easily concealed in Colombo owing to the structure of the roofs of the native dwellings, and the numerous burrows communicating in many cases with extensive untrapped underground drains. When the roof is taken off plague infected dwellings mummified rat carcases have occasionally been found among the tiles. The Java authorities seem to have a similar experience with bamboo roofs. The digging up of the burrows frequently reveals the presence of decomposed carcases, but this method of search can comparatively seldom be adopted here, as it generally entails demolition.

The percentage incidence among living E.N. is between two and three times greater than among E.R., for both years under record. This is in accord with the general experience and is probably to be associated with the corresponding difference in the flea index. See Table No. 12 (p. 562).

On the other hand the proportion of infected dead rats is much the same for both species. The disease runs a slower and more characteristic course in E.N. and presumably this species comes out to die in the open less often when affected with plague.

We were fortunate in possessing a subordinate staff already trained to the work of rat collection and examination.

The first few hundred rats were subjected to a detailed examination

on the same lines as are employed in investigating the human cases. It soon became apparent that the ordinary macroscopic method could not be relied upon to detect plague in Colombo rats owing to the highly septicaemic form which the disease assumed and the comparative absence of distinctive post-mortem signs. It was also clear that if we continued to apply strict methods of investigation to the examination of the rats, we should not have time to examine a sufficient number to keep in touch with the spread of the epizootic.

Experienced workers in Bombay and many other plague infected localities can pick out the infected from the non-infected rats with the aid of the naked eye with a greater degree of reliability than by any other method, but a large proportion of the septicaemic rats in the Colombo epizootic appear almost normal to the naked eye and are accordingly not detected in the preliminary macroscopic examination.

In the routine method adopted here the macroscopic method is combined with a microscopic examination of the spleen and abnormal tissues, and the results are checked at intervals by inoculations of suspected material into guinea-pigs, and latterly by means of the thermo-precipitin test. It is not practicable to examine all of the very large number of trapped rats by such a method.

The following are examined daily:

Group 1. All dead rats found within the city limits.

Group 2. All rats found alive in the vicinity of recently infected premises.

Group 3. An equal proportion of the rats from all over the town trapped by each overseer of the Rat Collection Department. These are drowned at the Depot.

Numbered brass tickets are pinned to the bodies of the rats. A list is forwarded with the rats from the Depot showing the locality of collection for each number.

The method of examination differs somewhat and the results are interpreted in a slightly different manner according to whether the rat's carcase is fresh or decomposed.

In fresh carcases reliance is chiefly placed on the microscopic examination, frequently controlled by the isolation of the specific organisms in cultures from the organs or from the tissues of guinea-pigs inoculated with organ emulsions, and latterly in the case of the more septicaemic specimens, by the thermo-precipitin test. The

carcases of Groups 2 and 3, *i.e.* trapped rats, are nearly always fresh when received in the Laboratory. One of us is personally responsible for all but a few of the microscopic examinations.

In decomposed carcases the microscopic method by itself is of little value since plague organisms rapidly disappear from the tissues at ordinary Colombo temperature and are replaced by strongly staining saprophytes which overgrow the cultures. In such cases one is obliged to supplement the microscopic method by cutaneous inoculation of guinea-pigs, and by the precipitin test. It is however impossible to obtain reliable results in the case of decomposed septicaemic rats since not only is the microscopic method of no value, but cutaneous inoculation often fails with decomposed material known to be plague infected.

In all rats not in an advanced state of decomposition the usual dissection is made by native laboratory attendants under the supervision of a trained assistant. The post-mortem appearances are carefully scheduled on forms designed to facilitate the analysis of the results. The species, sex, size, pregnancy and number of foetuses are also noted. Smears are made on glass slides from the spleen of every rat not in an advanced state of decomposition, also from such lesions as bubos, granular liver and pleural effusion.

The high degree of septicaemia usually found in plague infected Colombo rats is exceptionally favourable to the use of the microscopic method. In the great majority of infected rats, typical bacilli swarm in every field of the microscope. As in the corresponding human cases they were often particularly numerous when the macroscopic signs were inconspicuous. In the bubonic type the organisms are often less numerous and sometimes quite scarce, but here the macroscopic appearance helps in the diagnosis.

It is unsafe to give an opinion on the basis of the macroscopic examination alone when only a few bipolar organisms are noted. Bipolar staining bacilli of intestinal origin not uncommonly appear in splenic smears in small numbers quite a short time after the death of the rat. Other observers have called attention to their presence in the accessory genital glands and in non-plague pleural effusions (Macalister and Brooks, 1914). Experience however shows that when numerous bacilli of typical morphology are found, and especially if involution forms are observed, there is a very strong presumption of plague. The interpretation of the appearances observed in moderately decomposed tissues is much facilitated by a preliminary

study of the corresponding tissues of an artificially infected animal at different periods after its death.

The presence of plague infection is most likely to be overlooked when the animal dies at an early stage from the effects of plague toxins before the organisms have greatly multiplied in the tissues.

Principal post-mortem signs observed among 127 *plague-infected* E.R. *and* 109 E.N. *during* 1914.

	E.R.	E.N.
Marked subcutaneous congestion	26	62
Marked enlargement and congestion of lymphatic glands	25	48
Necrosis or suppuration of lymphatic glands	7	5
Effusion of clear fluid into pleural pericardial cavities ...	26	26
Granular liver	6	25

The most reliable single sign of plague among our rats was granular necrosis of the liver. We have not met with the necrotic liver due to infection with Gaertner's bacillus. The most generally useful sign is clear pleural effusion but in several rats with this abnormality we did not succeed in proving the presence of *B. pestis*.

Only twelve rats during 1914 showed really typical post-mortem appearances. These include rats showing at least three characteristic signs such as granular liver, pleural and pericardial effusion, bubo, subcutaneous congestion or haemorrhages.

It will be noted that the distinctive post-mortem appearances are much more common in the E.N. than in E.R.

Non-plague abscesses were noted in the lungs and in connection with the accessory genital glands in 46 rats. Many were of large size, the contents being either caseous or of a glairy consistency. The 21 non-plague abscesses of the lymphatic glands contained large numbers of a slender pointed Gram negative bacillus.

There were six cases of rat leprosy among the E.N. The non-plague morbidity of this species is much higher than that of E.R.

During February, March and April, 1914, congestion of the superficial lymphatic glands and of the subcutaneous tissues was very common in both species quite apart from plague infection. Many of these enlarged glands contain trypanosomes, and it is not unreasonable to suppose, since both infections may be conveyed by the rat flea, that the incidence of both may be influenced by similar conditions.

V. RELATION BETWEEN HUMAN AND RAT PLAGUE.

As already pointed out the incidence of human plague has been almost confined to certain insanitary, highly rat-infested quarters of the city. These areas are fairly well defined, and it is a matter of some interest to compare the incidence of rat plague at different periods within and without these areas, during the year 1914. For this purpose three such areas were marked out on the map. (See Map III.)

Number one comprised the original focus of infection in the Pettah Ward and the adjoining portions of San Sebastian and St Paul's Wards with a continuous strip of Maradana Ward to the East of Colombo Lake. Throughout the year this remained the area principally involved.

A second area in Slave Island Ward was considered to be infected for the months of February, March and April, after which it became almost free from human plague.

A third area in Demetagoda became a focus of human plague from June to the end of the year.

The accompanying table No. 9 shows the percentage incidence of plague infection among rodents in areas infected and non-infected with human plague.

The epizootic was established in Maradana Ward and a small area of St Paul's Ward nearly three weeks before human cases occurred.

TABLE 9.

Percentage incidence of plague infection among rodents in areas infected and non-infected with human plague.

Epimys rufescens.

	Infected area			Non-infected area		
	No. of rodents	No. infected	Percentage	No. of rodents	No. infected	Percentage
1st Quarter	192	13	6·76	248	10	4·03
2nd ,,	784	16	2·04	1284	15	1·16
3rd ,,	1960	15	0·76	2392	13	0·54
4th ,,	1655	9	0·54	2481	12	0·48

Epimys norvegicus.

1st Quarter	231	17	7·35	155	1	0·64
2nd ,,	598	29	4·85	428	12	2·80
3rd ,,	731	15	2·05	437	7	1·60
4th ,,	490	6	1·22	503	3	0·59

The discovery of rat plague preceded that of human plague in fifteen streets of the town, thus enabling a warning note to be sounded and precautions were taken in advance.

In June a small focus of rat plague was discovered in the south end of the town at Wellawatte but was not followed by any indigenous cases of human plague.

It is particularly noteworthy that the rat plague when it first appeared in new areas was almost always of the septicaemic type. It is clear therefore that for practical purposes it is important to adopt a technique which will detect this class of infection and that undue reliance should not be placed upon the macroscopic method as a guide to the spread of this type of epizootic.

VI. Rat Infestation and Plague Incidence in relation to Locality.

A very striking relation has been observed in Colombo between the incidence of plague amongst the people, and the conditions under which they are living, particularly as regards the character of their dwellings and the situation of these in relation to grain centres and thoroughfares.

It is not merely that in its spread the disease has selected with remarkable precision and regularity the most insanitary spots in the town, but it has during the two years of its stay, remained, in so far as the people are concerned, strictly confined to such areas, although on the other hand infection amongst the rats has been found to occur in practically every quarter of the town.

The explanation of this without doubt lies in the greater degree of rat infestation which prevails, and the closer domestic relation which is tolerated between rat and man in the poorer as compared with the better class quarters of the town.

The greater degree of rat infestation in plague infected areas, and the probable reasons for such infestation are indicated in the following description of various areas in the town.

We shall consider these areas in order, inversely to the degree of rat infestation:

(*a*) *Business quarter, Fort* (*A* on Map II). 9·3 *rats per* 100 *traps.*

The buildings in this quarter are for the most part used for business purposes, and (exclusive of hotels) only to a very small extent for

dwelling purposes. They are substantially constructed, many having an upper floor. The ground floors are invariably cemented, as are also many of the back yards which are, however, small. The lighting and ventilation of such as are used for dwelling purposes is good. General sanitary condition good. No case of human plague, and very few cases of rat plague have occurred here.

(*b*) *Residential quarter, Cinnamon Gardens* (*B* on Map II). 10·5 *rats per* 100 *traps.*

The houses are for the most part single-storey detached buildings, substantially constructed of brick or cabook, plastered and limewashed, floors are cemented, roofs covered with half-round country or flat Mangalore tiles and ceiled; light and ventilation ample, and general sanitary condition good. No case of human plague, and only a few sporadic cases of rat plague have been detected in this part of the town.

(*c*) *Native quarter, fairly densely populated, Slave Island* (*C* on Map II). 16·6 *rats per* 100 *traps.*

The houses in this quarter are almost entirely small single-storey dwellings, the main building being in most cases constructed of roughly cut cabook bricks set in clay or coarse sand mortar; the foundations are similarly built and are shallow, the walls are plastered with chunam, the roofs are low and covered with half-round country tiles; there is as a rule no ceiling. The kitchens are frequently merely one end of the back verandah enclosed by wattle and daub walls. The floors are for the most part of beaten earth. The lighting and ventilation are defective, owing partly to the irregular disposition and overcrowding of the buildings, and partly to the absence of windows and the existence of interior rooms. General sanitary condition is bad. The walls of such houses are generally riddled with rat runs. A small but distinct outbreak of both rat and human plague occurred in one part of this area in 1914, but only four human and no rat cases were detected in 1915.

(*d*) *Native quarter densely populated, San Sebastian* (*D* on Map II). 18·7 *rats per* 100 *traps.*

The houses in this quarter, which occupies the side of a slope, are constructed much as in (*c*), but are more closely crowded together in continuous rows, and there are many long ranges of back to back tenements which are densely populated. The people are very insanitary in their habits, and the general sanitary condition of the quarter is

bad. Comparatively little rat plague has been found in this quarter, but it was the scene of a sharp outbreak of human plague in 1914. This area is in comparatively close proximity to the grain-centre area described next.

(*e*) *Grain Centres, Pettah and St Paul's* (*E* on Map II). 21·1 *rats per* 100 *traps*.

This area is the chief centre of the grain trade, and is fairly accurately indicated by the densely crowded spots at *E* on the attached map. It lies adjacent to the harbour and contains, besides the grain stores, large numbers of dwellings between which, in fact, the grain stores are sandwiched. The grain stores are for the most part nothing more nor less than dwelling houses which have been converted into stores, additional accommodation being obtained by the simple expedient of roofing over the small back yard. The buildings present a combination of the fairly well built, cement-paved house, and the badly built unpaved tenement. In practically all cases however the walls are quite pervious to rats as is shown by their being riddled with rat runs. An important feature of this area is the existence of an old underground system of untrapped rain-water drains which discharge for the most part into the harbour. It was thought early in the epidemic that the absence of dead rats might be explained by the finding of large numbers of their bodies in these drains, but an inspection proved this not to be the case. These drains however undoubtedly form great highways for the rats, and several of them have been proved to have direct communication with the interiors of the dwellings by means of rat runs.

This area was the first part of the town to be attacked by plague, and it has continued ever since to be the principal focus of the disease as regards both rat and human plague.

(*f*) *Semi-rural native quarter, Modera* (*F* on Map II). 23·3 *rats per* 100 *traps*.

Although this area shows one of the highest degrees of rat infestation, very little plague, either rat or human, occurred during the two years under reference. The houses are much the same as those described under area (*c*), but there is a larger proportion of the bamboo-framed wattle and daub building here, and in a number of cases either the whole or part of the house is roofed with thatch instead of tiles. The houses are more scattered than in other areas. There are no underground drains in this area. Rat holes are not as a rule so numerous as in the

other areas described which is probably attributable to the relatively small number of *E. norvegicus* here as shown by the following statement.

		Area (*e*)	Area (*f*)
Total rats examined	...	*3335*	*1033*
No. of E. rufescens	...	2014	864
No. of E. norvegicus	...	1321	169
Percent. of E. rufescens	...	60	83·6
Percent. of E. norvegicus	...	40	16·4

A distinctive feature of this area is its isolation. It forms a salient at the extreme north end of the town, and is bounded on three sides by the river and the sea, there being no through road to the country beyond. The result is that there is little traffic here compared with the other areas described. It is of interest to record that plague has appeared in this area subsequently to the period under consideration, and at the time of writing shows signs of a fairly widespread and active infection. Presumably this late appearance of the infection is due to the isolated position of the area.

(*g*) *Native quarter with bazaar, Maradana* (*G* on Map II). 27·6 *rats per* 100 *traps.*

This area which shows the highest degree of rat infestation is an extremely busy centre. In addition to being densely populated, it is a great centre for native retail grain and food shops. It is close to the principal railway station, and one of the principal roads of the town passes through it, there being an important road junction here. This area was early attacked by plague and was the scene of a very sharp outbreak of human plague in 1914. No case of either rat or human plague occurred in 1915.

The use of the number of rats caught per 100 traps as our index to rat infestation is open to the objection that rats will not enter the traps in numbers proportionate to the actual degree of rat infestation, if there be a great amount of tempting food easily accessible to them outside the traps; and on the other hand will enter the traps in disproportionately large numbers if their usual food supply is suddenly cut off by exceptionally vigorous scavenging operations.

During the period to which the figures refer, July, August, and September, 1915, the trapping and scavenging operations were being carried out on the same uniform system. The baits used in the cages are very tempting to rats and the cages are laid in similar situations in all the areas.

VII. Characters of our strains of Ceylon Plague.

All our strains are morphologically typical and show marked bipolar staining. On agar, growth appears in the form of discrete translucent streptococci-like colonies. Later the colonies usually coalesce to form a whitish somewhat opaque growth with raised colonies on the surface somewhat suggestive of a contamination. All our strains form typical stalactites in broth and grow in the form of long chains. No indol reaction to Bohme's reagent is given with any of the strains.

Many of our Colombo strains are remarkably parasitic, only growing scantily on agar or blood serum and requiring to be subcultured at frequent intervals in broth to keep them alive.

The fermentation reactions of these strains of human plague Nos. 2860, 2191 and 3870, and those of the rat plague Nos. 45, 47 and 32,188, have been carefully compared with one another and with a strain of *B. pestis* from the Bacteriological Laboratory, Bombay.

Peptone azolitmin water was used containing $\frac{1}{2}$ per cent. of the following substances: lactose, saccharose, dulcite, adonite, inuline, salicine, dextrine, glycerine, glucose, galactose, arabinose, fructose, sorbite, isodulcite and mannite.

On the 14th day acid was formed in arabinose, glucose, fructose, galactose, maltose, mannite, salicine, dextrine and a trace of acid in adonite.

Lactose, saccharose, dulcite, inuline, raffinose, isodulcite, sorbite, and glycerine, gave no reaction.

There was no appreciable difference between the Ceylon strains. The Bombay strain fermented salicine more vigorously and adonite hardly at all.

Our strains proved extremely virulent to Colombo rats. After subcutaneous injection of an emulsion in salt solution containing only 100 organisms per c.c. of strain 3870, two *Epimys rufescens* died within 48 hours of septicaemic plague. The cutaneous inoculation of a few loopfuls of the recently isolated broth culture into the shaved skin at the root of the tail killed four out of six of this species rapidly, in one instance in less than 36 hours. Our laboratory culture of plague is also very virulent to Colombo rodents but in a less degree. In this respect Colombo seems to come into line with the City of Madras and other places in India where low endemicity of plague is associated with great susceptibility of the rat population.

A few of the experimentally infected rats which died very rapidly showed a condition analogous to the toxaemic group of human plague to which reference has been made. The organs contained only a few *B. pestis* and the macroscopic appearances were a little abnormal. The vitality of the animals was probably low with the result that they died at an early stage of the bacterial invasion of the tissues from the effects of plague toxin. The corresponding condition has been observed in specimens of naturally infected *Epimys rufescens*.

Rats inoculated from a spleen emulsion of human and rat plague almost invariably die of septicaemia within two days. The post-mortem appearances are precisely similar to those found in the naturally infected septicaemic rats.

Guinea-pigs inoculated with fresh tissue emulsion of septicaemic plague often die within 48 hours and show a corresponding condition post-mortem to septicaemic plague in rats and human beings.

Guinea-pigs inoculated from cultivations however seldom die before the third day. Microscopically the viscera show the changes typical of plague.

The virulence of No. 3870 when recently isolated was compared with the Bombay strain on guinea-pigs, using eight pigs of approximately equal weight and an emulsion of *B. pestis* containing 10, 100, 1000, 10,000 100,000, 1,000,000 of strain 3870 and 1,000,000, and 10,000,000 of the Bombay strain. The cultures were 48 hours old. The suspensions in salt solution, after shaking for 15 minutes, were standardised with a Helber Glynn Haemocytometer. The injections were subcutaneous, care being taken to deliver a uniform quantity into the tissues. The pig receiving the smallest dose survived. That receiving 1000 organisms died of septicaemic plague in 48 hours. All the remainder died between the third and fifth day with typical post-mortem signs of plague such as granular liver and effusion into the pleural cavities.

Haemorrhage into the tissues is common in guinea-pigs inoculated with our strains if they survive more than three days. In experimentally infected rats it seems as uncommon as in the natural infected animals.

A comparatively large dose of *B. pestis* is required to reproduce the septicaemic type of infection in *Epimys norvegicus*. This rodent seems to be intermediary in this respect between *E. rufescens* and the guinea-pig.

Sydney Rowland (1915), experimenting with a culture of Ceylon plague isolated by Castellani, found it to be of low virulence for his rats, only killing 50 % of those inoculated. Rowland brings forward

evidence showing that the antigen of the Ceylon strain of plague differs in immunising power from his standard laboratory strain.

It follows that prophylactic vaccines intended for use in Colombo should be prepared from the indigenous strain. It seems probable however that vaccines would not give much protection against such a virulent strain as that responsible for the local epidemic.

Sydney Rowland (1915*a*) failed to immunise rats against a hypervirulent body strain of rat plague with the most effective vaccine he could prepare from this strain.

VIII. The Thermo-Precipitin Reaction.

Ascoli's thermo-precipitin test has been employed on a small scale. Our supply of suitable serum is as yet too limited to apply the test as part of our routine examination for plague.

The serum used was Yersin's antipest serum prepared at the Berne Institute.

It was often necessary to filter this serum through a porcelain candle before it became clear enough to be used.

The method is particularly useful as a rapid confirmatory test for septicaemic plague. A well-defined ring is usually visible at the junction of the fluids in about an hour with the technique recommended by C. E. Warner (1914). In our experience the results are distinctly better with fresh tissues.

In four out of seven extracts from moderately decomposed human plague spleens, and in two out of three rat spleens in a similar condition, a good reaction was obtained within two hours. In the case of the remaining three human spleens a good ring formed overnight. The other rat gave a dubious reaction.

A positive result will often be obtained by this method when it is practically impossible to isolate *B. pestis* directly from among the putrefactive organisms in decomposed plague infected tissues.

On 10th January 1916, we succeeded in obtaining a positive result with the aid of the test from five mummified rats found in the roof of No. 69^{11} Dam Street. A human death had taken place from bubonic plague on the 6th instant at 69^{8} Dam Street, a few yards distant in the same block of buildings.

The following are the details of this test:

An emulsion was made from the scrapings of the skin and bone of the five rats in the proportion of one gramme of scraping to four of salt solution. The emulsion was heated in a water-bath to 100° C. for five minutes, filtered first through ordinary filter paper and then through a Pasteur-Chamberland filter. A clear but discoloured filtrate was obtained. As controls similar extracts from the spleens of a plague infected rat caught in the same street and of a microscopically negative rat, after being heated in the same manner, were also passed through a sterilised filter candle. A control with rabbit serum was also prepared. Yersin plague serum from the same bulb was added to each tube.

The control positive tube showed a distinct ring within fifteen minutes. The mummified rat tube reacted distinctly in about one hour. The control negative tubes showed no reaction several hours later, but next morning a faint turbidity was visible at the junction of the fluids in the negative rat tube. By that time the two former tubes had precipitated.

The reaction seems to be sufficiently specific for practical purposes.

IX. PARASITOLOGY.

The following species of ecto-parasites have so far been identified from Colombo rats.

Siphonaptera	*Xenopsylla astia* Rothschild
	„ *cheopis* Rothschild
Gamasidae	*Dermannyssus muris* Hirst
	Laelaps echidninus Berlese
	„ *nuttalli* Hirst
Louse	*Haematopinus spinulosus*

Dermanyssus (*Liponyssus*) *muris* is a blood-sucking mite, *Dermanyssus gallinae* has repeatedly been found parasitic on man in Europe and America. The Dermanyssidae are generally parasitic upon birds.

The mites of the genus *Laelaps* are not parasitic upon man, but might possibly convey infection from rat to rat. Species of both *Dermanyssus* and *Laelaps* have now been found parasitic upon rats from all parts of the world.

The fleas were identified by the Hon. N. C. Rothschild, and the mites by Stanley Hirst from collections forwarded at intervals since 1912; the smallest species of mites are not included.

All the fleas in the collections forwarded to the Hon. N. C. Rothschild in 1912 were identified as *Xenopsylla astia*. In March 1914 the junior author observed some fleas which appeared to belong to a different species, probably *X. cheopis*. He included these fleas in a collection of 200 which was forwarded to Rothschild. Some of the male fleas of both species were cleared and mounted on glass slides and their characters carefully noted for future reference. One of the fleas sent had been caught on a man in the Colombo Museum, and was also cleared and noted; the remainder were from E.R. and E.N., captured in the principal area of plague infection.

Rothschild reported as follows: 28th April, 1914.

183	*Xenopsylla astia*
16	,, *cheopis*
1	*Echidnophaga gallinacea*
200	

On the glass slides two *X. cheopis* and four *X. astia*.

In May 1914, one of us estimated five out of 200 male fleas to be *X. cheopis*. We have not found this species at any time subsequently.

X. astia was originally described by Rothschild (1911) from specimens captured in Rangoon. We obtained a collection of rat fleas from Madras City. All were identified by Rothschild as *X. astia*. One of us (Hirst, 1913) has drawn attention to the epidemiological significance of the already ascertained facts with regard to the geographical distribution of *X. astia*.

We learn from Rothschild that about 5 % of the rat fleas in Bombay are *X. brasiliensis*, and that he proposes to publish a paper explaining the differences between these species to enable students to identify them with ease.

A series of parasitological experiments with *X. astia* are in progress, but our observations have not as yet been sufficiently continuous or complete to warrant publication in detail.

Observations made in 1913 before the outbreak of plague showed that *X. astia* bites man with great reluctance at temperatures over 80° F. We have experienced the greatest difficulty in transmitting plague from rat to rat under experimental conditions through the agency of *X. astia*.

Experiments in flea breeding cages of the usual pattern are attended with great difficulty in the moist Colombo atmosphere, on account of the rapidity with which the larval food is overgrown with moulds. We have, however, devised a method by which this difficulty is overcome.

Several attempts have been made to estimate the flea infestation of infected dwellings by using guinea-pigs as traps for fleas, after the method used by Liston with such success in Bombay. Our experience was quite different. It was exceptional to find any fleas at all on the animal. The highest count obtained was seven fleas on one pig. All the exposed animals survived.

In this connection it is noteworthy that here fleas comparatively seldom attack disinfecting coolies and others entering plague infected houses after the removal of the patient. This seems to be in marked contrast to the general experience in Northern India.

Everything appears to point to the conclusion that the conditions prevailing in Colombo are exceptionally unfavourable to the transmission of plague infection, since in spite of the virulence of the infecting organisms and the susceptibility of the human and rat population, the incidence of the disease is low for both except at the very commencement of the epidemic.

It is not yet possible to decide whether this is mainly due to the effect of climatic condition on the vitality of the flea, to the relative inefficiency of *X. astia* as a porter of plague, or to any other cause.

In view of the exceptionally high degree of septicaemia in many of our cases of human plague, the question of the possibility of the transmission of the infection from man to man through the agency of human ecto-parasites such as *Pulex hominis*, *Cimex rotundatus* or *Pediculus corporis* becomes of practical importance and especially in view of the work of Nicolle and his collaborators. We are not yet, however, in a position to record any fresh data bearing on this matter.

Batches of about twenty rats are brought to the laboratory three times a week alive in canvas covered cases for the purpose of estimating the flea index. After transferring rats from any cage containing more than one species, so that all the cases contain one species of rats, the whole cage in its bag is placed in a chloroform or cyanide box and the fleas counted after combing out the rats and shaking out the bag.

X. Seasonal Incidence.

The monthly mean temperature varies comparatively little in Colombo throughout the year. The nights are fairly cool as a rule in December and January when the mean monthly minimum atmospheric temperature may fall to 72° F.

Rise of temperature above 81° F. seems to have a decided effect on the incidence of plague.

The humidity ranged higher during 1915 than 1914. There seems to be more distinct relation between the curve of humidity and the flea index than between that of flea index and temperature.

Our curves show a very close correspondence between the periodicity of rat and human plague.

The sharp rise in the flea index (p. 562) in June 1915 was followed by a rise in the curve of plague incidence among E.N.

(See Chart on p. 533.)

TABLE 10. *Plague*, 1914 *and* 1915.

Human cases reported during each month.

	1914	1915
January	4	19
February	67	6
March	58	3
April	27	3
May	29	3
June	49	1
July	47	5
August	40	20
September	18	21
October	23	23
November	24	10
December	26	24
Totals	412	138
Mean	34	11·5

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TABLE 11 (*a*).

Monthly temperature and humidity at Colombo during 1914.

Month	Temperature: Maximum in shade	Temperature: Minimum in shade	Temperature: Mean of maximum and minimum	Humidity (mean)
	°	°	°	%
January ...	88·2	72·3	80·3	74
February ...	88·2	71·4	79·8	75
March ...	89·3	74·0	81·7	78
April	90·4	74·9	82·7	78
May	88·3	77·7	83·0	79
June	86·3	76·9	81·6	82
July	86·0	77·0	81·5	80
August ...	85·9	76·1	81·0	79
September ...	87·4	75·7	81·6	71
October ...	86·2	73·8	80·0	78
November ...	87·3	73·4	80·4	72
December ...	86·0	73·1	79·6	75
Mean for year	87·5	74·7	81·1	77

TABLE 11 (*b*).

Monthly temperature and humidity at Colombo during 1915.

Month	Temperature: Maximum in shade	Temperature: Minimum in shade	Temperature: Mean of maximum and minimum	Humidity (mean)
	°	°	°	%
January ...	86·8	72·3	79·6	77
February ...	89·8	72·3	81·0	79
March ...	89·9	74·5	82·2	78
April	90·7	75·5	83·1	82
May	89·0	79·3	84·2	79
June	87·7	77·6	82·6	80
July	84·6	75·5	80·0	84
August ...	85·2	77·2	81·2	83
September ...	85·0	75·4	80·2	85
October ...	85·5	75·4	80·4	84
November ...	84·0	73·8	78·9	85
December ...	85·8	71·5	78·6	78
Mean for year	87·0	75·0	81·0	81

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TABLE 12.

Monthly flea index during 1914 *and* 1915.

Month	1914						1915					
	Epimys rufescens			*Epimys norvegicus*			*Epimys rufescens*			*Epimys norvegicus*		
	No. of rodents	No. of fleas	Index	No. of rodents	No. of fleas	Index	No. of rodents	No. of fleas	Index	No. of rodents	No. of fleas	Index
January	—	—	—	—	—	—	269	788	2·92	91	475	5·22
February	22	77	3·50	—	—	—	309	957	3·09	88	554	6·29
March	35	62	1·77	—	—	—	233	636	2·72	119	471	3·95
April	16	23	1·43	—	—	—	188	457	2·43	104	370	3·55
May	45	76	1·68	—	—	—	132	356	2·69	83	425	5·12
June	107	201	1·87	39	124	3·17	181	323	1·78	95	237	2·49
July	216	431	2·0	62	193	3·11	280	791	2·82	146	1100	7·53
August	203	201	1·0	50	88	1·76	279	708	2·53	142	919	6·47
September	202	375	1·85	39	151	3·87	270	591	2·18	119	654	5·49
October	172	418	2·43	47	203	4·31	234	263	1·12	86	246	2·86
November	246	513	2·08	46	171	3·71	213	276	1·29	68	303	4·45
December	232	569	2·45	94	325	3·45	160	215	1·34	68	178	2·54
Total and average Index	1496	2946	1·96	377	1255	3·32	2748	6361	2·31	1209	5932	4·9

XI. PREVENTIVE MEASURES.

The routine preventive measures adopted consist of removal of patients to hospital, segregation of contacts, house-to-house inspections, keeping all fever cases under observation, disinfection of the building including the use of a pulicide (crude petroleum or a mixture of kerosine and cyllin), removal of the roof to let the sun in, sulphur fumigation of rat runs by means of Clayton machines, blocking up of rat holes with broken glass, bricks, etc., and cement mortar, cleansing and limewashing of the premises generally including search for rat nests and dead rats, evacuation of insanitary tenements in infected areas pending the carrying out of structural improvements, closure of wholesale rice stores in infected areas, steam disinfection of second-hand clothes prior to despatch upcountry, capture and poisoning of rats, bacteriological examination of rats, estimation of flea index.

The danger associated with the rat infested privately owned wholesale rice stores has been greatly mitigated by the action of Government in erecting up-to-date rat proof warehouses for the storage of rice, and prohibiting the transport of rice upcountry from the insanitary rice stores in the town.

Fairly early in the course of the outbreak a supply of anti-plague vaccine was obtained from Bombay, and its use was widely advocated. Almost immediately, however, the wildest stories as to the danger of its use began to circulate, set afoot, it is believed, by persons operating for ulterior motives, with the result that a panic ensued amongst the cooly classes who began to bolt to India in such large numbers that a labour famine was threatened. Consequently all attempts to induce these people to be inoculated had to be abandoned.

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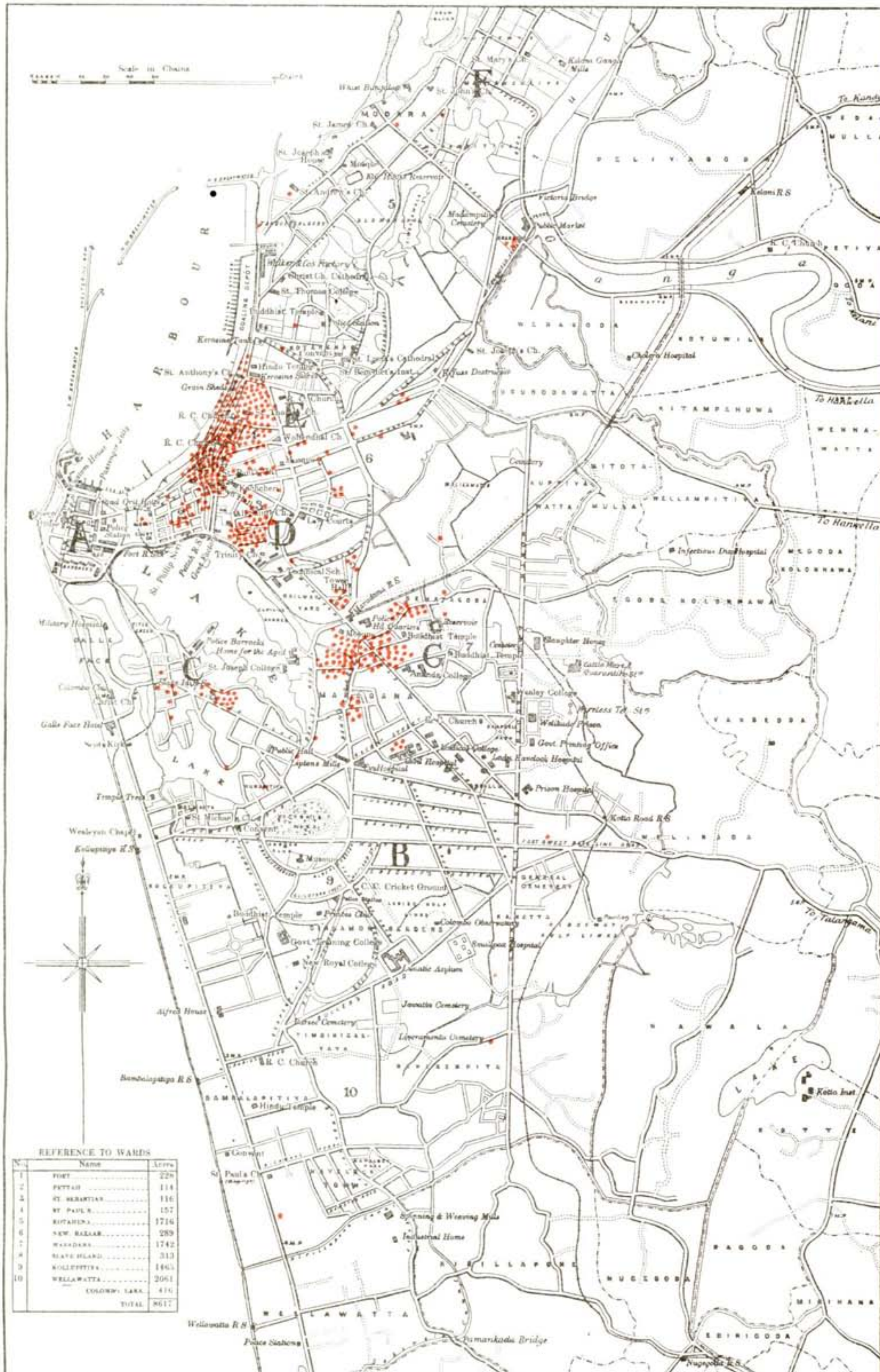

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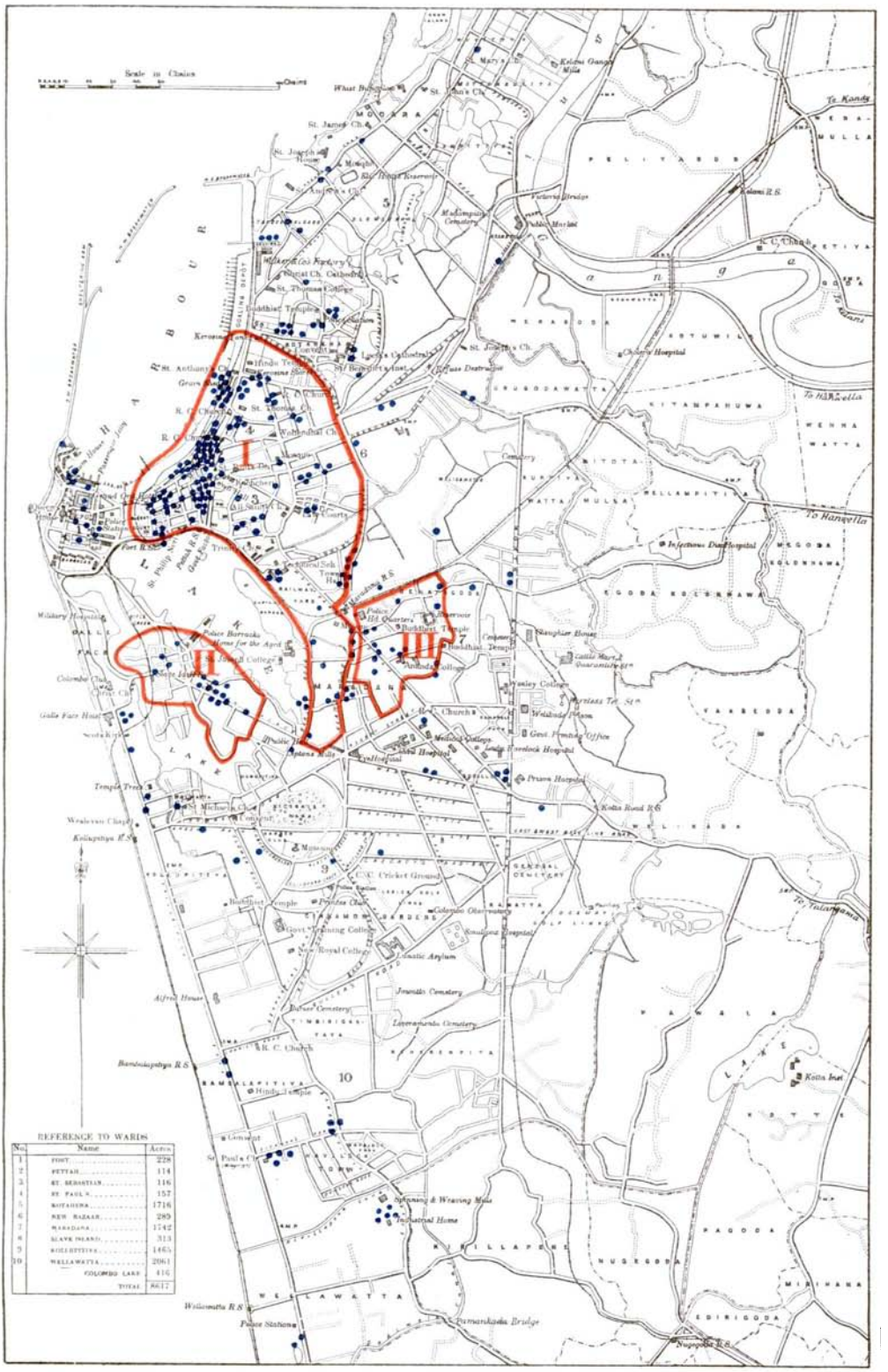

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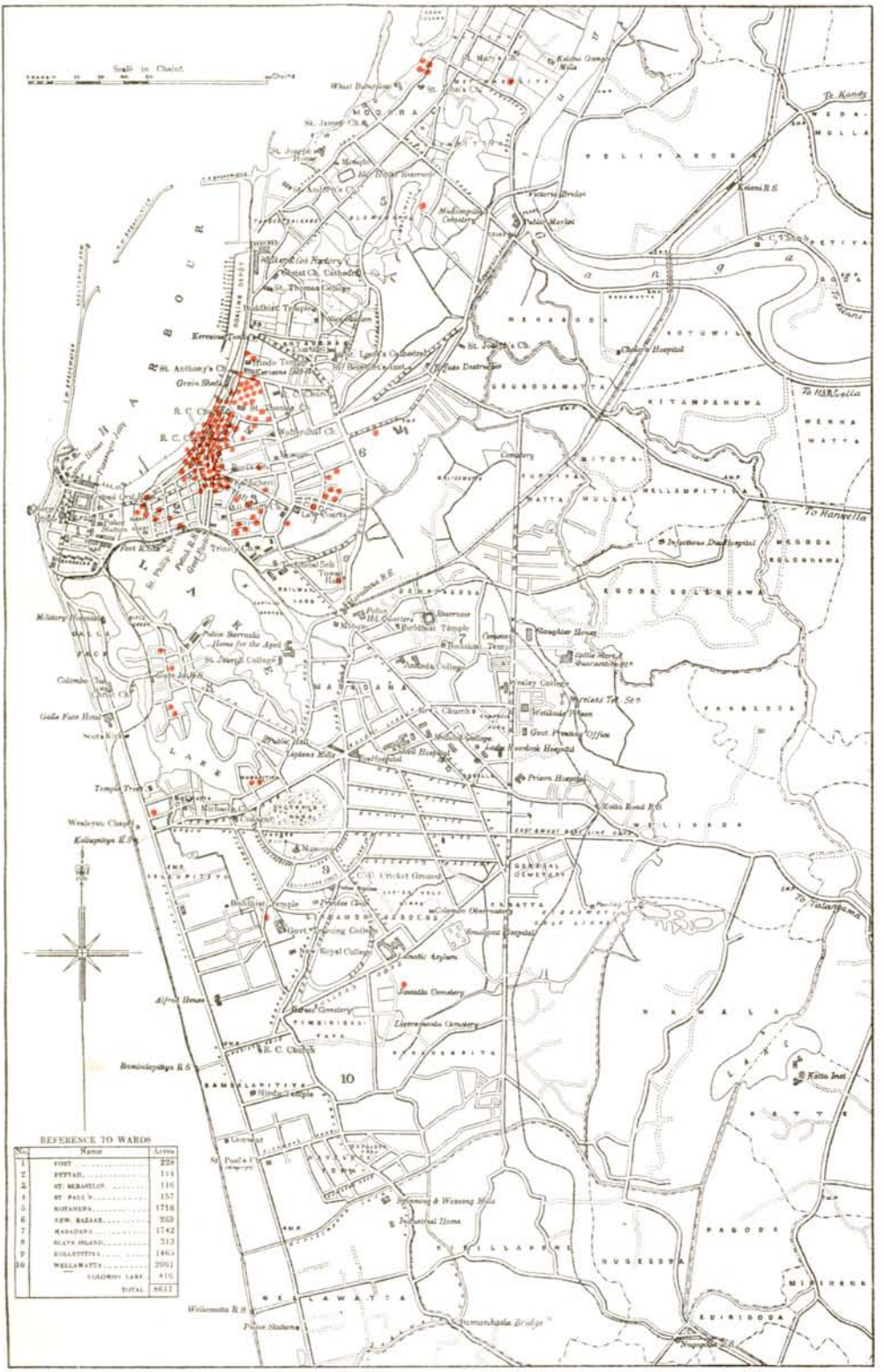

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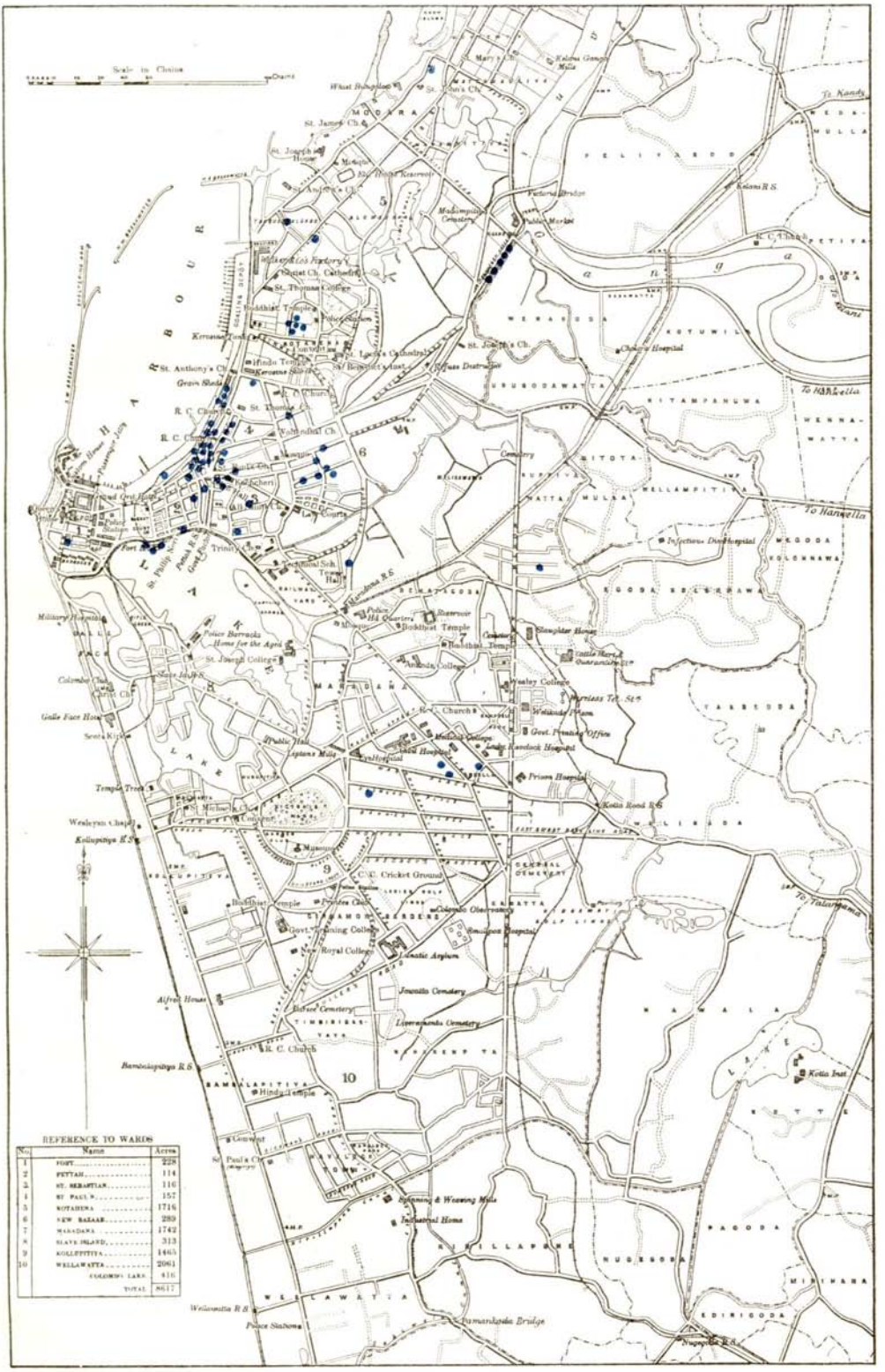

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