OBSERVATIONS ON THE EPIDEMIOLOGY OF BUBONIC PLAGUE, WITH SPECIAL REFERENCE TO THE REASON FOR ITS ABSENCE FROM GREAT BRITAIN IN SEVERE EPIDEMIC FORM SINCE THE MIDDLE OF THE SEVENTEENTH CENTURY.

by

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C O N T E N T S .

C O N T E N T S (Cont.)

INDEX TO TABLES.

I. to XX.

INDEX TO TABLES (Cont.)

I. INTRODUCTION.

(a) Showing how great epidemics have had their origin in ship-borne infection.

With the exception of the Justinian Plague which lasted in Britain from 664 to 685 and a doubtful record for 1010-11, English plague experience on a large scale is confined to a period of some 350 years, commencing with the importation of the Black Death, probably at Weymouth in 1348, and ending a few years after the Great Plague of London in 1665. Although the point cannot be regarded as settled, the majority of epidemiologists hold, I believe, that the origin of the present pandemic in India, the 1896 outbreak in Bombay, was probably ship-borne from Hong-kong. Again, according to Ashburton Thompson (1) plague which made its appearance in Australia at Sydney in 1900 and recurred each year till 1909 was the result of not continuous but repeated infection.

(b) Plague in Great Britain during the twentieth century.

The cases of plague occurring in this country since 1900 are set out in detail in Appendix I. (2) pages 65-68.

T A B L E I.

Showing number and type of cases of plague, also death rate and number of plague-infected ships occurring in Great Britain since 1900.

Total No. of cases of plague (including pneumonic cases)	126
Total No. of deaths.	61
Percentage of deaths from plague.	48.4%
Total No. of cases of bubonic plague.	109
Total No. of deaths.	45
Percentage of deaths from bubonic plague.	41.2%
Total No. of cases of pneumonic plague.	17
Total No. of deaths.	16
Percentage of deaths from pneumonic plague.	94.1%
Total No. of ships with human plague only.	11
do. do. rodent plage only.	11
do. do. human and rodent plague.	9

T A B L E II.

Showing months in which outbreaks of plague occurred in Great Britain. 1900 to 1929.

January.	3 (1 pneumonic)
February.	4 (1 pneumonic)
March.	2
April.	3
May.	4
June.	4 (1 pneumonic)
July.	4
August.	10
September.	6 (1 pneumonic)
October.	5 (1 pneumonic)
November.	3
December.	Nil.
Unknown.	3

T A B L E III.

Showing probable source of infection in the case of plague-infected ships.

Source of infection.	No. of plague-infected ships.	Percentage of plague-infected ships.	No. of cases of plague.	Percentage of cases of plague.
Egypt.	6	19.3	11	23.9
India.	14	45.1	28	60.8
West Africa.	1	3.2	Nil.	Nil.
River Plate.	7	22.5	6	13.04
Other Ports.	3	9.6	1	2.1

Appendix I. shows that all the cases, with the exception of those occurring in Suffolk County, occurred in seaport towns. Even these latter cases were thought to be due to an importation of infected rats in grain through the Port of Ipswich (3). From Table II. it will be seen that the majority of the outbreaks occurred in the late summer or autumn.

As might be expected in view of the continued prevalence of plague in India and the amount of trade carried on between the two countries, India constitutes our chief source of infection, and of all types of cargo, grain is the ideal vector as it affords both food and nesting for rats. Of the 31 vessels on which plague was found, 17 at least carried grain cargo.

It is seen, therefore, that although there has been repeated importations of plague at most of the large seaports in Great Britain, yet no epidemic on a large scale has taken place. This cannot be attributed entirely to the efficient preventive efforts taken at the ports. All the outbreaks have been sporadic in character and in no case has the disease spread beyond the neighbourhood where it made its first appearance. Ship-borne infection can be accepted as the cause of all the outbreaks. With the possible exception of the cases in Glasgow in 1900 and 1901 and in East Suffolk during 1910 and 1911, no cases have occurred in the same port in two successive years, except where it could be proved definitely to be a case of re-importation.

(c) Mode of spread of infection.

Although the study of the epidemiology of plague on modern scientific lines may be said to date from the discovery of B.pestis by Yersin and Kitasato in 1894; nevertheless throughout the literature (4) on bubonic plague there has been from the earliest times, repeated reference to mortality among rats and mice preceding plague in man. Within recent years investigators when cases of human plague have occurred have occasionally been perplexed at the inability to find plague-infected rats, as during the early part of the outbreak in Glasgow in 1900. Further careful search has usually revealed dead rats.

Ashburton Thompson (5) has drawn attention to the small number of plague-infected rats usually found on single premises: that is to say from three or four to half a dozen. Occasionally however, the number is large. The experience of most observers is that the progress of the disease among rats infesting any premises is usually quite slow. Our experience in the case of the s/s "TIRRENO" (vide p.42) bears out this statement. Moreover, the healthy rats on a plague-infected vessel do not become alarmed and desert the ship as soon as she reaches port.

The slow insiduous nature of the spread of the epizootic is well illustrated by the following outbreak which occurred at one of the dock warehouses in Hull (6). On the 25th. February, 1909, it was reported to the Medical Officer of Health that a number of dead rats had been found in No. 35 Shed at the Albert Dock. On further investigation 29 rats, recently dead, were found behind a number of bags containing maize which had been landed by lighter from the s/s "MIKADO" which arrived in Hull from Odessa on the 23rd. October 1908. Examination of the rats proved them to be plague-infected. It was ascertained that a cat had been found dead in the shed referred to, about two months previously, and prior to the 25th. February about 20 dead rats had been discovered one or two at a time.

The cat had been thrown into the River Humber. From the same shed between the 25th. February and the 12th. March about 45 dead rats and 58 rats trapped alive were examined and most of the dead rats were found plague-infected. No further plague-infected rats were found and no case of human plague occurred.

No reference is made to the species of the rats found,[x] but if, as was thought at the time, infected rats were imported from the s/s "MIKADO" in all probability a certain proportion of them at least were black. The features worthy of note are the limited extent of the outbreak although there was ample opportunity and time for extensive spread, and as one would expect in February and March the number of fleas must have been small, otherwise it is fairly certain the dock labourers would have been infected. The apparent ease with which the outbreak was stamped out in an area where there are plenty of rats and therefore, fleas, indicates that other factors must be considered.

A perusal of Appendix I. shows that of 46 outbreaks of bubonic plague recorded in Great Britain since 1900, infected rats have been found on 29 occasions.

It is now generally accepted that an interval elapses between the beginning of epizootics and the attack of man. Time must elapse before rats which are usually infected in such uninhabited places as wharves, etc. can sufficiently penetrate to the dwellings of man (7). Moreover, an interval is always observed even between the invasion of individual houses and the occurrence of cases in them. That this is so is substantially proved by the fact that in practically all cases where human plague is found, dead rats are found in an advanced stage of putridity in the house or in its immediate neighbourhood. These remarks of course do not apply to the sporadic cases which are contracted by dock labourers working on ships where plague exists among the rat population. It follows that where human plage has occurred in any of our ports in all probability plague-infected rats have been introduced into some warehouse during the spring or early summer. This is well illustrated by the cases of human plague at Naples (vide p. 49) which did not occur until September although plague-infected rats were known to have been introduced in June.

[x] The Sanitary Inspector who was in charge of the rat destruction at the time states that all the dead rats were of the black variety.

The work of the Indian Plague Commission (8) proved conclusively that the transmission of the plague bacillus from rat to rat, and from rat to man is effected through the agency of the rat-flea. Lethem (9) has put forward the theory that plague once introduced into a household is spread from man to man by Pulex irritans. However, as few of the human cases have been septicaemic in type it is difficult to conceive how the Pulex irritans becomes infected.

The evidence is greatly in favour of the view that its seat of election is the lymphatic system and the commonest mode of receiving the infection is by inoculation through the skin (10). In accordance with this view is Tidswell's (11) experience that the bacillus is rarely to be found in the peripheral blood stream before the agonal stage of the disease in which he agrees with the great majority of observers.

As Liston (12) has pointed out the epidemiology of pneumonic plague is altogether different from that of bubonic plague; the latter is essentially a disease of rodents. The disease may assume, though rarely, the pneumonic form in men who have been infected previously from rodents, and in these circumstances infection can be transferred from man to man in the absence of rodents. True bubonic plague, however, is almost always conveyed directly from rodents to men; the infection in these circumstances is acquired more or less rapidly as men are brought more or less in close propinquity to rodents.

II. FACTORS AFFECTING THE SPREAD OF BUBONIC PLAGUE.

(a) Climate.

(1) Has the climate of this country changed since the days of the Great Plague?

There has been much controversy regarding climatic changes in historical times, but as Simpson (13) points out there is little evidence for any appreciable change in temperature but that there is quite a mass of evidence for moderate changes in the amount of rainfall. It is clear that the historical period is much too short to show any appreciable part of the large but slow changes which give rise to the main changes of climate shown in the geological record and of which the ice age is the last example. He shows that the effect of changes in solar radiation are chiefly counterbalanced by a change in the general circulation of the atmosphere and increased cloud and precipitation rather than by large changes in the temperature. It is not surprising, therefore, that what fluctuations there have been, have been chiefly shown by fluctuations in rainfall; the best evidence of which is seen in the changed level of lakes without efflux, the changed boundaries of deserts and the relics of old cultivation in places where now cultivation is impossible. We see, therefore, that there has been no appreciable change of temperature in this country since the great pandemics of the past.

(2) Experimental evidence.

From observations carried out by the Indian Plague Commission (14) it was shown that the rise of the epizootic and in consequence of the human epidemic depends upon:-

(1) A suitable mean temperature somewhere below 85°F. and in general about 50°F.
(2) A sufficient number of susceptible rats.
(3) A sufficient number of rat fleas.

Climate, especially temperature and atmospheric humidity, influences the seasonal prevalence of plague in so far as it reacts on the life history and habits of the flea. Bacot (15) experimentally, has shown the greater susceptibility to low temperatures on the part of X.cheopis than in the case of P.irritans and C.fasciatus. In all stages, save the imaginal, low temperatures below 45°F. were fatal to X.cheopis.

The mean midwinter temperatures at British seaports, which vary from 36-45°F. are, therefore, unsuitable for breeding X.cheopis.

(3) Epidemiological considerations.

Today we find that bubonic plague is confined to an area between 40° North and 40° South Latitude, together with districts about the Mediterranean and Black Sea. Yet we know that bubonic plague in its present form spread over Northern Europe during the seventeenth century and was as virulent in the north as in the south.

(b) Change in the type of rat found in British Port Sanitary Districts.

During the great epidemic of plague in Britain during the seventeenth century, the black rat (Mus rattus) was chiefly prevalent. The brown rat (Mus norvegicus) began to invade England early in the eighteenth century, about 1728 (16), and soon almost entirely replaced its smaller and weaker rival. The brown rat in towns is found chiefly in sewers, docks, slaughter houses, granaries, etc. In the country it lives in burrows in the hedgegrows and ditches and in hay ricks. Briefly, it is timid of man and chooses an outdoor life, whereas the black rat is a more domesticated animal and prefers the warmth of houses and grain stores on the dockside. Liston (17) drew attention to the importance of this difference in the mode of life of the two species in the spread of plague.

More recently, Reece (18), from rat returns furnished by four of the principal ports, London, Liverpool, Hull and Cardiff, has stated that the rat population of this country has undergone a further change which points to the fact that rats from abroad have gained means of entrance into our ports and the black rat is now to be found in many of the docks and port towns of England. In Hull of 1,903 rats caught on quays, wharves and warehouses during the years 1928-29, 358 were black and 1,545 were brown rats.

(c) Social conditions, housing, sanitation etc.

Housing and social conditions are vastly different today from what they were in the days of the Great Plague. It is stated that in the seventeenth century each house in London had its quota of black rats.

Although the best type of dwelling house today can be regarded as rat-proof and street cleansing and refuse disposal are carried out on a systematic basis, there are still in the older parts of our seaport towns, houses little better than those which existed almost three centuries ago.

(d) How does B.pestis maintain itself during quiescent periods.

One of the most striking characteristics of plague once it has become endemic in a locality is its seasonal prevalence. At or about the same date it yearly reappears, rises, declines and disappears. In populous centres the disease commonly disappears for at least six months.

It was at first thought possible that the infection might remain latent in the form of chronic plague in rats. The conclusion of the Indian Plague Commission (19) was that the pathological appearances at first thought to be "chronic plague" were stages in the process of recovery from the acute disease and should be named more appropriately "resolving plague". It is generally accepted that the plague bacillus does not survive for more than a few days outside the bodies of men, animals or fleas. As evidence of the continuance of the disease by acute plague, Blue (20) cites the fact that at San Francisco, on tearing up wooden flooring and similar harbouring places, extensive catacombs were found, in many cases containing large numbers of rodent cadavers. These he states varied from fresh bodies to mummified carcases showing that the epizootic had ranged over a considerable time. In almost all such cases in which bacteriological examination was possible they were found to have died of plague. This would appear to indicate that plague epizootics were continued in inaccessible and undiscovered places. In support of this view is our experience in the case of the s/s "TIRRENO" where rats in varying degrees of putridity and mummification were thought to have been shot into the holds with the grain and been the origin of the plague epizootic found on the ship.

Although the matter cannot be regarded as finally settled the trend of the work done up to the present on the subject would appear to indicate that the epizootic continues in an abated form during the "off plague season" and when the flea prevalence increases once more the epizootic and thereafter the epidemic recurs. Outbreaks in new places must be regarded as due to importation of the infection.

(e) Type of rat-flea which spreads plague.

Following on the work of the Indian Plague Commission, Cragg (21) and Hirst (22) showed that the predominant flea in the immune areas of India and Ceylon was Xenopsylla astia and not Xenopsylla cheopis. This led to the assertion that the presence or absence of X.cheopis is the determining factor in the infectibility of any port. Both fasciatus and astia may exceptionally transmit plague from rat to rat as was shown by the Indian Plague Commission (23) and later by Taylor and Chitre (24), but the mass of epidemiological evidence is convincing that in nature this does not occur with sufficient frequency to maintain an epidemic. It will be shown (vide p. 49) that although plague-infected rats were ship-borne from the same source, and almost simultaneously, in the early summer of 1929 to Hull, Hamburg and Naples, only at Naples and in September did two cases of human plague occur.

From observations throughout the world Mus norvegicus appears to be the natural host of C. fasciatus just as Mus rattus is that of X.cheopis. Hirst (25) has put forward the view that X.astia was originally the indigenous rat-flea of the plains of India and the tragedy of the spread of plague in India as in Ceylon, Japan and Australia, followed upon the gradual extension of the area within which this flea is indigenous on rats.

If X.cheopis is regarded as the only rat-flea worthy of consideration in the spread of bubonic plague under natural conditions; the corrolary is that it was the indigenous flea of this country during the 350 years during which plague prevailed here. No concrete evidence can be adduced to show that this was so. However, we know that M.rattus was the common rat in this country and also that it is the natural host of X.cheopis. Moreover, Hirst (26) has shown that the indigenous flea of Ceylon has changed during the present century from X.astia to X.cheopis coincident with the arrival of plague for the first time in that country.

The experience of plague in Glasgow (27) during 1900 and 1901 is of particular interest as illustrating several factors influencing the spread of plague to which attention has been drawn in the preceding and succeeding paragraphs. In August and September, 1900, thirty-six cases of plague were recognised in the city. The origin of the disease could not be discovered, but the first cases occurred in a house occupied by a dock labourer. All the subsequent cases were more or less

associated with one another and arose chiefly from three houses in which wakes were held over the bodies of the individuals who died of plague in the houses. Although some 236 rats were caught in the infected area, many of them in and about the infected houses and were examined bacteriologically, none were found infected. In the following year during August, a group of five cases mainly associated with a rag factory situated in the area infected in the previous year, came under notice. On this occasion a single plague-infected rat was discovered. However, five weeks after the occurrence of the last case of the five just referred to, a new group of five plague cases came to light in another part of the city. Here dead rats were found in association with and antecedent to, each of the cases; some of these rats were proved bacteriologically to be infected with plague. Further investigation showed that plague-infected rats existed in a number of adjoining premises, for example in the basement of certain tea-rooms. A rat warren was also discovered in another situation which gave a bag of 65 rats; 13 of these were dead, the remainder were killed and among them no less than 40 were found infected with plague. The epizootic was thus shown to be fairly widely distributed throughout the city. Plague-infected rats continued to be found in Glasgow during the next two years at irregular intervals though no cases of human plague were discovered or notified in connection with this epizootic. According to R.M.Buchanan (28) 150 rats were found infected and of these the great majority were M. norvegicus, but a few obtained near the docks belonged to the species M.rattus. Reviewing the outbreak - the largest which has occurred in Great Britain during this century - in the light of our present day knowledge, it can be accepted reasonably that it had its origin in plague-infected black rats from a ship gaining access to some warehouses on the dockside. During the early summer months of 1900 the epizootic must have spread until in August, which we know to be the month when fleas are most prevalent - a dock labourer becomes infected - the first of 36 cases. Nothing more happens until August of the following year when a further 10 cases occur. This is one of the exceptional occasions when plague appeared in the same area of the same city in two successive years. To account for this we must assume that X.cheopis using M.rattus as a host found particularly favourable circumstances for breeding during the winter months. We know that during the summer of 1901 the epizootic had become fairly widespread yet no further case occurred. This was no doubt due

to the fact that the colony of black rats had been either exterminated by disease or by the brown rats. If C.fasciatus is of equal importance in the spread of plague there appears no reason why the epizootic and therefore, the epidemic should not have been much more prolonged and assumed much more serious proportions.

It would appear that in this country the mode of life of M.norvegicus in addition to being unfavourable for the spread of plague by reason of its outdoor existence is unfavourable for the persistence of X.cheopis, whereas, M.rattus as a host provides the flea with a habitat wherein it is able to survive the winter months.

If we compare the Glasgow outbreak to that which took place in Australia (29), we find that the beginning was very similar. The definiet history of plague in Australia commenced on the 19th. Jan. 1900, when a carman, regularly employed in carrying goods from city warehouses in Sydney to Central Wharf, Sydney, fell ill with bubonic plague. From New South Wales the disease spread to Victoria, Queensland, South Australia and Western Australia, and was present each year until 1909. The total number of cases in Australia for the whole period of ten years was 1,212. From the first appearance of plague at Sydney in 1900 to the 31st. Dec. 1920, 316,632 rodents were examined. Of these 98,399 or 31.08% were M.norvegicus, 121,002 or 38.21% M.rattus and 97,229 or 30.71% M.musculus: and of 1,135 found infected with plague 397 or 34.98% were M.norvegicus, 567 or 49.96% M.rattus and 171 or 15.06% M.musculus. Both species of rats are equally susceptible to plague infection. From 1909 to 1920, 152,611 rodents have been examined for fleas at Sydney and on these 10,498 fleas were found; 5,290 or 50.39% were X.cheopis, 1,597 or 15.21% C.fasciatus and 3,611 or 34.39% L.musculi.

Glasgow is in 55°N. Lat. and Sydney in 33°S. Lat. but we know that the difference in temperature alone cannot be accepted as a satisfactory explanation of the marked difference in the result in the two cities, as plague spread in Glasgow in the seventeenth century: the housing conditions are not essentially different, but whereas X.cheopis is the common flea in Sydney, C.fasciatus, as will be shown in the next section of this report, is the common flea in British seaports apart from shipping.

(f) Plague among mice and domestic animals.

Some of the earlier writers (30) on plague were of opinion that domestic animals such as cats, dogs, pigs, poultry, cattle sheep, etc. died of plague and this received support from experiments by Simpson and Hunter (31) in Hong Kong in 1902. However, after very full investigation the Indian Plague Commission (32) came to the conclusion

that plague in domestic animals either does not occur or occurs so seldom that it cannot be said to possess any significance from an epidemiological standpoint.

It is, however, beyond question that outbreaks in mice are not infrequently to be found concurrently with the rat epizootic. This occurred in the case of the s/s "TIRRENO" (vide p. 42). The common flea on the house mouse (Mus musculus) in Great Britain is Ctenopsylla musculi, although occasionally C.fasciatus has been found (33). Martin and Rowland (34) during their investigations into the outbreak on pneumonic plague in East Suffolk in 1910 found 2 plague-infected rabbits out of 40 examined. From the same group of rabbits 115 fleas were obtained, of which 113 were Spilopsyllus cuniculi, the common rabbit flea, and 2 were Ceratophyllus fasciatus. During the same outbreak plague-infected hares were also found. Presumably the rabbits and hares were infected from plague-infected rats which were found in the same neighbourhood at the same time.

(g) Dispersion of fleas by means of merchandise, grain and clothes in the absence of their host.

It can be regarded as an undisputed fact that merchandise, grain, etc. which have been visited by rats may have fleas deposited on them and these fleas may be transferred with these articles to distant places. This may reasonably be regarded as the cause of the accidental sporadic cases of human plague which have occurred from time to time in this country especially amongst persons working in rag factories, grain warehouses, etc. where no plague-infected rats have been found. However, as was pointed out by the Indian Plague Commission (35) adult fleas in the absence of any host to feed on rapidly die and generally in about 5 days. Nevertheless, larvae, since they can feed upon almost any kind of organic rubbish and pupae which require no food, can be carried considerable distances in merchandise, i.e. for periods as long as 1 or 2 months. The larvae and pupae so carried would in the course of time develop into adult insects, other circumstances being favourable, but would then require a host to feed upon. In the absence of a suitable host they will perish within a fortnight of the time of their developement into the adult or imago state. However, as has been already pointed out Bacot (36) subsequently showed that the temperature of this country is unsuitable for the persistence of X. cheopis.

(h) Cheopis Index as a measure of infectibility.

In America (37) the cheopis index, i.e. average number of X.cheopis per live rat disregarding all other species of fleas is now commonly used to estimate the infectibility or otherwise of a port. The critical cheopis index is the lowest average number of X.cheopis per rat necessary for plague to spread from rat to rat in an increasing ratio. If we accept the cheopis index as giving some idea of the infectibility of a port we must next consider what is to be regarded as the critical index.

As a result of experiments carried out by the Indian Plague Commission (38) in order to determine the minimal number of infected fleas necessary to infect a healthy rat, it was found that even when B. pestis contained in infected fleas is highly virulent no infection is likely to take place when their number is less than five. As a practical figure this is much too high. A priori it is only reasonable to suppose that all the fleas are not in constant attendance on their host. Many will remain in the nest of the rat and many will be dropped on and picked up from cargo from time to time, thus even the most careful combing can give only an approximation to the number of fleas per rat. The result of our experience of the examination of nests for fleas is reported in its appropriate place, (vide pp. 40-41)

Grubbs (39) points out that in New Orleans where plague has occurred the average number of cheopis per rat was nearly 3 in May and June 1916 and was 1.71 per rat in the 12 months beginning 1st. July 1921. In Pensacola, Florida, in 1921 the year in which 36 plague-infected rats were found the average number of cheopis per rat was 6.1. In New York an examination of 4,756 rats over a 22 months period gave a cheopis index of 0.2165, and only in one month did this exceed 1. (Oct. 1923) when it was 1.25. In Boston 1922-23, 1,524 rats gave a cheopis index of 0.8 per rat. Practically all the figures so far available indicate that as we go north the number of cheopis decreases and that it is usually less than one per rat north of 40° North Latitude. Empirically, therefore, it would appear than one cheopis per rat is a suitable working critical cheopis index.

III. RAT-FLEA SURVEY OF PORT OF HULL.

(a) Aim of investigation.

This investigation was undertaken with the purpose of ascertaining the infectibility or otherwise of Hull as estimated by the cheopis index. Owing to the limited staff of rat catchers our efforts for the first year were confined to ships entering the port, later some work was undertaken on the dock estate and in the city.

(b) Methods.

Live rats were caught in wire cage traps and transported to the laboratory in the traps in which they were originally captured. No canvas covering was placed on the traps during transport as it was found that on occasions fleas left the rats and were found on the covering. A wooden box with a glass top, movable on a hinge, was used as a chloroforming chamber (40). In one end of the box a round hole was cut which could be closed by a sliding partition through which the rats could pass from a cage trap. At the other end of the box a similar hole was cut. Over this hole on the inside a piece of copper gauze was nailed. On the outside over the hole a nose-piece similar to that covering a camera lens was fixed. When a rat was to be chloroformed the nose-piece was removed and in it was placed a piece of cotton wool saturated with chloroform before it was replaced. The interior of the box was painted white. As soon as the rat had entered the box the slide was dropped and the opening of the trap closed if there was more than one rat in the trap. Only one rat was chloroformed at a time. As soon as the rat was dead, as observed through the glass top, it was removed from the box and heavy forceps was clamped about the neck to prevent resuscitation, following which it was combed with a fine tooth comb for fleas on a table covered with white paper. After the chloroforming of each rat the box was inverted over a sheet of white paper and rapped sharply to shake out any fleas that might be in the box. The next rat was introduced into the box and chloroformed whilst the first rat was being combed. Fleas and other ecto parasites were preserved in 80% alcohol and examined without clearing under the misroscope. The fleas from each rat were placed in small tubes containing 80% alcohol and labelled with a reference number. If there was any doubt as to the identification of the fleas they were cleared in potassium hydroxide, passed through water and alcohol to xyol and finally mounted in balsam on a slide.

Each rat was autopsied but no evidence of plague was found. The number of foetuses in the case of pregnant females was recorded.

1. SHIPS.

(a) Gross Results.

This part of the survey was commenced on the 1st. July 1929 and completed on the 30th. June 1930. During this period traps were set on 410 ships arriving at Hull from all parts of the world, and 1,862 rats were trapped alive, and on these 2,142 fleas were caught.

(b) Species of rat found.

Of the 1,862 rats trapped, 940 or 50.4% were Mus rattus, 907 or 48.7% Mus alexandrinus, and 15 or .8% Mus norvegicus. It has been the experience of observers throughout the world that practically a hundred per cent of rats found on board ship are of the black variety, which includes M.rattus and its cousin M. alexandrinus.

(c) Sex and Breeding.

In the case of the 940 M.rattus, 500 or 53% were females, and of the 907 M.alexandrinus, 530 or 58% were females. This preponderance of the females is in accordance with the experience of observers in various parts of the world, although the percentage in the case of M.alexandrinus is rather high. No useful observations can be made on the small number of M.norvegicus found.

From Table V. it will be seen that of 1,030 female rats of the species M.rattus and M.alexandrinus, 240 were pregnant, and yielded 1,538 foetuses or 6.4 per pregnant female. The largest number of foetuses in any one rat was 13. In Table VII. are presented the monthly proportions of pregnant rats and the average number of embryos. It will be observed that multiplication on ships takes place fairly evenly throughout the year, although from the figures presented M.alexandrinus would appear to be more fertile than M.rattus.

The detailed findings month by month are shown in Table V.

(d) Type and sex of fleas found and species of rat on which they were found.

Of the 2,142 fleas examined, 1,625 or 75.9% were Xenopsylla cheopis, 492 or 22.9% Ceratophyllus fasciatus, and 25 or 1.2% Leptopsylla musculi. In the case of all species of fleas found the females were preponderant.

of 1,625 X.cheopis, 994 or 61% were females, similarly 492 C.fasciatus showed 299 or 61% females, and of 25 L.musculi 14 or 56% were females.

From Table VI. it will be seen that no particular flea showed preference for any particular type of rat as a host.

(e) Influence of Temperature and Relative Humidity on Total Flea Index and Cheopis Index.

The rats and fleas caught month by month with the temperature and relative humidity are shown in Table IV. The figures given are the mean monthly temperature and mean monthly relative humidity as recorded at the meteorological station in the centre of the city: whereas the rats and their fleas have been caught chiefly in the holds of ships, where temperature and humidity are likely to be influenced in many ways, e.g. adjacency to the boiler-room, type of cargo and climate of the last loading port.

Temperature readings were taken in the holds of ships and the results recorded in diagrammatic form on pages 33-35. The method employed was to insert an earth thermometer into the grain at various points and take the highest temperature observed over a 15 minutes insertion at each point. The marked difference between the temperature on the quayside and that found in holds will at once be observed. Unfortunately no readings were taken during winter months, when it is fairly certain that the difference would be even more marked.

A perusal of the results, Table IX. shows that fleas taken from rats captured on ships from all parts of the world are fewer in winter than in summer, although many of the ships have come from the southern hemisphere and passed through all shades of temperature. Hence it follows that it is the temperature at the port of discharge which is the chief factor. It is clear that the flea catch varies with the temperature. Humidity does not appear to be an influence in this country.

The cheopis index or the average number of Xenopsylla cheopis per live rat during the period was .87. The number of rats caught during the months of August, April and June are abnormally low compared with the other months, and therefore, cannot be regarded

as fair average. However, it is evident that the cheopis index is highest during the summer months from July to October and as we have seen the majority of the cases of plague which have occurred at seaport towns in this country in the last thirty years have occurred during these months.

Diagram IV. shows the cheopis index, total flea index, mean temperature and relative humidity charted month by month.

Perhaps a truer index of the months when rats have the greatest number of fleas is shown in Table VIII. Again, however, it is seen that July to October are the months during which fleas are most prevalent.

(f) Species of rat-flea found on the various Trade Routes.

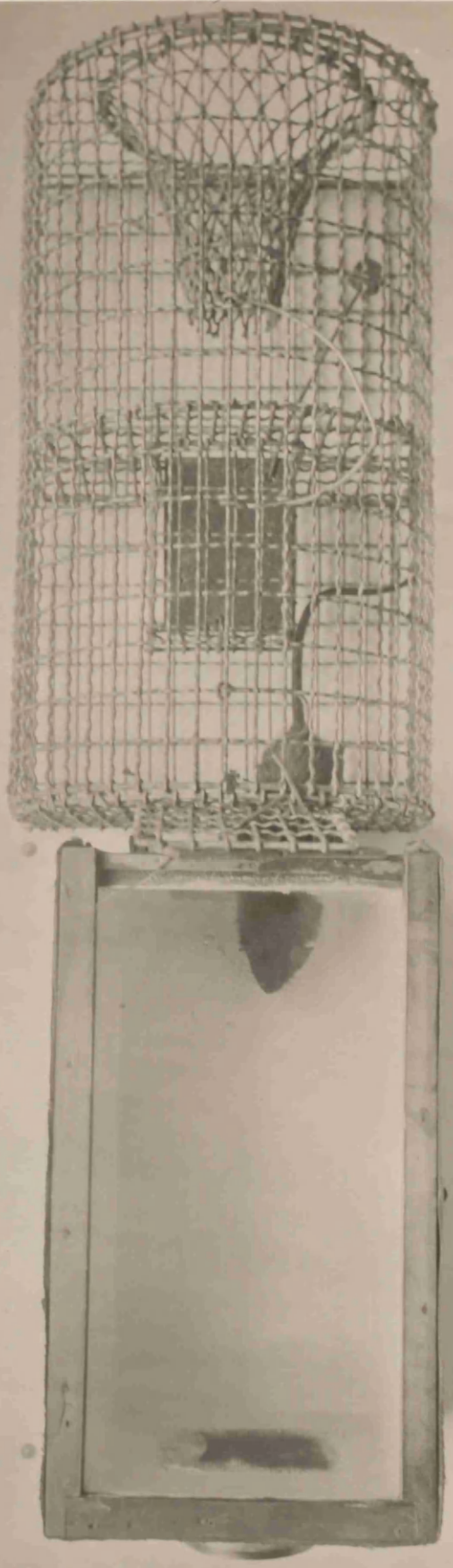
It is obvious that the small number of ships included in this enquiry coming from certain parts of the world renders any statistical observations of little value. However, a summary of fleas taken on ships coming from ports within 40°N. and 40°S. Latitude, gives a cheopis index of .93 and a fasciatus index of .21, whereas the fleas taken on ships from ports outside this area give a cheopis index of .32 and a fasciatus index of .69. This is in agreement with our knowledge that the indigenous flea of Europe and North America is C.fasciatus, whereas X. cheopis is the common flea in tropical and sub-tropical countries.

When we come to investigate the results on ships coming from countries which have been shown as the result of experience to be the principal sources of infection we find that of 101 ships from River Plate Ports and the Argentine on 54 of these rats were found, giving a cheopis index of 1.2 and a fasciatus index of 2.6. From the West Coast of Africa 33 ships were examined and on 16 of these rats were found, giving a cheopis index of 1.06 and a fasciatus index of .07. Forty-one vessels from the North Coast of Africa gave 13 ships with rats and a cheopis index of 1.21 and a fasciatus index of .21. The results of the investigation of 54 vessels from India showed only 14 with rats and a cheopis index of .25 and a fasciatus index of .14. The unusual figures in the case of ships from India cannot be taken as the true cheopis index. The number of ships investigated is too small and moreover the main line of ships trading between India and Hull are very good

class and are fumigated frequently as shown by the small percentage having rats.

On only 3 out of 20 ships from Australia were rats caught and the cheopis index given for this trade route must be regarded as unreliable.

I think that sufficient has been said to demonstrate clearly that on ships trading within the plague belt the predominant flea is X.cheopis and on ships trading outside this area C.fasciatus is the prevailing flea.



Box used for chloroforming Rats and Fleas.
The method is illustrated.

TABLE IV.

RAT AND FLEA CATCH BY MONTHS SHOWING THE CHEOPIS INDEX AND THE FASCIATUS INDEX TOGETHER WITH THE MEAN TEMPERATURE AND THE MEAN RELATIVE HUMIDITY.

Month.	No. of rats caught.	No. of rats having fleas.	Percentage of rats having fleas.	Number and species of Flea found.										Total No. of fleas.	Total flea index.	Fasciatus index.	Cheopis index.	Mean Temperature.	Relative Humidity.
				[1] X.c.		[2] C.f.		Ct.c.[3]		L.m.[4]		E.g.[5]							
				m.	f.	m.	f.	m.	f.	m.	f.	m.	f.						
1929. July.	171	82	47.9	82	90	67	75	-	-	4	9	-	-	327	1.9	.96	1.0	62	72%
August.	81	47	58.02	147	222	9	25	-	-	-	-	-	-	403	4.9	.41	4.5	61	77%
September.	236	90	38.1	91	119	21	27	-	-	4	1	-	-	263	1.13	.20	.89	60	77%
October.	204	81	39.7	103	214	35	53	-	-	-	1	-	-	406	1.9	.43	1.5	49	80%
November.	269	56	20.7	59	125	15	33	-	-	-	-	-	-	232	.8	.17	.68	43	84%
December.	172	31	18.0	16	53	10	8	-	-	-	-	-	-	87	.5	.10	.40	42	84%
1930. January.	129	39	30.2	43	46	5	15	-	-	-	-	-	-	109	.8	.15	.69	43	85%
February.	115	26	22.6	16	40	1	2	-	-	-	-	-	-	59	.5	.02	.48	40	83%
March.	211	29	13.7	29	28	2	7	-	-	-	-	-	-	66	.3	.04	.27	42	78%
April.	41	8	19.5	16	22	1	5	-	-	2	2	-	-	48	1.17	.14	.92	46	79%
May.	159	45	28.3	25	24	18	29	-	-	1	1	-	-	98	.6	.29	.3	50	74%
June.	74	23	31.08	4	11	9	20	-	-	-	-	-	-	44	.59	.39	.2	57	76%
Totals.	1862	557	29.91	631	994	193	299	-	-	11	14	-	-	2142	1.15	.26	.87	-	-

1. Xenopsylla cheopis.
2. Ceratophyllus fasciatus.
3. Ctenocephalus canis.
4. Leptopsylla musculi.
5. Echidnophaga gallinacea.

TABLE V.

DISTRIBUTION OF RATS BY MONTHS.

Month.	Total No. of rats.	MUS RATTUS.								MUS ALEXANDRINUS.								MUS NORVEGICUS.								Percentage of rats having fleas.
		Adult male.	Young male.	Total male.	Adult female.	Young female.	Total female.	Pregnant female.	No. of foetuses.	Adult male.	Young male.	Total male.	Adult female.	Young female.	Total female.	Pregnant female.	No. of foetuses.	Adult male.	Young male.	Total male.	Adult female.	Young female.	Total female.	Pregnant female.	No. of foetuses.	
1929. July.	171	46	33	79	33	27	60	19	130	4	7	11	10	10	20	2	18	1	-	1	-	-	-	-	-	47.9
August.	81	17	5	22	8	6	14	2	11	17	3	20	13	8	21	5	31	1	-	1	3	-	3	2	12	58.02
September.	236	10	5	15	9	7	16	3	19	44	38	82	54	68	122	29	169	1	-	1	-	-	-	-	-	38.1
October.	204	41	13	54	58	27	85	23	164	17	6	23	29	12	41	10	71	-	-	-	1	-	1	-	-	39.7
November.	269	31	3	34	41	9	50	7	40	71	6	77	94	14	108	30	197	-	-	-	-	-	-	-	-	20.7
December.	172	41	5	46	57	3	60	8	48	31	-	31	35	-	35	9	61	-	-	-	-	-	-	-	-	18.0
1930. January.	129	25	-	25	34	-	34	3	15	26	1	27	39	-	39	17	102	2	-	2	2	-	2	-	-	30.2
February.	115	34	7	41	44	8	52	10	63	6	-	6	13	-	13	4	23	1	-	1	2	-	2	1	12	22.6
March.	211	44	-	44	46	-	46	8	52	52	-	52	69	-	69	24	143	-	-	-	-	-	-	-	-	13.7
April.	41	13	1	14	18	1	19	2	12	3	-	3	4	1	5	2	12	-	-	-	-	-	-	-	-	19.5
May.	159	25	18	43	26	18	44	5	36	18	13	31	25	15	40	9	60	-	-	-	1	-	1	-	-	28.3
June.	74	16	7	23	12	8	20	3	16	11	3	14	15	2	17	6	45	-	-	-	-	-	-	-	-	31.08
Totals.	1862	343	97	440	386	114	500	93	606	300	77	377	400	130	530	147	932	6	-	6	9	-	9	3	24	29.91

T A B L E VI.

TYPES OF FLEA FOUND AND SPECIES OF RAT ON WHICH THEY WERE FOUND.

Species of Rat.	No. of rats caught.	Percentage of total No. of rats caught.	No. of fleas caught.	Percentage of total No. of fleas caught.	Species of Flea.			Cheopis index.	Fasciatus index.
					X.c.	C.f.	L.m.		
Mus rattus.	940	50.4	1216	56.8	922	277	17	.98	.294
Mus alexandrinus.	907	48.7	910	42.5	688	214	8	.75	.235
Mus norvegicus.	15	.8	16	.8	15	1	-	1.0	.06

TABLE VII.

The proportion of pregnant rats (based on the total number of rats - males and females of each variety) and the average number of embryos, by months.

	Mus rattus.		Mus alexandrinus.	
Month.	Per cent pregnant.	Average number of embryos.	Per cent pregnant.	Average number of embryos.
1929.				
July.	13.6	6.8	6.5	9.0
August.	5.6	5.5	12.2	6.2
September.	9.7	6.3	14.1	5.8
October.	16.5	8.0	15.6	7.1
November.	8.3	5.7	16.4	6.6
December.	7.5	6.0	13.6	6.8
1930.				
January.	5.1	5.0	25.7	6.0
February.	10.8	6.3	21.0	5.7
March.	8.9	6.5	19.9	6.0
April.	6.0	6.0	25.0	6.0
May.	5.8	7.2	12.7	6.7
June.	7.0	5.3	19.3	7.5
	9.9	6.5	16.2	6.4

T A B L E VIII.

SHOWING THE COMPARATIVE DISTRIBUTION OF THE FLEAS IN GROUPS OF FIVE AND TEN ON RATS CAUGHT MONTH BY MONTH.

No. of Fleas.	0.	1-5	6-10	11-15	16-20	21-30	31-40	41-50	51-60	61-70	71-80
1929. July.	89	61	12	6	1	2	-	-	-	-	-
August.	34	19	15	7	3	2	-	-	-	1	-
September.	146	79	11	-	-	-	-	-	-	-	-
October.	123	64	10	5	1	-	-	-	-	-	1
November.	213	44	12	-	-	-	-	-	-	-	-
December.	141	28	3	-	-	-	-	-	-	-	-
1930. January.	90	37	1	1	-	-	-	-	-	-	-
February.	89	25	1	-	-	-	-	-	-	-	-
March.	182	28	1	-	-	-	-	-	-	-	-
April.	33	5	2	-	1	-	-	-	-	-	-
May.	114	42	3	-	-	-	-	-	-	-	-
June.	51	23	-	-	-	-	-	-	-	-	-
Totals.	1305	455	71	19	6	4	-	-	-	1	1

TABLE IX.

SHOWING THE RELATIVE FLEA PREVALENCE ACCORDING TO SPECIES ON DIFFERENT TRADE ROUTES.

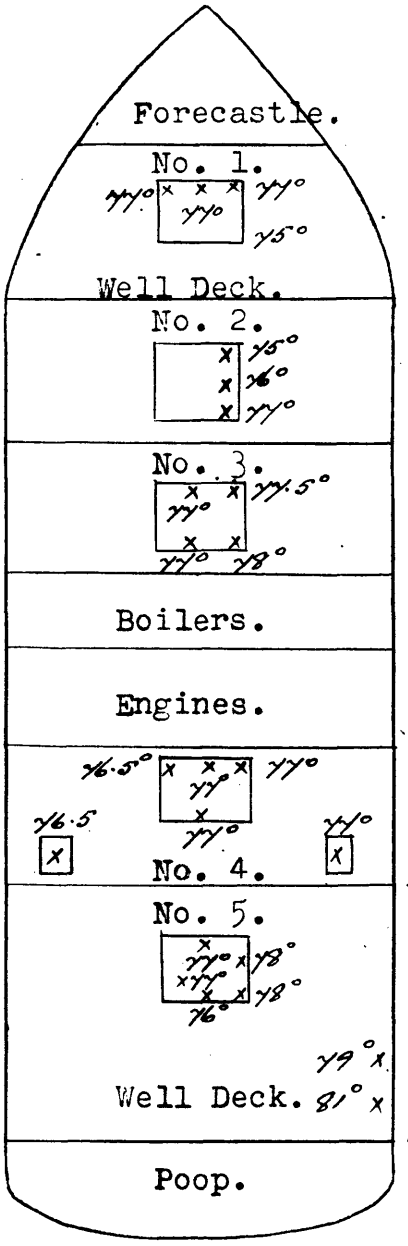
Region. (Within 40° N. & S. Lat)	No. of ships.	No. of ships with rats.	No. of rats caught.	Variety of Rat.			No. of fleas caught.	Variety of Flea.					Total flea index.	Cheopis index.	Fasciatus index.
				M.R.	M.A.	M.N.		X.cheopis.	C.fasciatus.	L.musculi.	Ct.canis.	E.gallinacea,			
River Plate Ports and the Argentine.	101	54	684	327	352	5	1009	824	182	3	-	-	1.47	1.2	.26
West Coast of Africa.	33	16	101	75	26	-	116	108	8	-	-	-	1.14	1.06	.07
South Coast of Africa.	23	15	330	177	151	2	217	130	74	13	-	-	.65	.39	.22
East Coast of Africa.	2	2	12	7	5	-	16	16	-	-	-	-	1.3	1.3	-
North Coast of Africa. (including Alexandria)	41	13	190	72	117	1	276	230	40	6	-	-	1.45	1.21	.21
India.	54	14	158	95	63	-	63	40	23	-	-	-	.39	.25	.14
Australia.	20	3	28	7	20	1	169	166	3	-	-	-	6.03	5.9	.1
Far East, (China, Japan, Manchuria, Malay States, South Sea & Pacific Isles)	29	7	37	12	24	1	25	23	2	-	-	-	.67	.62	.05
Levant, (Greece, Cyprus,etc)	4	4	25	24	-	1	23	13	10	-	-	-	.92	.52	.4
West Coast of the U.S.A.	10	1	-	-	-	-	-	-	-	-	-	-	-	-	-
East Coast of the U.S.A.	9	8	94	32	62	-	18	7	11	-	-	-	.19	.07	.11
West Coast of South America.	7	1	1	-	1	-	2	-	2	-	-	-	2.0	-	2.0
East Coast of South America (excluding River Plate Ports & Argentine)	5	1	1	1	-	-	-	-	-	-	-	-	-	-	-
North Coast of South America.	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
West Indies.	6	1	3	1	2	-	3	3	-	-	-	-	1.0	1.0	-
Totals.	346	140	1664	830	823	11	1937	1560	355	22	-	-	1.16	.93	.21

T A B L E IX. (Continued)

Region. (Outside 40° N. & S. Lat.)	No. of ships.	No. of ships with rats.	No. of rats caught.	Variety of Rat.			No. of fleas caught.	Variety of Flea.					Total flea index.	Cheopis index.	Fasciatus index.
				M.R.	M.A.	M.N.		X.cheopis.	C.fasciatus.	L.musculi.	Ct.canis.	E.gallinacea.			
Black Sea Ports.	16	12	49	24	24	1	34	13	21	-	-	-	.69	.26	.42
Mediterranean Ports, (Italian Ports, etc)	3	3	5	-	2	3	-	-	-	-	-	-	-	-	-
Canada.	8	2	22	18	4	-	2	-	2	-	-	-	.08	-	.08
Baltic, Norwegian & White Sea Ports.	21	12	76	36	40	-	151	36	112	3	-	-	1.98	.47	1.47
Greenland.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Continental Ports.	7	4	5	4	1	-	-	-	-	-	-	-	-	-	-
South Atlantic.	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
British Ports.	7	6	41	28	13	-	18	16	2	-	-	-	.43	.39	.04
Totals.	64	39	198	110	84	4	205	65	137	3	-	-	1.03	.32	.69

DIAGRAM I.

Diagram showing temperature in the holds of the s/s "MATRONNA" King George Dock, Hull, as compared with the temperature taken on the Quayside, on the 22nd. and 23rd. August, 1930. The ship arrived at Hull on the P.M. tide, 21st. August, 1930, from Theodosia (Black Sea) with a cargo of grain in bulk.



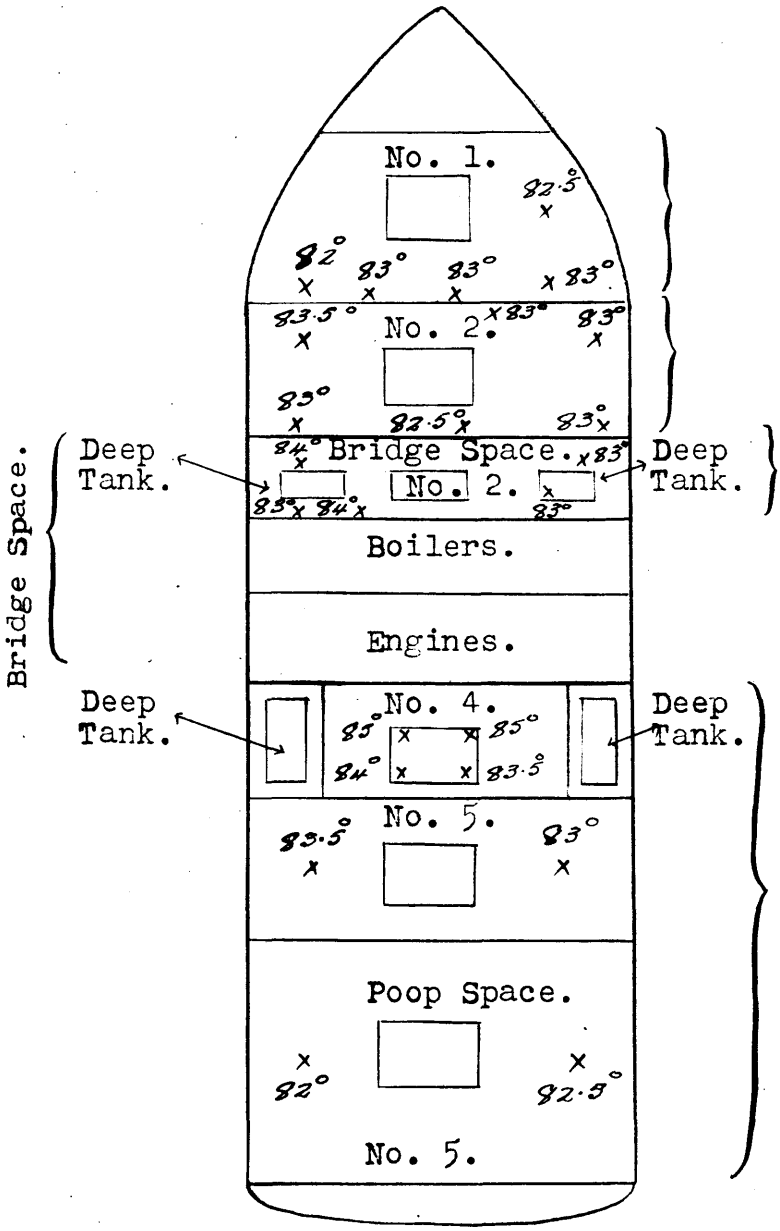
Temperatures taken in this space between 7 and 7.30 am. 23/8/30, with shade temperature reading 51°F.

Temperatures taken in this space between 10 and 11.0 am. 22/8/30. with shade temperature reading 60°F.

Temperatures taken in this space between 5 and 5.30 pm. 22/8/30. with shade temperature reading 60°F.

DIAGRAM II.

Diagram showing temperature in the holds of the s/s "TABARISTAN", King George Dock, Hull, as compared with the temperature taken on the Quayside on the 28th. and 29th. August, 1930. The ship arrived at Hull on the P.M. tide 27th. August, 1930, from Abadan, with a cargo of grain in bulk.



Temperatures taken in Tween Deck 28/8/30 between 10 and 11.0 am. with shade temperature reading 80°F.

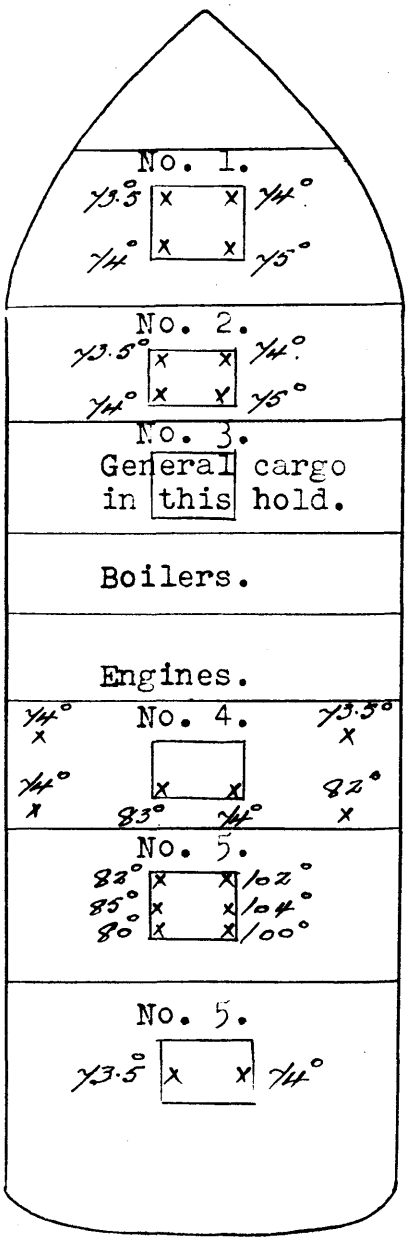
Temperatures taken in lower hold 29/8/30 between 10 and 11.0am. with shade temperature reading 77°F.

Temperatures were taken inside port tank but only at coamings level in starboard tank, between 10 and 11.0 am. 28/8/30.

Temperatures taken in No. 4. Hold 29/8/30. between 10 and 11.0 am. at the level of the coamings to the lower hold. Those in No. 5. are readings from the lower hold.

DIAGRAM III.

Diagram showing temperature in the holds of the s/s "SIMONBURN", King George Dock, Hull, as compared with the temperature taken on the Quayside, on the 1st. September, 1930, between the hours of 10.15 am. and 11.30 am. with the shade temperature reading 66°F. The ship arrived at Hull on September 1st. from Buenos Aires with a cargo of maize in bulk.



Temperatures taken at coamings' level.

Temperatures taken at coamings' level.

Shelter Deck.

Temperatures taken in hold. The maize at these points was obviously in a "heated" condition.

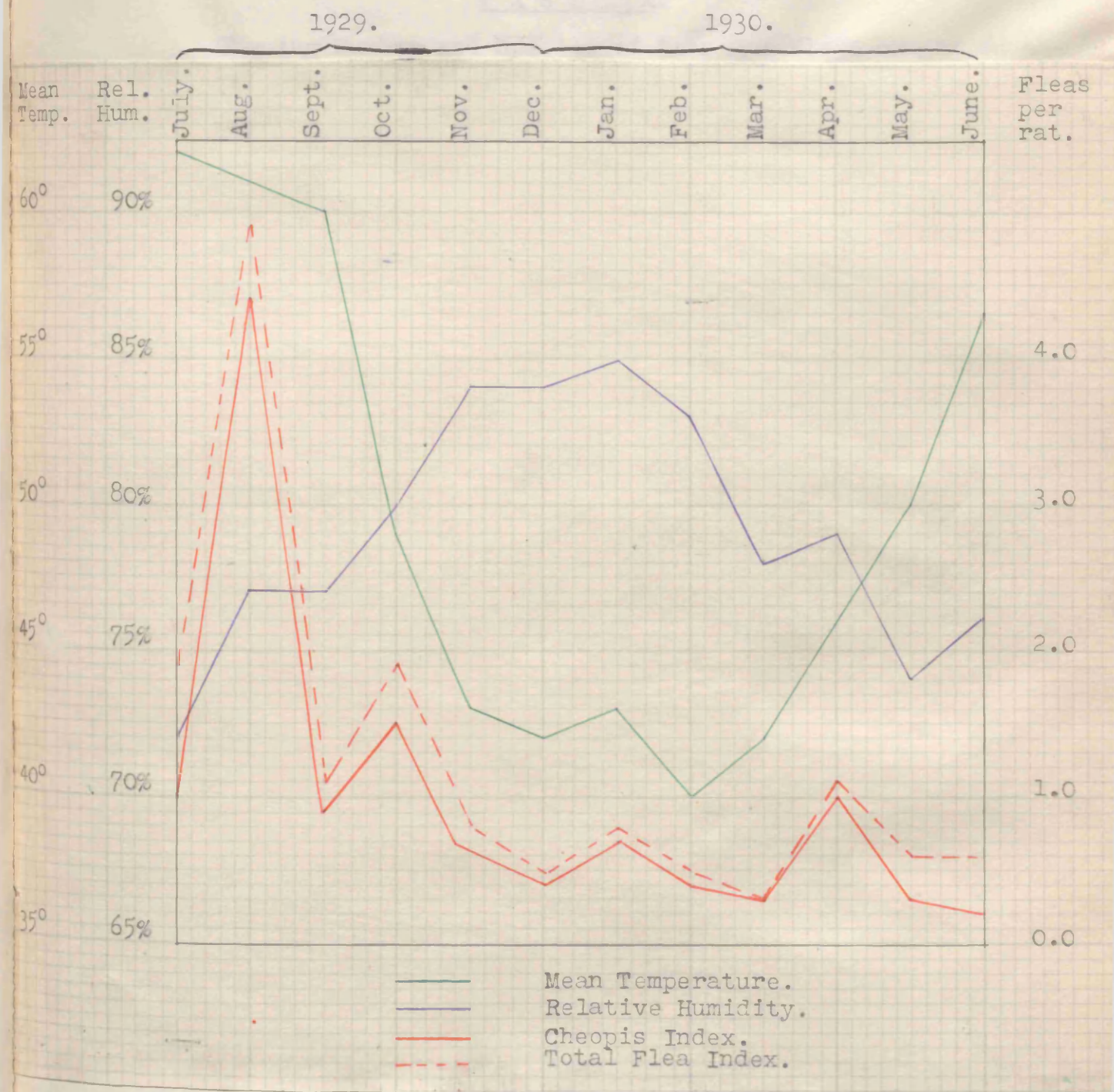
Temperatures taken at coamings' level. These excessive temperatures were obviously due to the "heated" condition of the maize.

Temperatures taken at coamings' level.

This vessel has no Tween Decks.
A double layer of bagged maize lay over the bulk cargo in each hold.

D I A G R A M IV.

GRAPHS SHOWING THE AVERAGE MEAN TEMPERATURE, THE AVERAGE RELATIVE HUMIDITY, CHEOPIS INDEX AND TOTAL FLEA INDEX BY MONTHS.



2. DOCK ESTATE.

This area includes all warehouses and land included within the dock boundaries.

Trapping was carried out from the 1st. August till the 30th. September 1930.

T A B L E X.

Showing Number and Species of Rats and Fleas caught on the Dock Estate, Hull, during August and September 1930.

Species of Rat.	No.of rats.	Species of Flea. Xenopsylla cheopis. m.	f.	Ceratophyllus fasciatus. m.	f.	Ctenocephalus canis. m.	f.
Mus rattus.	13	1	6	28	44	-	-
Mus alexandrinus.	7	-	-	3	6	-	-
Mus norvegicus.	42	4	4	77	94	-	1
	62	5	10	108	144	-	1

From Table X. it will be seen that 62 rats were caught alive and of these 20 or 32% were either M.rattus or M.alexandrinus. This is in accordance with the statement made earlier in this paper that the black rat is gaining a footing in wharves, quays and warehouses in British seaports. This was to be expected in view of our findings that practically all the rats found on ships were of the black variety. Of 268 fleas found on these rats, 15 were X.cheopis, 1 Ct.canis and the remainder C.fasciatus.

T A B L E XI.

Showing Species of Rats and where caught on which X.cheopis were found.

Date. 1930.	Species of Rat. M.R. m.	f.	M.A. m.	f.	M.N. m.	f.	Place.	X.cheopis. m.	f.
Aug.9th.	-	-	-	-	1	-	No.2.W. K.Dk.	2	-
" 18th.	-	-	-	-	-	1	E.D. K.Dk.	-	1
" 19th.	-	-	-	-	1	-	B.S. K.Dk.	1	-
" 21st.	1	-	-	-	-	-	No.2.W. K.Dk.	1	6
Sep.3rd.	-	-	-	-	1	-	S.& H. O.H.	-	1
" 4th.	-	-	-	-	1	-	do.	1	-
" 5th.	-	-	-	-	-	1	do.	-	1
" 9th.	-	-	-	-	1	-	do.	1	-
	1	-	-	-	5	2	-	6	9

It will be observed from Table XI. that of the 15 cheopis, 8 were found on 7 M.norvegicus and 7 on 1 M.rattus.

Although statistical observations on such small numbers must be regarded as unsatisfactory the overwhelming preponderance of C.fasciatus is at once apparent. The total index is 4.3 fleas per rat and the cheopis index .24.

As an adjunct to this work guinea-pigs were used as flea-traps. Four guinea-pigs were employed and were placed for seven day periods in wooden cages in various warehouses throughout the docks. Unfortunately two died of pneumonia. During the last week the two survivors were allowed to run free in warehouses. The results of combing are shown in Table XII.

T A B L E XII.

SHOWING SPECIES OF RAT-FLEAS CAUGHT ON FOUR GUINEA-PIGS USED AS FLEA-TRAPS IN WAREHOUSES ON HULL DOCKS.

GUINEA-PIG NO. 1.

Date. From.	Date. To.	Place where laid.	Material stored in warehouse.	Observations.	No. of fleas.	Species of Flea. X.c. m.	X.c. f.	C.f. m.	C.f. f.
2/7/30	9/7/30.	No. 22 Warehouse, Alexandra Dock.	Old bags.	Warehouse not rat-proof.	1	-	1	-	-
15/8/30	22/8/30.	No. 1. Warehouse, King George Dock.	Dunnage (old wood, etc)	Warehouse rat-proof; concrete floor.	3	-	-	-	3
30/8/30	6/9/30	Saner & Harrison's Warehouse. Old Harbour.	Grain.	Warehouse not rat-proof.	-	-	-	-	-
13/9/30	20/9/30	ditto.	Grain.	ditto.	3	-	-	2	1
20/9/30	27/9/30	Crown Warehouse. Old Harbour.	Grain.	ditto.	4	-	-	3	1
6/10/30	10/10/30.	No. 29. Warehouse. Alexandra Dock.	Cow hair.	Warehouse not rat-proof. Guinea-pig running free.	3	-	-	-	3
			GUINEA-PIG NO. 2.						
8/8/30	15/8/30	No. 4. Warehouse, King George Dock.	Oats and bags.	Warehouse rat-proof; concrete floor.	2	-	-	2	-
20/9/30	27/9/30	No. 22. Warehouse, Alexandra Dock.	Old bags.	Warehouse not rat-proof.	4	-	-	3	1
6/10/30	10/10/30	No. 29. Warehouse, Alexandra Dock.	Cow hair.	Warehouse not rat-proof. Guinea-pig running free.	4	-	-	2	2
			GUINEA-PIG NO. 3.						
6/9/30	13/9/30	John Good & Sons, Warehouse, Old Harbour.	Rags, ropes and provisions.	Warehouse not rat-proof. Guinea-pig died in laboratory from pneumonia 23/9/29.	-	-	-	-	-
			GUINEA-PIG NO. 4.						
13/9/30	20/9/30	Wilberforce Warehouse, Old Harbour.	Grain.	Warehouse not rat-proof.	3	-	-	1	2
20/9/30	26/9/30	ditto.	Grain.	Warehouse not rat-proof. Guinea-pig died on the dock from pneumonia 26/9/30.	9	-	-	3	6

3. CITY.

The whole city, with the exception of the dock estate, as previously defined, is included in this zone.

The routine method of rat destruction is by means of dogs and ferrets. Trapping is only used on a small scale, hence the number of live rats available was limited. From the 1st. August to the 30th. September 1930 all rats either dead or alive were brought to the laboratory for identification. During this period 67 dead rats, all of which belonged to the species M.norvegicus, and 31 live rats of which 8 were black, were found.

T A B L E XIII.

Showing Number and Species of Rats and Fleas caught in the City of Hull during August and September 1930.

Species of Rat.	No.of rats.	Species of Flea. Xenopsylla cheopis.		Ceratophyllus fasciatus.	
		m.	f.	m.	f.
Mus rattus.	7	-	-	-	-
Mus alexandrinus.	1	-	-	-	-
Mus norvegicus.	23	3	4	13	10
	31	3	4	13	10

Only live rats were combed and as will be seen from Table XIII. on these, 30 fleas were caught: comprising 23 C.fasciatus and 7 X.cheopis. The latter as shown in Table XIV. were found on 3 brown rats trapped at some distance from the docks.

T A B L E XIV.

Showing Species of Rats and where caught on which X.cheopis were found.

Date.	Species of Rats. M.R.		M.A.		M.N.		Place.	X.cheopis.	
1930.	m.	f.	m.	f.	m.	f.		m.	f.
Aug.8th.	-	-	-	-	-	1	S.H.E.	2	3
" 12th.	-	-	-	-	-	1	M.S.	1	-
" 18th.	-	-	-	-	-	1	24 C.A.	-	1
	-	-	-	-	-	3	-	3	4

In addition 5 nests were brought to the laboratory, and in these were found 33 young M.norvegicus and 11 fleas,

10 of which were C.fasciatus and 1 X.cheopis.

T A B L E XV.

Rat Nests.	Material used in construction of nest.	No. of rats in nest.	Species of Flea. Xenopsylla cheopis. m.	f.	Ceratophyllus fasciatus. m.	f.
No. 1.	Straw & paper.	7 M.N.	-	-	3	4
No. 2.	ditto.	6 M.N.	-	-	-	-
No. 3.	Straw,paper, rags & soil.	12 M.N.	1	-	1	2
No. 4.	Paper.	3 M.N.	-	-	-	-
No. 5.	Paper & straw.	5 M.N.	-	-	-	-

Even such a limited survey proves convincingly that C.fasciatus is the preponderant species of flea on rats found in the city. The 31 rats examined gave a total flea index of 1.0 and a cheopis index of .22

In this case, of a total of 103 rats identified only 8 or 7.7% were black. Of these 8 rats, 6 were found in a second-hand clothes shop some distance from the docks. Further traps were set in this shop and 4 M.norvegicus found. It is of interest to note that 6 C.fasciatus were found on these 6 black rats. Of the other two one was found in a chemist's shop in close proximity to the docks, and other in a banana crate in a warehouse near the docks. It is apparent, therefore, that black rats from time to time find their way in small numbers into the city.

Our experience, as one might expect, is that the number of black rats and X.cheopis decreases as we depart further from ships lying in the docks.

IV. DERATISATION OF SHIPS.

In the foregoing paragraphs attention has been drawn to the following points:

1. X.cheopis is the only flea which need be considered under natural conditions in the spread of bubonic plague.
2. M.rattus or M.alexandrinus is the natural host of X.cheopis.
3. Although M.norvegicus is the common rat throughout Great Britain, M.rattus and M.alexandrinus are found in considerable and apparently increasing numbers in quays, wharves and warehouses at British seaports, and form almost a hundred per cent of the rats found on board ships.
4. Rat-fleas can be transported in merchandise, clothes, etc. apart from their host and sporadic cases of human plague have occurred from plague-infected fleas being carried in this way.

All these facts indicate the desirability of destroying the black rat and its fleas at the point at which it can be most readily destroyed in bulk, and this is on board ships before the removal of the cargo. From a preliminary survey of the holds as soon as the hatch covers are removed, by the amount of excreta, whether old or recent, rat runs, damage to cargo, rat markings, trapping etc. an experienced rat searcher can now give a very accurate estimate as to whether or not there is a large rat population on a ship.

It has generally been accepted as a well established fact that a vessel cannot be deratised in an effective fashion while the cargo is in situ.

At Hull during the years 1929 and 1930 one ship on which plague-infected rats were found and three others on which the existence of plague amongst the rat population was suspected, were fumigated with hydrogen cyanide with cargo in the holds. Careful records were kept of the action taken and findings in each case. These are set out herewith.

A. Fumigation of ships with cargo in the holds.

(1) s/s "TIRRENO". This ship arrived at Hull from Rosario via Dakar on the 30th. March 1929. Her voyage had been:-

	Arrived.	Departed.
Barry Docks.	-	January 1st.
Buenos Aires.	February 7th.	February 19th.
Rosario.	February 20th.	February 22nd.
Dakar.	March 15th.	March 16th.
Hull.	March 30th.	April 20th.
Cardiff.	April 23rd.	-

She is an Italian vessel of registered net tonnage 2,633 and a crew of 34. The cargo consisted of wheat, maize and linseed. On removal of the hatches prior to the working of the cargo, a rat catcher found several dead rats in various stages of decomposition. Macroscopic and microscopic examination of one or two of the rats revealed the fact that some of them were plague-infected. An order was served on the Master asking him to make arrangements to have the ship fumigated forthwith with hydrogen cyanide.

The arrangements for fumigation were put in the hands of a Hull firm and the "Galardi" system was used. The essential principle is the use of liquid hydrogen cyanide in small glass bottles - similar to the ordinary soda-water bottle. The procedure consisted in removing the stopper and pouring the requisite amount of liquid into the compartment. Each bottle contained 100 grammes and it is usual to allow 100 grammes per 2,000 cubic feet of space; but in view of the importance of this particular fumigation an allowance of 2 hours per 1,000 cubic feet and an exposure of six hours were required. Every compartment in the ship was fumigated.

The advantages claimed for the system are:

(a) Safety in handling and less risk to the operator.
(b) The quantity of gas used can be exactly determined.
(c) Very simple and quick manipulation so that hundreds of small spaces such as cabins, cupboards, etc. can be quickly fumigated.
(d) No sudden evolution of gas with consequent risk to the operator.

As the liquid was poured on top of the grain in the holds and as unfortunately rain came on during the time of ventilation, concern was felt lest any of the hydrogen cyanide should be absorbed by the grain. A certificate was supplied by the fumigators to the effect that not only were the compartments free from gas but that no quantity of hydrogen cyanide likely to be dangerous to life remained in the grain. At the same time samples of the cargo were taken for analysis.

The fumigation took place on the evening of Thursday, April 4th. and the discharge of cargo was re-commenced on Monday, April 8th.

A sample of the liquid hydrogen cyanide was submitted to chemical analysis and was found to contain 89% of real hydrogen cyanic acid by weight.

Samples of foodstuffs were taken from the cargo after the fumigation by liquid hydrogen cyanide and submitted to chemical analysis.

Two samples of whole wheat and one sample of linseed proved to be satisfactory and to contain merely negligible traces of hydrocyanic acid.

The whole linseed was appreciably contaminated with hydrocyanic acid, there being about 120 parts per million; but having regard to the treatment which linseed generally undergoes in the manufacture of linseed cake etc. it was unlikely that any untoward results could follow the use of this material.

The supervision of the discharge of cargo was carried out by placing a sanitary inspector to watch each two shutes. An attempt was made to use small mesh chicken wire over the top of the shutes but it was found to be unworkable because the meshwork soon became blocked with string from bags etc.

A rat catcher attended each day and collected all rats in a canister containing paraffin oil. Table XVI. shows the catch day by day:-

T A B L E XVI.

Date.	Decomposed Rats.	Mummified Rats.	M.R. (freshly dead)	M.R. (live or killed by violence)	M.A. (freshly dead)	M.A. (live or killed by violence)	M.N. (freshly dead)	M.N. (live or killed by violence)	Rats Examined.	Totals.	
1929. April 2nd.	3	-	2	-*	-	-	-	-	2	5	‡
3rd.	1	-	-	1*	-	-	-	-	1	2	‡
8th.	-	-	24	-	1	-	-	-	2	25	§
9th.	-	-	17	-	-	-	-	-	-	17	§
10th.	-	21	32	-	-	-	-	-	-	53	§
11th.	-	11	33	-	-	-	-	-	-	44	§
12th.	-	22	7	-	-	-	-	-	-	29	§
13th.	-	4	-	-	-	-	-	-	-	4	§
15th.	-	47	-	-	-	-	-	-	-	47	§
16th.	1	5	-	1†	1	1†	1	-	4	10	§
17th.	3	10	-	-	-	-	-	-	-	13	§
18th.	8	11	-	-	-	-	-	-	1	19	§
20th.	-	-	2	-	-	-	1	-	3	3	//
	16	131	117	2	2	1	2	-	13	271	

* Trapped alive.
† Killed by violence.
‡ Before fumigation. Total 7.
§ After fumigation by H.C.N. (Galardi method) Total 261. of which 12 were decomposed and 131 mummified.
// After fumigation by Zyklon B. Total 3.

All cargo was discharged by late on the 18th. April and arrangements were made for the second fumigation to be commenced early on the following day. On this occasion *Zyklon B. was used as the method of fumigation. Zyklon B. is packed in various sized tins labelled with the available H.C.N. content in grammes. The tins are rolled in cardboard and grease paper to prevent damage from knocking together and to avoid rust. The requisite tins were placed in position beside each compartment and with a hammer and special opener each tin was opened and a rubber cap placed on. The corner of the tarpaulin in the case of the holds was turned aside and the material emptied into the hold, or in the case of compartments sprinkled on the floor and the door sealed up. The fumigating personnel wore gas masks specially designed for use with this material. Great pains were taken to see that the ship was properly prepared before this second fumigation; all stores, dunnage, etc. were moved and the bilges were thoroughly opened up.

In this case the equivalent of 2 ounces of available H,C.N. per 1,000 cubic feet and an exposure of six hours to the fumigant were required. Only three dead rats were found after the operation.

The accompanying chart and tables show the details of the findings, and it will be observed:-

(1) That only one rat was found in the neighbourhood of the forecastle, and this was the only rat trapped alive on the ship and was not plague-infected. The risk run by the officers living in the deck houses was not great as the epizootic appears to have been confined chiefly to the holds which were covered with tarpaulin and battened down, and thus practically flea-proof. Of the other possible points of infection no dead rats were found in the food storerooms, and although after the first fumigation twelve freshly-dead rats were found in the bunkers it is quite possible that the rats emerged from No. 2. Hold as the result of the fumigant, as it is unlikely rats woudl prefer coal to grain for nesting and food, and these compartments are only separated by a wooden bulkhead.

(2) That where old grain was present the number of rats is greatest and the mummified state of the carcases would seem to point to the fact that they had been dead some considerable time, and also as practically all the mummified rats were found mixed up in the bulk grain and under such circumstances that they did not appear to have died in situ, it would appear that they had been shot into the ship with the grain.

*Zyklon B. consists of a highly absorbent inert material (kieselguhr) saturated with liquid hydrogen cyanide which has added to it a proportion of a very powerful lachrymant or tear gas.

(3) That a large percentage of the rats were mummified, or in such an advanced state of decomposition as to render diagnosis by macroscopic appearances, or by smears from the spleen impossible.

A rat apparently freshly dead was found in the bilges two days before the discharge of the cargo was completed. A smear from the spleen of this rat showed abundant B. pestis.

(4) That one rat was trapped alive, two were killed by violence, and three were found freshly dead after the second fumigation, and in none of these was plague diagnosed. From observations the conclusion was reached that the possibility of finding bacillus pestis in smears from the spleens from active live rats is rather remote. Briefly, the bacteraemia from which the rats die leads to death in a few days and for most of that time the rat is sick and unlikely to run about in a normal way and thus be trapped alive.

(5) Only two brown rats were found on the vessel, and although both were submitted to bacteriological examination, neither showed evidence of plague. One must leave to surmise how they arrived on board. Did they gain access by the ladder or gangway before the ship was placed in the middle of the dock or were they carted in with bags? This latter suggestion is unlikely as a careful watch was kept on everything coming aboard. They may, however, have come from the River Plate.

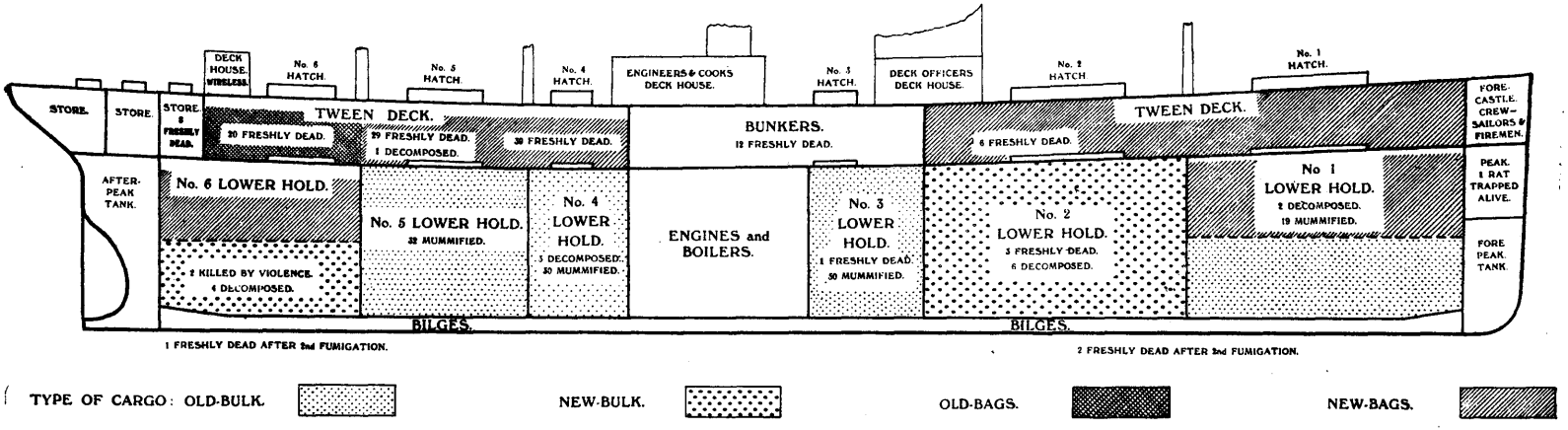
(6) The importance of visiting ships as soon as the holds are open in search for dead rats is demonstrated in the case of this particular ship.

(7) No live fleas were observed on any of the rats after the first fumigation. One would expect this as the lethal time is shorter and the dosage smaller for fleas than that required to kill rats by hydrogen cyanide.

(8) Even with the vessel practically fully loaded, and most of the grain in the holds in bulk, only three rats survived till the second fumigation.

(9) Lastly, but most important, there is the question as to whether or not there is any danger to human beings from the consumption of this grain in which plague-infected rats, and, therefore, plague-infected fleas have lived. Certain experiments carried out by the Indian Plague Commission help to answer this question. These experiments show:

DIAGRAM V.



TYPE OF CARGO: OLD-BULK. NEW-BULK. OLD-BAGS. NEW-BAGS.

s/s "TIRRENO" (Italian). Registered Tonnage: 2,633.

	Arrived.	Departed.
Barry Docks	—	January 1st
Buenos Aires	February 7th	February 19th.
Rosario	February 20th	February 22nd.
Dakar	March 15th	March 16th.
Hull	March 30th	April 20th.
Cardiff	April 23rd	—

	Previous to 1st Fumigation.	After 1st Fumigation.	After 2nd Fumigation.	Total.	Submitted to Bacteriological Examination.	Plague Infected.
Mus Rattus	6	126	2	134	8	4
Mus Alexandrinus	1	3	—	4	3	2
Mus ~~Decumanus~~ NORVEGICUS	—	1	1	2	2	—
Mummified Rats	—	12	—	12	—	—
Mummified Mice	—	119	—	119	—	—
Total	7	142 rats 119 mice	3	152 rats 119 mice	13	6

Cargo in Holds.

No. 1 Lower Hold. 2,192 bags Rosafe Wheat, new crop.
976 tons Rosafe Wheat, old crop
Tween Deck. Semelin Flour (bags).

No. 2 Lower Hold. 1,922 tons Rosafe Wheat, new crop.
Tween Deck. Linseed in bags.

No. 3 Lower Hold. 749 tons Rosafe Wheat, old crop.

No. 4 Lower Hold. 731 tons Rosafe Wheat, old crop.
Tween Deck. Linseed in bags.

No. 5 Lower Hold. 1,143½ tons Rosafe Wheat, old crop.
Tween Deck. 1,473 bags Yellow Maize, new crop.
452 bags Cing Maize, new crop.
1,849 bags Maize, old crop.

No. 6 Lower Hold 1,533 bags Rosafe Wheat, new crop.
861½ tons Rosafe Wheat, new crop.

(a) That the maximum time which rat fleas fed on septicaemic rats might remain infective was 15 days (41)
(b) That when plague bacilli were placed on the floors of houses they died off in a comparatively short period of time. After forty-eight hours it was not found possible to reproduce plague by inoculation with material from floors which had been grossly contaminated with cultures of the bacillus (42).

In this case, however, it is practically certain that all the rats and fleas were killed as the result of the cyanide fumigation, and, therefore, the spread of plague was very unlikely. Moreover, although it is known that bacillus pestis is found in large numbers in the faeces of infected fleas, having regard to the length of time which was likely to occur before the grain reached the consumer and that the usual mode of infection is by the bite of an infected flea and not by the ingestion of infected material, it can be definitely stated that the grain was perfectly safe for human consumption.

The following reports of plague at other ports in Europe read in association with the above cases are instructive.

"Rat Plague at Hamburg (43). On the 9th. April 1929, the Portuguese steamship "SAUDADES" coming from Rosario (Argentine) arrived at Hamburg with a cargo of cereals (Refuse grain). During the discharge of cargo on the 11th. April two dead rats were found which were ascertained on examination to be infected with the plague bacillus. Before the bodies of the suspected rats were discovered, part of the cargo had already been discharged on river craft which had left for the interior of the country, going up the Elbe, when the existence of rat plague was recognised. The competent authorities of the places of destination of these boats have been notified and all measures have been taken to prevent a spread of the plague infection. No human cases have occurred".

"Suspected Plague on Ship (44). Despatches received from the British Consuls at Venice and Trieste dated respectively, 19th. and 22nd. June, 1929, report that the s/s "CITY OF GANDIA" arrived at Trieste from Rosario with a cargo of grain on the 4th. June. Several dead rats were found which were examined bacteriologically with negative result. The ship was fumigated as a precaution and the crew and their effects were disinfected. Four coloured seamen were sent to hospital for observation for plague, but they were released before the departure of the vessel, which sailed from Trieste for Venice on the 11th.

June. On the 14th. June two Arabs from this ship were admitted to the isolation hospital at Venice with a diagnosis of suspected plague. The remainder of the crew, as well as those who had been associated with the ship from the shore were inoculated and the vessel was removed to the quarantine station where the remaining cargo is being discharged into lighters".

"Plague in Italy, (From the Italian Ministry of Foreign Affairs, Rome) (45). On the 25th. September, 1929, the High Commissioner of the Province of Naples stated by telegram that as a result of routine sanitary inspection of workmen labouring in the mills and in the food paste factories in all the communes of the Province of Naples, a suspected case of plague was notified in a workman at the "Savino" Mill situated in the territory of San Giovanni, at Teducio, in the Province of Naples. This workman was immediately transferred to the isolation hospital for infectious diseases. A second telegram dated 29th. September, stated that a second suspected case of plague had been notified in another man working with the first in the same mill. This patient, who had fallen ill on the 25th. September, died on the 28th. of the same month.

The diagnosis of plague was confirmed after biological and laboratory examinations in both cases (the first showed inguinal adenitis and the second had had septicaemic symptoms).

Further investigations made immediately show:-

(1) That during the first half of the month of April, a cargo of grain coming from South America had been delivered at the "Savino" Mill.

(2) That dead rats had been found in the same mill and that subsequently laboratory examination gave positive results confirming the diagnosis of plague in three cases (2 in Mus rattus and 1 in Mus norvegicus)

(3) That there is no epizootic plague present in the other mills at San Giovanni, Teducio, and the rest of the province.

(4) That no rat suffering from plague has been found in the port zone of Naples since the beginning of the year.

Persons who have been in contact with the two patients have been placed under sanitary observation in the place set apart for the purpose, and their respective dwellings have been disinfected, deratised and disinsectisized. Similar measures have been taken with regard to the mill where the two men worked; the mill has been closed for disinfection, the whole of the workmen belonging to it have been subjected to sanitary surveillance and vaccinated against plague.

This very limited manifestation of an episodic character which has been strictly limited has had no sequel. No further case either local or imported has been observed at San Giovanni, Teducio, or elsewhere. Neither has any plague-infected rat been found since the 25th. September, to date (15th. October).

Nevertheless the anti-plague prophylactic service has been intensified both by a more active campaign against rodents and by more thorough sanitary inspection of the working population which is most exposed to danger; those groups of persons who by reason of their occupation are more exposed than others to the possibility of infection have been vaccinated against plague.

According to these notifications and in view of the measures taken, we may consider that all danger of infection has entirely disappeared. (Dated 21st. October, 1929)".

(2) s/s "HANNAH". This ship arrived at Hull from the River Plate on the 8th. April, 1929. Her voyage had been:-

	Arrived.	Departed.
Rosario.	February 6th.	February 18th.
Monte Video.	March 1st.	March 1st.
St. Vincent.	March 22nd.	March 23rd.
Corcubian.	April 3rd.	April 3rd.
Portland (England)	April 6th.	April 6th.
Hull.	April 8th.	April 20th.

She had a crew of 27 hands including the Captain, and a net registered tonnage of 2,321. The cargo consisted of flour, wheat, maize and linseed.

The unloading of the vessel commenced on the 9th. April. No dead rats were seen until the 13th. when five were found but all were badly decomposed. The usual measures were taken to prevent rats getting ashore by the use of rat guards etc. Traps were set on arrival and every day. No rats were caught. After the discovery of the dead rats as a precautionary measure, the vessel was taken into the middle of the dock and fumigated with liquid hydrogen cyanide in the proportion of 2 ounces per 1,000 cubic feet of space on the same day and left under the fumigant overnight. On the 14th. April when the holds were opened up, 17 freshly dead rats were found. On examination none showed evidence of plague.

The vessel returned to her original berth and the remainder of the cargo was discharged under supervision. The discharge of cargo was completed on the 19th. April.

The following statement shows the rats found and examined. None showed evidence of plague. The rats found subsequent to the fumigation were either mummified or so decomposed as to render examination impossible:

T A B L E XVII.

Date.	Mus rattus.	Mus alexandrinus.	Mus norvegicus.	Mice.	Rats. examined.
April.					
* 13th.	5 (5 mummi-fied)	-	-	-	-
14th.	17 (1 mummi-fied)	-	-	1	17
16th.	4	-	2 (mummi-fied)	-	-
18th.	1	-	-	-	-
20th.	4	-	-	-	-

* Fumigated by H.C.N. overnight.

Total No. of rats found.	34.
Total No. of rats examined.	17
Total No. of rats plague-infected.	None.

Traps were set and a careful search of the vessel was made before she sailed, but no evidence of rats was found.

(3) s/s "ESSEX JUDGE". This ship arrived at Hull from the River Plate on the 26th. May 1929. Her voyage had been:-

	Arrived.	Departed.
Rio Grande.	-	-
San Nicolas.	April 1st.	April 12th.
Buenos Aires.	April 14th.	April 21st.
St. Vincent.	May 11th.	May 11th.
Las Palmas.	May 16th.	May 16th.
Hull.	May 26th.	

She had a crew of 27 hands including the Captain, and a net registered tonnage of 2,283. The cargo consisted of wheat, maize and linseed. The usual precautionary measures were taken to prevent rats getting ashore. Traps were set on the day of arrival and on each succeeding day.

The unloading of the vessel commenced at midday on the 27th. May and that afternoon a rat catcher discovered one dead rat and three live rats. These were all examined bacteriologically but no evidence of plague

was found. Instructions were given for a rat catcher to keep a careful watch on the vessel. By midday on the following day another dead rat was found but was so decomposed as to render bacteriological examination impossible. Later three dead rats and one live rat were found. These were submitted to bacteriological examination but no definite evidence of plague was discovered.

It was pointed out to the Master that in view of the unusual mortality amongst the rats, the evidence that there was abundant evidence of live rats and the fact that the vessel intended to proceed to the silo to complete the discharge of her cargo, it was desirable that the vessel should be fumigated with hydrogen cyanide at the earliest convenient moment. The vessel was fumigated with Zyklon B, in the proportion of 2 ounces of Zyklon B. per 1,000 cubic feet of space. The vessel was closed down at 8.0 pm. on the 29th. May and opened up at 2.0 am. on the 30th. May. The discharge of cargo was re-commenced at 8.0 am. the same day.

The following statement shows the rats found and examined:-

T A B L E XVIII.

Date.	Decomposed Rats.	Mummified Rats.	M.R. (live or freshly dead)	M.A. (live or freshly dead)	M.N. (live or freshly dead)	Rats Examined.	
May.							
27th.	1	-	-	3	-	4)	
28th.	4	-	1	-	-	4)	
29th.	-	2	14	-	-	14)	
29th.	-	-	36	5	-	-)	
30th.	-	4	4	-	-	2)	
30th.	-	-	4	1	-	5)	After fumigation by Zyklon B.
31st.	-	-	1	5	-	6)	
31st.	-	-	2	-	-	1)	
June						)	
1st.	-	-	1	-	-	1)	
3rd.	26	-	-	-	-	6)	
3rd.	-	-	1	-	-	1)	
	31	6	64	14	-	44	

Of the 31 decomposed rats, 3 were M.R. 1 M.A. and in 27 the variety was indistinguishable.

Trapped alive

The total number of rats recovered was 115; of these 44 were examined bacteriologically, and none showed evidence of plague. It is possible that in this case the unusual rat mortality was due to poison bait set several months before. Only one rat was trapped alive subsequent to the fumigation.

(4) s/s "ORANGEMOOR". This ship arrived at Hull from the Far East on the 22nd. Feb. 1930, with a cargo of soya beans. Her voyage had been:-

	Arrived.	Departed.
Darien.	29th. November.	8th. December.
Sebang.	23rd. December.	23rd. December.
Suez.	12th. January.	12th. January.
Port Said.	13th. January.	13th. January.
Algiers.	21st. January.	21st. January.
Vigo.	29th. January.	13th. February.

The discharge of cargo commenced on the 24th. Feb. and on that date a rat searcher boarded the vessel and as a result of his examination reported that there was marked evidence of a large rat population. Later four dead rats were discovered, one of which was mummified, one in an advanced state of putrefaction and two freshly dead. No examination was possible on the mummified or putrescent rats. On examination the two freshly dead rats showed no definite evidence of plague.

The Master was informed of the whole circumstances of the case and agreed with the suggestion that arrangements should be made to fumigate the vessel overnight on the 25th. with Zyklon B. The vessel was closed down by 9.0 pm. on the 25th. Feb. and opened up for preliminary ventilation at 1.0 am. Two ounces of Zyklon B. were required per 1,000 cubic feet, but in view of the fact that practically the bulk of the cargo remained in the holds, four hours exposure was required.

The vessel was cleared by 6.0 am. and the work of discharging the cargo was continued at 8.0 am. on the 26th.

The following table shows the number of rats found and examined day by day:-

T A B L E XIX.

Date.	Trapped alive.	Freshly dead.	Decomposed.	Mummified.	Rats examined.	Plague infected.
Feb. 24th.	-	2	1	1	2	Nil.
25th.	5	-	-	-	5	1 rat found with enlarged gland in axillary and suprapubic regions.
		Fumigated overnight with Zyklon B.				
26th.	-	201	-	-	15	Nil.
27th.	1	55	1	-	10	Nil.
28th.	-	30	-	-	6	Nil.
Mar. 4th.	-	5	-	-	-	-
Totals.	6	293	2	1	38	

B. Partial fumigation of ships with cargo in the holds.

The following cases which occurred in 1917 are of particular interest.

Both vessels came from the infected port of Bombay and both carried cargoes attractive to rats. In each instance the ship had touched at an intermediate port and discharged part cargo, the holds afterwards being fumigated according to the local port regulations. In both vessels plague appeared among the crew about 10 days after leaving the intermediate port. The results indicate clearly the danger of fumigating only the holds of a ship and thereby driving the rats to the living quarters of the crew.

(1) The s/s "SARDINIA" (46) from Sydney and Melbourne, arrived at Bombay on March 19th. and remained there till the 22nd. loading a cargo of grain. She reached Marseilles on April 13th. and discharged part of her cargo, after which the holds were fumigated by means of Clayton's apparatus. She left Marseilles on April 16th. and not long afterwards some dead rats were found near the food store in the forepeak. On April 27th. the first human case of plague occurred on board and up to May 6th. seven cases were reported with five deaths. Six of those attacked were lascars and one a European storekeeper. It is believed that infected rats found their way on board the "SARDINIA" while she was loading in Bombay Harbour. Until the vessel was fumigated at Marseilles plague was confined to the rats among the cargo, but presumably these animals were driven out of the holds by the fumigation into other parts of the ship not affected by the sulphur fumes, including the forepeak, where the rats came into contact with the native crew and other persons,

and communicated the disease to them. The "SARDINIA" arrived in the Thames on May 2nd. when the surviving cases of plague were taken to the London Port Hospital at Denton, along with some contacts. Two cases among the latter were subsequently reported, one on May 3rd. and the other on the 6th. These are included in the seven mentioned above, their infection having been contracted on the ship. It can, therefore, be said that there was no extension of the infection after the vessel had been dealt with in London.

(2) The s/s "MATIANA" (47) took on board at Bombay a cargo, part of which was oilseed and other matters attractive to rats, and sailed for England on June 9th. calling at Delagoa Bay on June 26th. and unloading part cargo there. She remained in that port till July 6th. and before resumption of the voyage was fumigated with sulphur according to the Portuguese port regulations. Dead rats were found in the forecastle some days after leaving Delagoa Bay, and a number of other rats were trapped in and about the crew's quarters. The first case of human plague on the "MATIANA" began on July 6th. i.e. 10 days after the ship left Delagoa Bay. Up to August 14th. ten native members of the crew had been attacked by the disease and seven of them died. The vessel arrived in the Thames on August 13th. While the cargo was being discharged 77 dead rats were found, most of them of the "black" variety (Mus rattus) the common rats of India. No extension of the outbreak occurred after the ship reached the Thames. The last human case was reported on August 14th. his infection having been contracted before his arrival.

The conclusion to be drawn from the foregoing cases is that ships with cargo in the holds can be fumigated efficiently with hydrogen cyanide, and that the only satisfactory method of carrying out such fumigations is to do all the compartments simultaneously including the crew's quarters. The overwhelming advantage of this type of fumigation as opposed to fumigation after all cargo has been discharged as a measure for preventing the importation of plague will not, I think, be controverted.

T A B L E XX.

Ships dealt with at Hull for the purpose of International Certificates - either Deratisation or Exemption between July, 1928, and August, 1930, grouped according to comparative rat yields.

No. of rats.	None.	1-5.	6-10.	11-30.	31-50.	51-100.	101-150.	151-200.	201-250.	250+
No. of ships.	80	27	14	17	12	11	6	5	1	1

Our experience as evidenced by Table XX. shows that of 173 ships dealt with only on 24 or 13.8% were more than 50 rats per ship found. These are the potential plague carriers. The logical action, therefore, is to fumigate with hydrogen cyanide all heavily rat infested vessels as early as possible and before all cargo has been discharged. Maritime quarantine today is designed so that there is as little hindrance to shipping as possible, but as fumigation can usually be arranged to be done overnight, no interference with the discharge of cargo need take place.

V. SUMMARY AND GENERAL CONCLUSIONS.

I. Introduction.

1. Between 1900-1929, 109 cases of bubonic plague occurred in Great Britain. The majority of the cases occurred during the late summer or autumn months and all were reported in seaport towns.

2. Ship-borne infection was proved or thought to be the cause of all the cases. Of 31 plague-infected vessels, 14 arrived from India, 7 from the River Plate and 6 from Egypt. Seventeen at least of the 31 vessels on which plague was found carried grain cargo.

3. Although there has been repeated importations of plague into Britain, no serious spread has taken place; in most cases it has died out with little or no intervention.

II. Factors affecting the spread of Bubonic Plague.

4. The climate of Britain has not changed since the days of the Black Death or the Great Plague. The temperature in the holds of ships is markedly different from that on the quayside.

5. Bubonic plague is confined today to an area between 40° North and South Latitude together with districts about the Mediterranean and Black Sea.

6. The black rat is now to be found in many of the docks and port towns of Britain.

7. Evidence has been adduced to show that Xenopsylla cheopis is probably the only flea that transmits plague under natural conditions.

8. If this be so, then the cheopis index will measure the infectibility or otherwise of any locality, and experience has shown that a suitable working critical index is one cheopis per rat.

III. Rat-flea survey of Port of Hull.

9. Between 1st. July, 1929 and 30th. June, 1930, 1,862 rats were trapped alive on 410 ships at Hull, and on these rats 2,142 fleas were caught. Ninety-nine per cent of the rats were of the black variety. Of the fleas 1,625 or 75.9% were Xenopsylla cheopis and 492 or 22.9% Ceratophyllus fasciatus. The cheopis index for the year was .87. July, August and October were the only months when the cheopis index was over one, and therefore, must be regarded as the months during which plague is most likely to spread.

10. Evidence has been produced to show that the early spring and summer are the most dangerous seasons for the introduction of plague-infected rats, because if this does take place rats can sufficiently penetrate from quays, wharves and warehouses to the dwellings of man by the time the rat-flea prevalence is at its height, i.e. from July to October.

11. A summary of fleas taken on ships coming from ports within 40° North and 40° South Latitude gives a cheopis index of .93 and a fasciatus index of .21, whereas the fleas taken on ships from ports outside this area give a cheopis index of .32 and a fasciatus index of .69.

12. Between 1st. August and 30th. September 1930, 62 rats were trapped alive on the dock estate, Hull, and on these 268 fleas were found. Twenty per cent. of the rats were of the black variety; and of the fleas, 252 were C.fasciatus, 15 X.cheopis and 1 Ct.canis.

13. During the same period 4 guinea-pigs were used as flea-traps in various warehouses on the docks and on these 36 fleas were caught, comprising 1 X.cheopis and 35 C.fasciatus.

14. In the city during the same two months 31 live rats were caught and 8 of these were of the black variety. On these, 30 fleas were caught, comprising 23 C.fasciatus and 7 X.cheopis.

IV. Deratisation of Ships.

15. Details are given of four ships fumigated at Hull with hydrogen cyanide with cargo in the holds.

16. Two ships are quoted as having had human plague 10 days after fumigation of the holds only. This indicates the danger of fumigating only the holds of a ship and thereby driving rats to the living quarters of the crew.

17. Only 13.8% of ships dealt with at Hull for certificates of either deratisation or exemption between July, 1928 and August, 1930, yielded more than 50 rats each, and it is suggested that the most efficacious method of dealing with such ships for the purpose of plague prevention is to fumigate all compartments simultaneously with hydrogen cyanide on their first arrival in port.

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A P P E N D I X I.

Particulars of cases of Human and Rodent Plague occurring in England, Scotland and Wales.

1900 to 1929.

Year.	Port or Township.	Ship.	Cargo.	Month of year.	Human Plague.	Rat Plague.	Ports of Call.	Remarks.
1900.	Glasgow.	---	---	August.	36 cases-16 deaths.	—	---	236 rats caught in the infected area - none found plague-infected.
1901.	Glasgow.	---	---	August.	10 cases-5 deaths.	+	---	150 plague-infected rats found.
1901.	Hull.	s/s "FRIARY"	Cotton seed.	January.	9 pneumonic cases-8 deaths.	—	Alexandria.	---
1904.	River Tyne Ports.	s/s "BISHOPSGATE"	Grain.	September.	1 case.	+	Rosario.	---
1904.	London Docks.	s/s "WEYBRIDGE"	Grain.	November,	1 case.	—	River Plate Ports.	---
1905.	Liverpool.	s/s "CREWE HALL"	Cotton in bales, rice and rice meal in bags.	January.	1 case-died.	—	Rangoon.	---
1905.	River Tees Ports.	s/s "HYLAS"	Grain.	June.	1 case-died.	+	Rosario.	---
1905.	Leith.	---	----	May.	4 cases-1 death.	—	---	Town case. 1 case worked in a rag store.
1907.	Glasgow.	---	---	August.	2 cases-1 death.	+	---	Town case; worked in a rag store.
1908.	Liverpool.	---	---	Oct/Nov.	3 cases- 2 deaths.	—	---	1st.Mate of coaling barge, 2nd.Mate and wife of same craft. No connection with sea-going vessels.
1908.	London Docks.	---	---	Aug/Sept.	---	+	---	Rats caught on West India Docks near vessel from South America.
1909.	Elstree.	---	---	February.	1 pneumonic case-died.	—	---	Medical practitioner engaged in laboratory work re plague.
1909.	London.	---	---	November.	---	+	---	7 dead rats found in grain warehouse on the docks.
1909.	Hull.	---	---	February.	---	+	---	Dead rats found on docks among cargo of grain from Odessa.
1909.	Bristol.	s/s "VERA"	Cotton seed.	November.	---	+	Alexandria.	8 dead rats found.
1910.	London.	s/s "OCEANA"	Grain.	Sept/Oct.	1 case.	—	Bombay.	---

A P P E N D I X I (Continued)

Year.	Port or Township.	Ship.	Cargo.	Month of year.	Human Plague.	Rat Plague.	Ports of Call.	Remarks.
1910.	London.	s/s "HIMALAYA"	Grain.	Sept/Oct.	1 case.	+	Bombay.	9 dead rats found.
1910.	London Docks.	---	---	October.	---	+	---	17 dead rats found.
1910.	East Suffolk.	---	---	September.	4 pneumonic cases-4 deathe.	+	---	4 miles from Ipswich-part at which a large number of grain laden vessels from South America discharge cargo. Mortality amongst rats and hares in this district.
1911.	East Suffolk.	---	---	October.	1 pneumonic case-died.	+	---	See above remarks. (E. Suffolk 1910)
1911.	Glasgow.	s/s "CITY OF BENARES"	Grain.	May.	1 case-died.	—	Karachi.	---
1912.	Liverpool.	---	---	July.	1 case.	+	---	Boy,age 7 years, 5,500 rats found, 3 plague-infected near where boy visited.
1912.	Liverpool.	s/s "ITALIAN PRINCE"	Fruit & grain.	April.	1 case-died.	+	Mersina.(Asia Minor)	1 plague-infected rat found on ship.
1912.	River Tyne Ports.	s/s "BELLAISLA"	Grain.	September.	1 case-died.	+	Rosario.	1 tame rabbit died on board from plague. (2 deaths from plague ex ship at Hamburg)
1916.	Bristol.	---	---	---	4 cases.	+	---	Worked in rag factory.
1916.	Hull.	---	---	August.	2 cases-1 death.	—	---	Dead rats found in an advanced state of decomposition. Men employed on empty ship from Alexandria.
1916.	Hull.	s/s "STUART PRINCE"	Cotton seed and oil cake.	October.	---	+	Alexandria,Malta, & Gibraltar.	---
1916.	Liverpool.	---	---	---	6 cases-4 deaths.	—	---	5 rag factory employees. 1 employed at grain store. Grain from River Plate.
1917.	London.	s/s "SARDINIA"	Grain.	May.	2 cases.	+	Bombay.	Altogether 7 cases occurred with 5 deaths. Fumigated, Marseilles,Apr.13th. 1917. Part cargo. 1st. human case Apr.27th.

APPENDIX I. (Continued)

Year.	Port or Township.	Ship.	Cargo.	Month of year.	Human Plague.	Rat Plague.	Ports of Call.	Remarks.
1917.	London.	s/s "MATIANA"	Oil seed.	August.	1 case.	—	Bombay.	Altogether 10 cases occurred with 7 deaths. Fumigated, Delagoa Bay, July 5th. 1917. 1st. human case July 16th.
1918.	London.	s/s "SOMALI"	Castor oil seed, linseed, leather, silk & raw silk.	May.	4 cases-2 deaths.	+	Bombay, Aden, Suez, and Port Said.	1 plague-infected rat found in ched at Tilbury Docks on June 28th. 1918.
1918.	London.	s/s "HECTOR"	Cocoanut fibre in bales and myro-balans in bags.	August.	5 cases.	—	Calcutta, Colombo, Aden and Suez.	Dead rats found. None fit for examination.
1918.	Dundee.	s/s "MOORA"	Grain.	August.	3 cases- 2 deaths.	—	Calcutta, Colombo, Aden and Suez.	---
1918.	Hull.	s/s "MOROCCO"	Margarine, castor seeds and eggs.	March	---	+	Bombay, Suez and Alexandria.	8 dead rats found.
1918.	East Suffolk.	---	---	June.	2 pneumonic cases-2 deaths.	+	---	See notes re cases in 1910.
1919.	Liverpool.	---	---	July.	1 case-died.	—	---	Owner of warehouse used for storing damaged grain.
1919.	London.	s/s "NAGOYA"	Baled & boxed goods, rice and tapioca.	October.	7 cases-1 death.	+	Yokohama, Kobe, Shanghai, Hong-kong, Singapore, Penang, Colombo, Port Said and Marseilles.	---
1919.	Bristol.	s/s "FRAMLINGTON COURT".	Barley in bulk.	July.	2 cases.	+	River Plate.	---
1919.	Liverpool.	s/s "CITY OF SPARTA"	(Troopship)	April.	1 case-1 death.	—	Bombay, Perim, and Port Said.	---
1919.	Gravesend.	s/s "CLAN LAMONT"	General: some grain.	July.	1 case.	—	Calcutta, Colombo, Durban, Cape Town, Monte Video, Buenos Aires & St.Vincent.	---
1919.	Liverpool.	s/s "MUSICIAN"	Bananas, tomatoes, and onions.	August.	---	+	Maceio, Pernambuco, Cabadello, Las Palmas.	---
1920.	London.	s/s "ALPS MARU"	Potatoes, beans & ground nuts.	February.	2 cases-2 deaths.	—	Kobe, Yokohama, Moji, Shanghai, Hong-kong, Singapore, Colombo, Suez and Port Said.	---
1920.	Liverpool.	---	---	---	1 case.	+	---	Worked in warehouse in which damaged grain was stored.
1922.	Liverpool.	s/s "WARWICKSHIRE"	Grain.	February.	---	+	Rangoon, Colombo, Suez, Port Said & Marseilles.	Fumigated with S.O.2. Holds empty. Result: 64 rats, 2 mice. 1 mouse plague-infected.

A P P E N D I X I. (Continued)

Year.	Port or Township.	Ship.	Cargo.	Month of year.	Human Plague.	Rat Plague.	Ports of Call.	Remarks.
1922.	Liverpool.	s/s "ELPENOR"	Grain.	April.	---	+	Japan & China, via Port Said & Genoa.	Fumigated with S.O.2. 1 mouse plague infected.
1922.	Liverpool.	s/s "ARDEOLA"	Grain.	June.	---	+	Las Palmas.	Fumigated with S.O.2. Holds empty.
1926.	Liverpool.	---	---	August.	2 cases-1 death.	—	---	Father and son. Father employed as watchman on Mersey Docks.
1926.	Liverpool.	s/s "ZARIA"	West African Produce.	September.	---	+	West African Ports.	2 deaths from plague during voyage.
1927.	London.	s/s "PLUTARCH"	Grain.	June.	---	+	Rosario.	1st. fumigation by H.C.N. Cargo in holds, 291 rats found. 2nd. fumigation by H.C.N. Holds empty. 5 rats found.
1928.	London.	s/s "KAISAR-I-HIND"	General.	January.	---	+	Bombay.	Fumigated with H.C.N. Holds empty.
1929.	Hull.	s/s "TIRRENO"	Grain.	March.	---	+	Rosario.	7 dead rats found before fumigation. 261 rats found after 1st. fumigation by H.C.N. Part cargo. 3 rats found after 2nd. fumigation by Zyklon B. Holds empty.