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THE IMPACT OF PROTOZOA ON WORLD ECONOMIC PROBLEMS*

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In the short time at my disposal it will obviously be impossible for me to do more than skate around the fringes of my subject, but I hope to produce enough evidence about some of the more important protozoa affecting the economy of mankind to indicate beyond any cavil or question that the subject of my address deserves immediate, energetic, and well-directed action.

The phylum Protozoa is a large one both in number of species and in distribution on the earth and in the water, and its members exercise an influence in these spheres which, while immense and essential, is still merely one part of the integrated ecology participated in by animals, plants, and inanimate nature. The part played by protozoa in this ecological complex is too vast a field to be more than mentioned, and so I propose to concern myself only with some of the parasitic protozoa which, by their direct action, affect the social economy of man. As examples of these I shall confine myself to three groups of protozoa which I have chosen as examples partly because of the great importance they possess for man, but also because they are groups upon which man can exert a direct influence to lessen their impact on his economy. The three groups I have chosen are the trypanosomes, the plasmodia, and the piroplasms.

THE TRYPANOSOMES

By this term I do not wish to imply the whole family Trypanosomidae, but merely the genus *Trypanosoma*. The trypanosomes have been recognized as of importance to the economy of man since the discovery of Evans in 1880 of a trypanosome which caused "surra," a disease of horses, camels, and other animals. In 1902 Forde was the first to recognize trypanosomes as a cause of disease in man in Africa, and the knowledge which has since accumulated of their ubiquity in and importance to the domestic animals of man, especially in the African continent, has made them one of the major problems requiring attention if meat and dairy products, which constitute so important a part of man's dietetic needs, are to be made available in quantities adequate for the continually growing population of the world.

I propose here to do no more than mention the ravages produced by trypanosomes in man on the east and west coasts of Africa and in South America, important as the effects of these were and are on the distribution, vitality, and general welfare of the popula-

tions affected. This is because, from the broader aspects of man's economy, I consider the trypanosomes affecting man's domestic animals to be far and away the more important when the whole picture is looked at in perspective. As Hornby (1949) has stated, trypanosomiasis has the unique distinction of being the only disease which *by itself* has denied vast areas of land in Africa to all domestic animals except poultry. These areas total one-fourth of the land surface of the continent. Apart from these completely unstocked areas, there is a still greater aggregate of land surface in every continent except Australia where trypanosomiasis is one of the major scourges of stock. The factors concerned and the results brought about by trypanosomiasis can be illustrated by Vogt's formula $C = B:E$, where C is the carrying capacity of the land, B is the biotic potential, and E is the environmental resistance. In this study I wish to indicate how much C is lowered by the part of E due to trypanosomiasis.

Still limited by my time allowance, I can consider only bovines among man's domestic animals, but, as these are among the most important of animals used by him as food, the effect of infections on them will serve as a measure of the full effect of trypanosomes in reducing the quantity and quality of beef supplies and dairy products.

Three Main Groups

The most important trypanosomes pathogenic to bovines fall into three main groups, which, in the absence of easily applied differentiating specific characters, I shall refer to as the *vivax* group, the *congolense* group, and the *brucei* group. In some areas one is the prevalent pest, in others another, while very often two or even all three may coexist and take their toll of stock. The members of all these groups are carried from animal to animal by various species of tsetse fly, so that the protozoological problem now becomes linked with an entomological one. While cyclical transmission by tsetse flies is the normal method, it would be unwise to assume that direct mechanical transmission by other biting flies is of little importance. The proof of this is the establishment of foci of *Trypanosoma vivax* endemicity in South and Central America, Mauritius, and the West Indies, where tsetse flies do not now occur.

The distinction between these three groups is relatively simple from the entomological angle, as the dissection of infected flies will supply the answer in any given area. When tsetse flies display the presence of cyclical forms in the salivary glands we can say the

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infecting trypanosome belongs to the *brucei* group. When the infection is found both in the midgut and in the mouth parts, the cyclical forms being in the latter situation, the trypanosome belongs to the *congolense* group, while the presence of multiplying trypanosomes in the mouth parts alone indicates the *vivax* group.

It would be fruitless to make any estimate of the bovine population of even one continent such as Africa, and much less of the world. Of all the continents, however, it is in Africa that trypanosomiasis ranks most highly as a cause of cattle losses, and it would be interesting, therefore, to know the degree of risk to which cattle are exposed in, or passing through, fly belts in Africa. Mere impressions are often unreliable, and the amount of accurate evidence on this point is limited, but certain detailed observations recently made by Unsworth (1951) are revealing.

Mortality and Morbidity Due to Trypanosomiasis

In the course of experiments devised for other purposes, 10 control cattle were introduced into an area infested with *Glossina palpalis*. All contracted infection with trypanosomes and all died within 146 days. The trypanosome concerned was *T. vivax*.

In similar experiments in another area 10 control cattle were introduced into an area infested with *Glossina morsitans*. All became infected with trypanosomes, eight died within 81 days, one died after 154 days, and one escaped after 110 days but was later found dead—probably owing to trypanosomiasis. The trypanosome concerned was again *T. vivax*. Admittedly these figures are small, but they relate to carefully controlled experiments and are an indication of the losses which would be sustained by unprotected cattle in areas infested by either *G. palpalis* or *G. morsitans*.

These experiments, while striking evidence of the potentially disastrous consequences of bringing cattle into such areas, need not be regarded as necessarily applicable everywhere. There is good evidence to show that there are considerable strain variations in virulence, so that *T. vivax* in one area may produce a virulent infection with high mortality, while in another area the infection may be mild with low mortality.

Mortality, however, is not the only criterion of the damage sustained by herds due to trypanosomiasis. Affected cattle, even if they do not die, often lose condition to a marked degree, are emaciated and weak, and such animals, if trekked to markets or otherwise subjected to strain of any kind, will often succumb when they might have survived if rested. But rest is not the fate of most cattle in Africa. The cattle of the Fulani, those nomadic herdsmen, have to follow their food, and, as the seasons of the year change and grazing grounds alter, must accommodate their movements accordingly. These wanderings sooner or later bring them through fly belts, and the consequences, in the absence of protective measures, are inevitable. The only possible way to prevent this wandering habit, which, after all, is dictated by the need for water, would be the provision of permanent water supplies, but, as this is a matter for engineers and is outside the scope of my paper, we need not pursue the subject further, although it will come in for brief mention at a later stage.

Mortality and loss of condition, however, are only part of the failure to reach maximum productiveness

in numbers and economic usefulness of bovine resources. These are direct losses in existing herds, but quite immeasurable are the indirect losses due to the exclusion, on account of the presence of trypanosomes and tsetse, of what would be vast potential herds from pastures otherwise admirably suited for them. Still more indirectly one has to consider the losses due to overstocking in fly-free areas on account of the restriction of grazing grounds due to the presence of tsetse. Such losses include also the effects of loss of condition, helminthic and bacterial diseases, and infertility.

All this means that the mere mortality in herds due to trypanosomes in any particular area is only a very partial picture of the losses, actual and potential.

Control Measures

This brings us, logically, to consider control measures. These, although outside my present subject, must be touched upon, as they are the natural concern of all who are faced with the practical control of trypanosomiasis. They resolve themselves into measures, direct and indirect, against the tsetse and direct measures against the trypanosome, or a combination of these.

Direct measures against the tsetse are confined to the use of insecticides. Such means may be of value against species such as *G. palpalis* with a limited range or a range limited by environmental factors, such as belts along river courses, but are at present inapplicable or would be inordinately expensive against species such as *G. morsitans*, widely dispersed over large areas. In any case, the indiscriminate use of insecticides on such a large scale might have unexpected and harmful effects due to unselective slaughter of insects.

Indirect measures have probably a wider and more useful application. These consist of selective clearance of bush under skilled supervision in the case of riverine tsetse, and settlement and agriculture of fly-infested areas, where this is possible, in the case of the more widely dispersed species, such as *G. morsitans*.

I do not propose to go into the subject of bush clearance, which is a highly specialized affair, but would merely draw attention to my use of the word "selective" in regard to bush clearance. Preservation and improvement of water supplies is of paramount importance in Africa, and therefore indiscriminate removal of blocks of forest or of fringes of forest along river courses is indefensible if it can be avoided. Possibly, chemical means of destruction of tsetse along the edges of sharply cut corridors in the forest would suffice, the corridor giving access to the river for watering.

G. morsitans is essentially a "game" fly, and goes when game goes. In this way agricultural development and settlement alone will remove it. As food, it prefers game to cattle and cattle to man, but it must be remembered that mere clearance of game without alteration of the other conditions suitable for *G. morsitans* might merely substitute cattle as a perfect alternative to game. On the other hand, agricultural development means an increase in the human population, with consequent and essential changes in the fly's environment, until an increase in the population up to 200 or over per square mile will so alter conditions as to eliminate *G. morsitans*.

We have here been considering only the control of tsetse, but it must not be forgotten that mechanical transmission of trypanosomes by biting flies may be an important method of transmission. *Trypanosoma evansi*

is transmitted wholly by this means, although there is a distinct possibility that it may once have been cyclically transmitted by tsetse flies but have lost this capacity, while *T. vivax* has spread far beyond tsetse areas and maintained itself by mechanical transmission, still retaining its transmissibility by tsetse flies. Thus, as already mentioned, it is now firmly established in South America and other tsetse-free areas.

Prophylaxis

Direct measures against the trypanosome are treatment of infected animals and prophylactic treatment of cattle. There are drugs now available, and more seem to be on the way, which are effective in the treatment of trypanosomiasis in cattle. This efficacy, however, is not equally potent against all species of the trypanosome. One of the latest of these drugs is phenanthridine 1553, which has given striking results from treatment by a single subcutaneous injection of 1.5 mg. per kg. body weight of a 1% solution. Cases of photosensitization following this treatment have been remarkably few. Successful as this treatment has proved, such drugs may be of still greater value when used prophylactically on herds which have to pass through fly belts or have to live in fly-infested areas. Such use would not only prevent infection of the cattle but would protect the cattle of uninfected areas from infection by imported infected cattle.

The value of "antricide" used as a prophylactic has been investigated in a series of carefully controlled experiments by Unsworth (1951), whose conclusions were:

"It would appear that the effectiveness of antricide prophylactic mixture in protecting cattle against infection and death from trypanosomiasis depends very largely on the intensity of the trypanosome challenge to which the cattle are exposed. Where the quantum of infection is low, such as might result from exposure to riverine tsetse in Northern Nigeria, the inoculation of cattle at three-monthly intervals with antricide prophylactic mixture will give complete protection against death and will protect 88% to 95% of cattle against infection with trypanosomiasis. The small proportion of cattle in which trypanosomes do 'break through' the drug are apparently cured by subsequent inoculations. Where, on the other hand, the quantum of infection is great, such as might result from exposure to an average challenge from *G. morsitans*, the inoculation of cattle at three-monthly intervals with antricide prophylactic mixture cannot be relied upon to give complete protection, either against infection or against death from trypanosomiasis. Moreover, such a procedure is not unattended by danger, for in the experiment which we have just described at Lumu there were indications of the development of an antricide-resistant strain of trypanosome, eight months after the cattle had first been introduced to the area."

His conclusions indicate the uses and limitations of antricide as a prophylactic, and may be taken to summarize the present position as regards prophylaxis.

A Controversial Question

Having now considered the effects of trypanosomes on human economy we have to deal with the more controversial question of what might happen were we able by one means or another altogether to eliminate the pathogenic cattle trypanosomes.

I must refer again to Vogt's formula $C = B:E$. C , representing the carrying capacity of an area, would not necessarily be augmented by eliminating trypanosomiasis. Even if we leave out of consideration other

bovine diseases, protozoal or otherwise, there remains man's cupidity, which might result in his attempting to keep a larger stock of animals than the land at his disposal could with advantage support. It may be, therefore, that trypanosomiasis acts as one of the checks on this evil, and that careful thought should be taken before removing it entirely in any care-free manner.

We have to bear in mind the fact that although tsetse flies limit the areas where stock can thrive or even exist, yet they are not a bar to their existence to the extent that many people imagine. On the contrary, there are great areas where large numbers of domestic animals succeed in existing in contact with tsetse flies so long as the latter are not numerous or effective enough to cause repeated infections.

In areas from which the presence of tsetse flies utterly debars stock, though otherwise suitable for them, the removal or reduction in numbers of tsetse flies would allow the land to be made use of and so greatly increase the carrying capacity of the country and lead to a better distribution of stock. This would also tend to prevent overstocking of areas at present usable and overstocked. Tsetse flies, however, are not the only factor influencing distribution of stock; there is, as I have already said, the distribution of permanent water, which in its turn influences the distribution of human population, with consequent effects on agriculture and the diminution in numbers of tsetse flies which follows this sequence. There is a third factor governing distribution of stock which we consider in another place—namely, tick-borne disease; and yet a fourth, helminthic disease, which, however, is outside the scope of this paper.

Were we to remove, if it were possible, all these factors limiting the increase of stock, the numbers of the latter would certainly lead to overstocking and greatly accelerated soil erosion, so that there would result an economic evil which would be largely irreversible. This same overstocking would also result in an increase in the incidence of many other diseases of stock—viral, bacterial, protozoal, and helminthic—so that better distribution would be of all-round benefit. However, the complete removal of limiting factors is not in sight, and I only sound a warning. On the other hand, there is no doubt that tsetse flies do cause overstocking of areas free or relatively free from flies and so hasten soil erosion in them. The removal, therefore, of tsetse flies or of trypanosomes would allow a better distribution of stock and so act indirectly as a measure of soil conservation. It would also help in more widespread use of composting to fertilize the hungry soil.

To sum up, the menace of trypanosomiasis is bound up with many other menaces, and all these should be considered as an intimate complex in devising and putting into effect measures of limitation or prevention. Only in this way can we ensure that man's economy in regard to more and better supplies of meat, milk, dairy products, and agricultural crops shall be best served and debilitating deficiency diseases be reduced.

THE PLASMODIA

In the previous section it will have been seen that the impact of protozoa on man's economy was primarily on his food supplies, and thus only indirectly on man himself. In the case of the plasmodia the direct impact is on man and only indirectly on his food supplies and general economy. The impact in this case has a much

wider contact than in the case of the trypanosomes, for there is no continent where plasmodia do not exert a major influence on man's activities, even to the extent, in some tropical areas, of prohibiting them entirely.

Now when one considers the relatively low mortality from malaria over the entire population, even in areas of high endemicity, one might imagine at first that the effect on man's general economy would be small, whereas we know that, in truth, the effect is enormous. This apparent paradox is due to the fact that the influence of malaria is exerted for the most part indirectly. While relatively few die, enormous numbers are debilitated to a greater or lesser degree, work hours are lost, physical capacity for work is lowered, mental capacity is impaired, and the vigour and vitality of a people are diminished. All these damaging results are roughly proportional to the degree of endemicity, and I am in disagreement with those who assert that a very high degree of endemicity has little effect on the economy of the people affected. The argument of this school of thought appears to be that in such an area there is a high degree of immunity, or rather tolerance, in the adult population and the adult is looked upon as the main or chief economic unit. This seems to me to be a very one-sided way of looking upon the picture.

In a community such as that envisaged, the high adult tolerance is accompanied by a high infant mortality, and in assessing the effect on the general economy of the community in a long-term view this wastage must be taken into account. Among figures given by Wilson (1936) for a tribe living in Tanganyika in an area such as we are considering, the average number of children surviving to women who had completed their child-bearing life was only 1.13. If we take the sex ratio as approximately 1:1, this means that only one woman in two would have a surviving female child to produce children of her own. It is only too evident that such a community would be a dying one unless reinforced by immigration.

It seems to me quite irrational to maintain that such a community has a healthy economy because its adult population shows a tolerance to malaria, enabling the adult unit to work more or less continuously and with a minimum of lost working hours. It may be true that the working units are in a stable condition of health as regards malaria, but the community as a whole is like a man living on his capital and having no regularly paid income to keep him in a financially sound condition.

In order to get some idea of the total effects of the plasmodia on man's economy one has to consider this economy as a many-sided figure and to examine each facet separately.

In pre-human days, when man was a higher ape wandering in the forests in smaller or larger family groups, it is possible that he lived, as some of the primates now appear to do, in a partnership with his malaria parasites. Each group would occupy a relatively limited tract of country, and the aggregate of all these groups would be infinitely small as compared with present human populations. Each group, which might be composed of several families, would be infected with its own strain of malaria parasite, and in the course of time would develop an immunity or at least tolerance to that strain on evolutionary lines by the continued survival of the more resistant individuals. A time would

arrive when the prehuman being and his malaria parasites would have come to a *modus vivendi* whereby mammal would provide a habitat to protozoan, and protozoan would cause a minimum of inconvenience to mammal.

The prehuman being, however, having a divine discontent with his limited surroundings, began to wander outside his group's natural terrain and so came in contact with other groups. In this way adjacent groups might amalgamate into larger communities, which probably accelerated the human evolutionary process and led towards much greater agglomerations of fully human communities. This led inevitably to man coming into contact with strains of plasmodia foreign to his old economy and against which he had little or no immunity. In other words, part of the price man paid for progress towards true manhood was an increasing tribute to malaria.

We may now consider the forms which this tribute took and the effect it had on man's economy.

Effects on Distribution of Population

When one examines the distribution of people on maps of the world it becomes evident that the most important single factor encouraging or limiting this distribution is the presence or absence of permanent surface fresh water, in the forms of rivers or lakes.

It does not follow from this that areas with the most lavish water supplies are necessarily the most thickly populated, because other factors besides water are in operation. This would apply, for instance, in the great Amazon basin, with its mighty rivers and forests but very sparse human population. On the other hand, scarcity of water is always accompanied by a sparse population, as in the desert or semi-desert areas. That this sparsity is due to lack of surface water is exemplified by the relatively small population in most of Iraq and the country between Mosul and the lower Tigris and Euphrates, where formerly a much denser population with thriving cities, such as Ur, Babylon, Nineveh, and others, once existed owing to a vast irrigation system of communicating canals. When these fell into disrepair owing to various causes, the ravages of the Mongols among others, the cities and the thriving population were swallowed up in the arid desert. It would appear, therefore, that on a world scale malaria does not play a decisive part in the distribution of population.

Plenitude of water, however, facilitates occupation by both mosquito and man, the latter on account of its use for his agricultural activities. According to MacDonald (1950), in some such rich agricultural areas in Africa *Anopheles gambiae* has been unable to prevent a concentration of population, although in India and Ceylon there are large areas where, in the absence of preventive measures, *A. fluviatilis*, *A. minimus*, or *A. culicifacies* deny the use of the land for human settlement. Thus in certain foothill areas of the Himalayas and of the Western Ghats of India the country is almost uninhabited owing to the presence of the almost exclusively anthropophilic *A. fluviatilis*.

Effects of Redistribution of Population

We have so far been considering the effect of malaria on more or less static populations, but we must now look into what happens when population movements on a greater or lesser scale take place. The causes of

such displacements are varied. Migration of population may be due to the pressure of overpopulation in healthy and prosperous areas, causing a spill over into more malarious country. It may be due to mass movement of labour to areas where public works such as dams or bridges are being constructed, or of labour required in mining and similar large-scale operations. There is a third form of two-way migration in certain parts of India, where a population normally engaged in agriculture flocks in large numbers to cities, such as Bombay, to work in cotton mills during the off season in agriculture and returns to the latter occupation for the sowing and harvesting seasons.

In all these cases, except possibly the last, the tendency is for the population to move from a less malarious to a more malarious area, but this is not invariably the case. The effects, however, in the absence of preventive measures are the same—an increase of malaria sometimes on a disastrous scale, either on the immigrants or on the population of the area invaded. Although many other factors come into operation in producing malaria in epidemic form under the conditions cited, the most important factor is probably one inherent in the malaria parasite itself.

It is well known, and can easily be experimentally demonstrated, that the immunity to malaria parasites is species-specific. This means that a mammal infected with one species of malaria parasite cannot be superinfected with the same species, but may easily be infected with any other species to which it is susceptible. In other words, a man carrying *P. vivax* cannot be superinfected with *P. vivax* but can easily be infected with *P. falciparum* or *P. malariae*. This specific premunition goes even more deeply than species, because it is found to be not merely species-specific but also strain-specific. Thus a man carrying a strain of *P. vivax* acquired in area A cannot be superinfected with that strain, but can be superinfected with a strain of *P. vivax* derived from area B. These facts supply the clue to the danger of introducing populations from non-malarious to malarious areas or even of introducing populations well adapted to one species or strain of parasite to an area where a different species or strain is present.

Where no precautions are taken such movements of population may have disastrous results. To cite a case coming within my own experience, I may mention what happened in one area of Assam during the recent world war. In the mainly rice-growing district of Sylhet the country is very low-lying, a mere 20 ft. or so above mean sea level, although situated 150 miles from the sea. The communications are by earth roads raised above the level of the surrounding country. The villages are mostly situated on the highest ground available. During the monsoon the whole country is inundated and the villages exist as island areas connected by the raised roads. In spite of these conditions the district was relatively non-malarious and the population non-immune. Large numbers of the men had gone to work as labourers on military works situated in malarious districts. When these returned to the area in question many were infected with strains of malaria parasites from the districts in which they had been working. The result was disastrous. A suitable carrier species of anopheles already existed; out of a population of about 40,000 people in this particular area some 7,000 to 8,000 died of malaria before any effective action was taken.

This is an instance of an infected population moving into an area of very low endemicity, but the results may be equally unfortunate when a comparatively healthy population enters an area of high endemicity or, as already stated, even when a so-called "salted" population moves into an area where their immunity to their own strain of malaria is comparatively inoperative against the new strains or against a different species of parasite. In other words, almost any kind of redistribution of population in malarious areas, even when the endemicity is not high, is likely to be accompanied by severe epidemics of malaria.

The possible economic effects of such disastrous epidemics will be only too obvious. The life of the community is completely dislocated, and this may be accompanied by a state of apathy that prevents any energetic action by the community itself, which can be saved only by outside help.

Effects on the General Life of a Community

This is a very comprehensive aspect, and includes effects on agriculture, industry, social services, including education, and the general welfare of the population.

Looked upon from this angle, the effect of malaria on a community may mean anything from a slight inconvenience to an almost complete cessation of individual and community activities. In the milder degrees of malarial endemicity the chief effect will be in the form of days lost to all beneficial activities on account of illness among the workers. This effect may be much greater than would be expected from the number of days lost, especially in tropical communities where, as Macdonald (1950) has pointed out, the success or otherwise of agricultural operations very often depends on the climatic conditions obtaining during a limited part of the year, generally that part when ploughing and sowing are carried out. If the sickness among the population coincides with this period the days lost and the impaired physical condition of the workers will have an effect on their productive capacity the results of which will endure throughout the remainder of the year in a way which would not have been the case had the malaria been prevalent at a less important part of the annual work cycle.

The effect will be further enhanced by the fact that children as well as adults are sure to be affected, and in most primitive communities the older children are themselves economic units in the community.

This represents the effect on the economy of a community working for itself, but under the same conditions the effect is the same when such a community is employed as labour in some local industry. The absenteeism and the diminished physical capacity, added to wastage of labour, needing new recruitment, and to provision of special measures of housing and medical care, will inevitably lead to loss of time in completion of projects and to a greatly added cost. There is no aspect of the life of the community which escapes the impact of malaria even in the milder forms we are considering. The future economic units, the children, are frequently ill, leading to absenteeism, which interferes with education and may in many produce a constantly recurring invalidism, conditions under which the child will certainly not receive the full benefits of attendance at school, and the money and other resources

applied to an educational policy will not bring commensurate results until the harmful influence of malaria is eliminated.

To proceed from a consideration of the conditions we have been contemplating where malaria merely slows down the pulse of a community, let us see what happens when malaria in severe epidemic form lays a community prostrate.

Only if such a catastrophe has been personally seen can any conception be formed of the extent of the blow struck upon the community. Such epidemics usually occur in areas where malaria transmission is chiefly confined to certain periods of the year and seldom, if ever, in hyperendemic areas where transmission is going on throughout the year. Typical of such epidemics was what has happened in the Punjab on various occasions, in Ceylon, and in various other parts of the world.

During one of the Punjab epidemics a village in the affected area at the height of the epidemic presented an astonishing sight and sound. The following account was given me by an eye-witness:

Most of the dispensaries of the district were closed because the staff were ill, and those open were neglected for the same reason. The countryside looked empty; cattle were wandering about unattended. As one approached a village a curious moaning sound was heard. This was the lowing of cattle waiting in vain to be milked. More than half the population were lying on "charpoys" unable to get up and neglected by all. Others were sitting about unable to work. Many huts had collapsed in the rain and remained un-repaired. Everyone looked half-starved, because none were well enough to grind the corn or fetch water for making "chappatis." Many young children and the old died of starvation, the former because their mothers could not attend to them. Many dead were lying untended on "charpoys" or on the ground. The village had ceased to exist as a human community. All the destruction was not directly due to malaria. Malaria was the *fons et origo mali*, but in its train starvation and dysentery played their part. Family ties were loosed, and brother did not care for brother or mother for child.

In case some of you should think this picture exaggerated, let me say that I have myself seen conditions where corpses were left unattended not only on the roads and by the wayside but even, in more populated places, on railway platforms. In other words, the whole organized structure of a community disintegrates on the failure of its human elements.

The general account I have given will leave no one in doubt about the profound effect of malaria on a community. The full effect may sometimes not be evident from a mere perusal of statistics showing the number of malaria cases occurring in a district and of mortality from malaria. A very striking instance of this was brought to my notice by Professor Macdonald. In Ceylon the total mortality over a period of nearly 50 years remained at a high relatively uniform level. In late 1946 effective antimalarial measures were begun, and in the next three years there was a very notable decrease in the total mortality. As the only notable new public health measure taken during this period was malaria control, the improvement can only be attributed to this, and is an indication of the direct, if not always apparent, effect which malaria exerts over the economy of a district, an effect which is much greater than would be expected from the known mortality due to malaria itself.

Sinton (1935) has calculated that in India alone 1,000,000 deaths a year are caused directly by malaria, another 1,000,000 are caused indirectly, and the number of cases of malaria occurring annually is 100,000,000. These figures seem incredible from one country alone, but on my putting this question to Professor Macdonald he said that, although at one time he was disposed to discredit the figures, his own subsequent studies have led him to the opinion that they may be an underestimate.

THE PIROPLASMS

The two types of protozoal parasites I have already dealt with, showing how severe is their impact on man's economy, are probably more familiar to most of you than the one I am now going to deal with—namely, a piroplasm, using this term in a broad sense. This is because both the former attack man as well as animal and so force themselves more directly upon our notice. The piroplasms, on the other hand, so far as we know, are animal parasites only, but their impact upon the animal food supplies of man makes them at least as important as the trypanosomes and plasmodia.

In the sub-order Piroplasmidea there are two families, the Babesiidae and the Theileriidae.

The piroplasms are parasites of a very large range of mammals—cattle, sheep, goat, pigs, horses, dogs, monkeys, antelopes, rodents, and other groups, so that their impact on mammals is a wide one. But, strangely enough, man seems to be immune, and the effect on his economy is entirely due to losses caused by this group to his domestic animals. I have already indicated the wide range of animals affected, but, again limited by my time allowance, I shall take as an example one group alone—the bovines. Cattle are parasitized by members of both the families I have mentioned, Babesiidae and Theileriidae, and each is the cause of various diseases of cattle, such as redwater, East Coast fever, and other diseases due to miscellaneous "small piroplasms." By far the most important of these diseases of bovines is East Coast fever, caused by the piroplasm *Theileria parva*, and I shall deal mainly with this in order to give a somewhat fuller account of its importance than could be attempted were I to deal with the other piroplasms as well.

East Coast Fever

In order to give an intelligible account of the effects of East Coast fever, I must describe, in the shortest manner possible, the life history of the causative parasite, as on a knowledge of this will depend methods of combating its menace to the food supplies of man.

East Coast fever is a blood-and-tissue infection of bovines with the parasites above mentioned, and is transmitted by various ticks such as *Rhipicephalus appendiculatus* and other species. The parasite in the blood is a minute organism 1–2 μ in diameter which attacks the red blood cells. Inoculation of blood into susceptible animals does not reproduce the disease, so presumably the blood forms are gametocytes destined for sexual reproduction in the vector tick. Asexual multiplication takes place in endothelial cells of the internal organs and glands, where intracellular masses of blue cytoplasm studded with minute red granules represent schizonts which are known as Koch's blue bodies. These

break up into very numerous minute merozoites which re-enter other endothelial cells or parasitize the circulating blood as the before-mentioned gametocytes.

When infected blood is taken up by the vector tick, whether adult, nymph, or larva, development of the parasite takes place, with the production of sporozoites. Now, each of these stages of the tick is passed on a separate host, and the parasites taken up by one stage are transmitted to another host by the next succeeding stage of the tick. The adult tick, when infected, does not transmit the infection through eggs to the next generation of larvae, as happens in the case of various species of *Babesia* such as the one responsible for red-water fever.

This is the explanation of some of the anomalies found when the two infections are compared. Thus every egg laid by a redwater-infected female tick produces, when hatched out, a larva which can at once infect another animal. On the other hand, eggs deposited by ticks infected with East Coast fever produce uninfected larvae, which have to feed on an infected animal before they become infected. After their first feed they drop off the animal and attain the nymphal stage, in which they, in their turn, are infective. The adult female dies after laying eggs. In this way a very few cattle infected with East Coast fever can provide infection for many thousands of larval ticks, which in the nymphal stage are infective. The symptoms of East Coast fever begin 10–20 days after exposure to infection and start with fever. Lymphatic glands become enlarged and there is oedema of the subcutaneous tissues, intestinal mucosa, and serous membranes, with haemorrhagic patches. Calves are less susceptible than adults. The fever continues until death or recovery.

East Coast fever has existed, certainly for centuries, in East Africa, and was well known to the natives before it forced itself on our attention. It is most prevalent in well-grassed areas with high rainfall, and absent or sporadic in arid districts. It is widely distributed on the eastern side of Africa, but appears to be absent on the western side.

Mortality Due to East Coast Fever

It is difficult to get reliable figures on this point, and, in any case, it would seem probable that mortality varies in different districts and in different classes of cattle—European and indigenous. This will be evident from the opinions given by different observers: (1) East Coast fever is the cause of more deaths in cattle than all other causes put together; (2) the calf mortality from East Coast fever varies between 5 and 50%; (3) in South Africa the mortality from the natural disease is 95%; (4) deaths in bovines, the property of Europeans alone, in Kenya for 12 months ending July 31, 1928, were 16,728 out of 55,421 deaths from all other causes.

All this goes to show that, whatever the actual mortality rate, East Coast fever, where it exists, is far and away the greatest parasitic killing disease among bovines.

Another way to assess the relative importance of East Coast fever is supplied by the records of laboratory examinations for diagnosis of cattle diseases. I have examined the records available to me of laboratory examinations made in Kenya, over a period of 26 years, for the diagnosis of disease-producing organisms in bovines. These I have recorded in tabular form, but

it will serve the present purpose if I indicate totals only. These are as follows:

Proportion of Diagnoses of East Coast Fever to all Other Diagnoses in Bovines

Year	Total Positive Bovine Specimens Due to Disease-producing Organisms Sent for Examination	No. Positive to East Coast Fever or Other Piroplasms, or Suspicious
1909–10 ..	413	344
1910–11 ..	939	847
1911–12 ..	900	699
1915–16 ..	1,101	505
1916–17 ..	813	395
1917–18 ..	550	357
1919–20 ..	829	671
1921 ..	1,321	938
1922 ..	1,340	475
1923 ..	1,153	456
1924 ..	1,407	769
1925 ..	2,586	1,594
1926 ..	4,808	1,969
1927 ..	2,670	1,929
1928 ..	2,072	1,640
1929 ..	1,445	1,008
1933 ..	1,581	865
1934 ..	1,426	774
1935 ..	3,037	434
1936 ..	3,286	741
1937 ..	1,564	696
1938 ..	1,877	947
1948 ..	557	284
	37,675	19,337

This assessment would give the astonishing result that diseases due to piroplasms, chiefly East Coast fever, are responsible for 51.3% of all diagnoses of disease-producing organisms. Now, even this gives no real idea of the economic importance of East Coast fever. The figures mentioned are merely those of specimens sent for examination. It takes no account of the probably immensely greater number of cattle affected but from which no specimens were sent, and it takes no account of the fact that these figures are for Kenya only. The figures have also to be considered in conjunction with the actual numbers of cattle in the area before an idea can be gained of the economic impact of this disease. I am indebted to Dr. E. Beaumont, Director, Veterinary Services in Kenya, for an estimate of the cattle population of Kenya, based partly on actual census-taking and partly on estimates. This indicates a cattle population of 5,773,554. To add to the blackness of the picture, mortality is not the only cause of economic loss, because infected animals which do not die are often badly out of condition and may remain stunted for a long time. This account might make you wonder how cattle exist at all on the east side of Africa. The fact is, of course, that areas of prevalence of East Coast fever are not continuous, nor are they all equally seriously affected.

Control

Methods of control do not strictly come within the scope of my address, but must be touched upon in general terms; and I do not propose to say anything at all about treatment of the disease.

Control measures are naturally directed against the ticks which are the vectors of the disease, and it is important to know that these measures can be very effective when properly applied and maintained. To put it in a few words, these methods are dipping, hand dressing, and fencing. These measures, carried out under strict supervision, are economically sound on valuable dairying land and can reduce the tick population over very large farms to proportions that are no longer a menace to the herds.

Conclusion

Man in his own estimation is the most important and culminating result of evolution in nature. How far this may be from the truth past events in the evolution of living things, which for a time dominated the earth and passed away, has shown, and as for the future, we cannot see it, so it behoves us to take a humble view, especially in the light of the most recent achievements of *Homo sapiens*. From our immediate point of view, however, we must consider man as just one unit in the vast complex of nature and realize that too great success may be disastrous. If he eliminates all the pests and diseases which afflict him he may multiply and eat up the earth and so destroy himself as the result of his success.

For these reasons, I would like to sound a note of warning against the danger that pests such as I have described should be treated, when preventive measures are considered, as if they produced their harmful results without reference to accompanying factors in their natural surroundings. Control measures must be devised in relation not only to destruction of a specific pest but in relation to all other circumstances which might follow the elimination of a single important unit in an ecological complex. Thus if the object in some areas is the complete removal of trypanosomiasis or piroplasmiasis we must first consider whether this would not involve the production of a still more serious problem of soil erosion. Preventive or eradication measures in such a case would have to be carefully planned in collaboration with experts on land usage *before* being put into operation, or we might find ourselves in the position of regretting the results of successful eradication when irreparable damage to the land had supervened.

In other words, an all-round approach must be made, and only after careful preparatory research should important measures of control be undertaken.

It must be remembered that in the case of bovines, which alone I have been able to consider, the chief evil at present is overstocking, and this is due to limitation of grazing lands by parasites of one sort or another. The scientific way of approaching the problem when eradication of pests is undertaken would be, in the first place, to use the method to reduce overstocking in areas already free of the particular pest or pests, and only then to try to increase the total head of cattle by extending still further the use of pasturage made safe by the eradication measures.

The theme, therefore, on which I would wish to close my address is a quotation from the report by H. E. Hornby on *Animal Trypanosomiasis in East Africa, 1949*, because I am sure that he would agree that his words have a wider significance than the context in which they were used. The quotation is: "The point to be driven home is that animal husbandry demands both pasture management and disease control. Improvement of pastures often encourages parasites by giving these protection from the sun, therefore it must be accompanied by disease control. This alone leads to overstocking, so it must be accompanied by pasture management to save the soil."

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RADIATION CANCER OF THE PHARYNX

BY

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There have been many examples of radiation cancer of the skin, but only a limited number of cases have so far been reported in which a tumour has developed in the deep tissues as a sequel to external therapeutic irradiation. The case histories of four patients who developed tumours in the laryngopharynx many years after irradiation of the neck may therefore be of some interest.

The majority of radiation tumours in the deep tissues have been sarcomata, which have arisen in bone. Hatcher (1945) reported three cases of sarcoma developing in irradiated bone, and reviewed the literature on the subject. He found a total of 24 cases. In 17 of these the condition primarily treated by irradiation was tuberculous arthritis, and the interval between irradiation and the appearance of a tumour varied between 3 and 12 years. There was a tendency for these tumours to develop when irradiation had been carried to excess in the form of repeated doses administered over a long period of time.

The only other cases in which cancer has been recorded as developing in the deep tissues after external therapeutic irradiation may conveniently be considered together, since their sites of origin lie within a somewhat limited anatomical field. Four of these tumours occurred in the laryngopharynx, one arose in the larynx, and one in the thyroid gland.

The first case was reported by Lossen (1936). A man was given x-ray treatment from 1919 to 1922 for tuberculous glands in the neck. In 1929 he developed a necrotic ulcer in the skin of the neck, and in 1935, 13 years after treatment, he developed a carcinoma of the larynx.

Kruchen (1937) reported the case of a woman aged 65 who developed a tumour on the posterior wall of the hypopharynx 20 years after irradiation of the neck for a goitre. The tumour had the structure of a carcinoma simplex. The skin on the anterior aspect of her neck was grossly telangiectatic.

Kindler (1944) reported two further cases. In the first of these a man of 54 developed an adenocarcinoma in the left lobe of the thyroid gland 24 years after x-ray treatment for tuberculous glands in the neck. He had marked post-radiation atrophy and scarring in the overlying skin and subcutaneous tissues. His second case was that of a woman of 59 who developed a tumour almost completely surrounding the pharynx at the post-cricoid level 20 years after irradiation of her neck for thyrotoxicosis.