Reservoir hosts and natural foci of human protozoal infections

Autor(en): **Hoare, Cecil A.**

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Wellcome Laboratories of Tropical Medicine, London

Reservoir Hosts and Natural Foci of Human Protozoal Infections.*

By Cecil A. Hoare

Introduction.

Among the diseases of man there are a number that are shared by lower mammals, which serve as sources or reservoirs of human infection and are therefore of importance both in human and veterinary medicine. Indeed such infections, known as zoonoses, represent a field where medical and veterinary science meet on common ground, especially in the sphere of epidemiology. In epidemiology Virchow's term Zoonosis is generally used in an anthropocentric sense, but it is actually a special kind of Paraxenosis, a name proposed by Moshkovsky (1943) for diseases that affect—in addition to any given host—other species of animals, which represent interchangeable links in the circulation of the parasite. In zoonosis, one of the hosts involved is man.

Zoonoses are known in various viral, bacterial, protozoal and helminthic diseases of man. The direction in which the infection circulates between man and other mammalian hosts is indicated by the following subdivisions of zoonosis:

(1) *Anthropozoonoses* (Koegel, 1951)—infections of man acquired from other vertebrates: e.g. tick-borne encephalitis, yellow fever, plague, Chagas' disease, Rhodesian Sleeping Sickness, leptospirosis, tick-borne relapsing fever, trichinosis.

(2) *Zooanthroponoses* (Wagener, 1957)—infections of vertebrates acquired from man: e.g. human tuberculosis in cattle, amoebiasis in dogs, schistosomiasis *(mansoni)* in baboons.

(3) *Amphixenoses* (Hoare, 1960)—infections interchangeable between man and other vertebrates: e.g. Chagas' disease, schistosomiasis *(japonicum)*.

(4) *Anthroponoses* (Pavlovsky, 1948)—infections at present restricted to man but presumably evolved from infections of lower animals: e.g. malaria, typhus and relapsing fevers.

Apart from its practical importance, the subject of zoonoses is essentially a chapter in the natural history of parasitic infections which concerns the ecological and evolutionary aspects of the host-parasite relations in the diseases in question. The problem viewed from this standpoint is therefore of interest not only to parasitologists but to biologists in general. The recognition of the epidemiological significance of zoonoses has led to intensive studies of the ecological conditions under which infections are maintained among wild animal hosts and vectors; from the valuable information thus obtained there has emerged a coherent pattern which provides a rational basis for the control of these diseases.

The interdependence between human and animal infections has been more fully studied in the case of protozoal parasites, to which this review is devoted. Before proceeding further, it is necessary to mention certain fundamental

* Dedicated to Rudolf Geigy with the author's cordial regards and sincere admiration.

principles regarding the host-parasite relationship in these infections, which concern the interaction between the human host and his protozoal parasites. Among the latter a number are pathogens producing diseases—such as malaria, sleeping sickness and amoebiasis—which vary in severity and frequently terminate fatally. It should be noted, however, that even the disease-producing protozoa do not invariably manifest their pathogenicity, for under certain conditions they may live in the human host without causing any damage to him. Indeed, from the biological point of view, a state of equilibrium between host and parasite represents the normal condition, since it enables the parasite to complete its life-cycle and ensures the survival of its species by transfer to new hosts. However, when the infection provokes disease, especially with lethal results, the parasite is frequently unable to propagate its species. When the resistance of the host and the virulence of the parasite are well balanced and the two live in harmony, the host is said to be a carrier of the parasite. Since the carrier state provides the most favourable conditions for the survival of both parasite and host, symptomless carriers are of primary importance in the maintenance and dissemination of protozoal diseases in human communities. On the other hand, the diseased condition reflects an imperfect adjustment of the relations between the human host and the parasite, probably indicating that the association between them has only recently been established. From this point of view, those animals in which a parasite produces no symptoms and which act as its carriers, can be regarded as the original and natural hosts of the given parasite.

The most interesting examples of protozoonoses are provided by leishmaniases and trypanosomiases.

Leishmaniases.

As is known, there are 2 main types of leishmaniasis:

(a) Cutaneous leishmaniasis, represented in the Old World by Oriental Sore (caused by *Leishmania tropica*) and in the New World by Espundia (caused by *L. braziliensis*), and (b) Visceral leishmaniasis or Kala-Azar (caused by *L. donovani*), which occurs both in the Old and New Worlds. All forms of leihmaniasis are transmitted by sandflies *(Phlebotomus)*.

Oriental Sore.

The epidemiology of Oriental Sore has been studied mainly in Middle Asia by Russian workers (KOJEVNIKOV, 1941, 1942; LATYSHEV & KRIUKOVA, 1942), who established the existence there of 2 distinct types of cutaneous leihmaniasis: (1) the urban or "dry" type, which is prevalent in towns and is characterized by a chronic course with late ulceration, and (2) the rural or "moist" type, occurring in open desert country and running an acute course with early ulceration. The incidence of infection among human beings with the rural type of Oriental Sore is particularly high in isolated settlements situated on the fringes of the open desert,

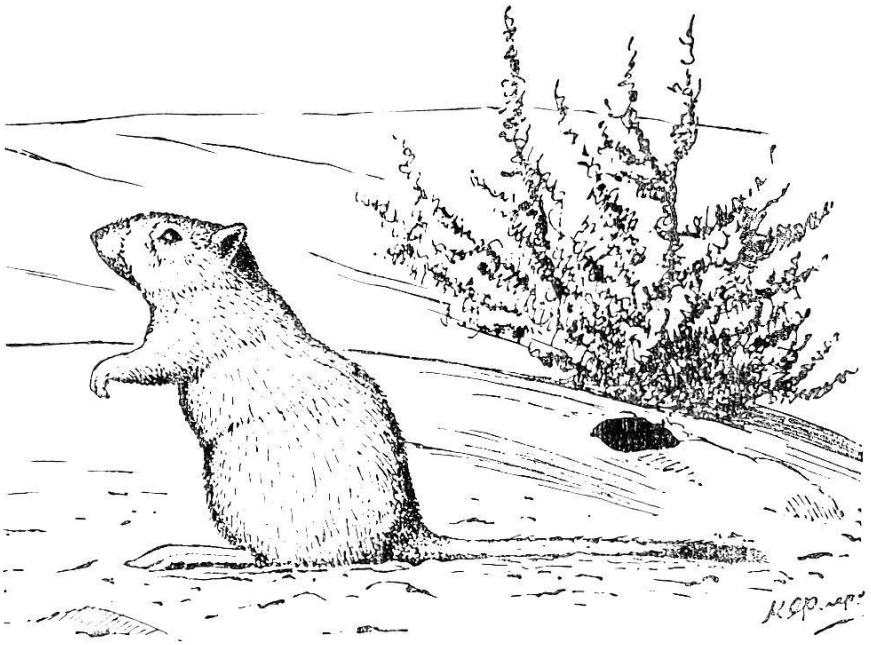

Fig. 1. Gerbil, *Rhombomys opimus:* reservoir host of Oriental Sore in S.W. Asia. (After PAVLOVSKY, 1934.)

where people frequently become infected after visiting uninhabited areas. The source of such infections was traced to infected sandflies living in the burrows of various ground squirrels, especially the gerbil *Rhombomys opimus* (Fig. 1), and transmitting the infection among them. These rodents naturally harbour *L. tropica,* which produces typical sores on their noses and ears, and it was demonstrated experimentally that the gerbil parasites were infective to man and *vice versa.* It was thus proved that in the desert areas of Soviet Middle Asia ground-squirrels are the reservoirs of human cutaneous leishmaniasis of the "moist" type (cf. HOARE, 1944).

A similar state of affairs was found in Persia, where the source of human Oriental Sore is also represented by infected gerbils, *R. opimus* (ANSARI & FAGHIH, 1953), and there is likewise some indication of the existence of rodent reservoirs of human cutaneous leishmaniasis in Africa and in South America. Thus, "Bouton de Biskra" in North Africa and in the former French West Africa has all the charcteristics of the "moist" type of Oriental Sore (LATYSHEV et al., 1953; LEFROU, 1948), and it is significant in this connexion that African ground-squirrels are highly susceptible to infection with human strains of *L. tropica,* while their ecology is similar to that of the rodents which are proven carriers of Oriental Sore in Asia. As regards South America, recent work has incriminated the agouti, *Dasyprocta aguti* (DEL PONTE, 1952) and the paca, *Cuniculus paca* (FORATTINI & SANTOS, 1955) as reservoirs of Espundia *(L. braziliensis)* in Paraguay and Brazil respectively,

while in Central America it was shown that spiny rats (*Proechimys* spp.) act as reservoirs of "Pian-bois" (HERTIG et al., 1957), and other rodents (*Ototylomys, Peromyscus, Heteromys*) were found to be naturally infected with Chiclero's ulcer (LAINSON & STRANGWAYS-DIXON, 1962). There is also considerable circumstantial evidence of the existence of natural enzootic foci of cutaneous leishmaniasis in Latin America (GARNHAM & LEWIS, 1959; PIFANO, 1960; PESSÔA, 1961).

In the light of the Russian observations, an attempt was made to control the disease in a primitive settlement situated on the fringes of a desert in Turkmenistan, where 70% of the population were affected with Oriental Sore of the "moist" type. After it had been ascertained that the flight-range of sandflies does not exceed 1500 metres from their breeding places in the desert, some half a million gerbil burrows were poisoned with chloropicrin over an area within a radius of 1200 metres from the village. A year later it was found that—as a result of this operation—the incidence of human infection in this village had dropped almost to zero. This campaign not only eradicated a hyperendemic focus of cutaneous leishmaniasis, but also proved the correctness of the epidemiological premises upon which the experiment was based. Since the introduction of this method of control of the desert form of Oriental Sore, it has been widely and successfully used in Soviet Russia (PETRISCHEVA, 1961).

The position in large rural settlements of Middle Asia is somewhat different, for here agricultural development had forced the wild rodents to retreat into open country, leaving the oasis practically free of infection, except along the periphery adjoining the open desert, where the incidence of human infection is low (2-3%) (LATYSHEV, KRIUKOVA & POVALISHINA, 1951). A further step in the evolution of the epidemiology of Oriental Sore is found in the towns of Middle Asia, where the "moist" type of the disease is replaced by the "dry" urban type. In urban areas the sandflies had completely lost contact with their wild rodent hosts, and established themselves in the proximity of man, having become synanthropic or "domiciliated". They presumably now transmit cutaneous leishmaniasis directly from man to man, since in towns no reservoir mammalian hosts have hitherto been detected with certainty (HOARE, 1944).

Visceral Leishmaniasis.

We now turn to Visceral Leishmaniasis which in represented by four main types of disease: (1) the classical Kala-Azar confined

to India, which affects chiefly adult persons, but does not occur in dogs; (2) the Mediterranean or infantile Kala-Azar, which is prevalent in children and occurs throughout the Mediterranean Basin, in Middle Asia, China, and Central and South America; (3) Sudanese Kala-Azar, which chiefly affects the same age-groups as in India and likewise does not occur in dogs, and (4) East-African Kala-Azar, which is similar to the Sudanese form, but is apparently associated with rodent reservoirs.

In endemic areas of the Mediterranean type of Kala-Azar, dogs are found to be naturally infected with *Leishmania donovani,* usually without showing any clinical manifestations. There is intimate connexion between the human and canine diseases, revealed in the close parallelism of their geographical distribution, incidence, and seasonal occurrence. Moreover, it has been demonstrated—in Sicily, Middle Asia and China—that systematic destruction of dogs in endemic areas has brought about a marked diminution in the incidence of human infection. The dog is therefore the reservoir of the Mediterranean form of visceral leishmaniasis, and the disease is in fact a zoonosis, being prevalent in up to 25% of these animals, from which it spreads to children. Transmission of the infection is facilitated by the fact that in dogs the parasites invade the skin, whence they are more readily picked up by the sandfly-vector (ADLER & THEODOR, 1932; DEANE & DEANE, 1962).

Nothing was known about reservoir hosts of visceral leishmaniasis among wild mammals till 1950, when Russian observers (LATYSHEV, KRIUKOVA & POVALISHINA, 1951) investigated outbreaks of Kala-Azar in Middle Asia among workmen engaged in the reclamation of previously uninhabited land in Tadzhikistan. The epidemiological situation pointed to the existence of some natural local focus of the infection, which was confirmed by the discovery of spontaneous visceral leishmaniasis among jackals, *Canis (Thos) aureus* (Figs. 2, 3), which are common in the jungles of this region. It was also established that natural enzootic foci of the disease were always present in the area in question, and when human beings first came in contact with jackals, which frequently visit human settlements in search of food, they acquired the disease from sandflies feeding on these animals, with the result that the latter became reservoir hosts of Kala-Azar (PETRISCHEVA, 1962). Again it is significant that the infection in jackals runs a symptomless course, indicating the antiquity of the association between the parasite and this host.

Subsequently, when the primitive settlements developed into modern villages surrounded by cultivated land, the jackals were forced out or eliminated. In some instances this caused the epi-

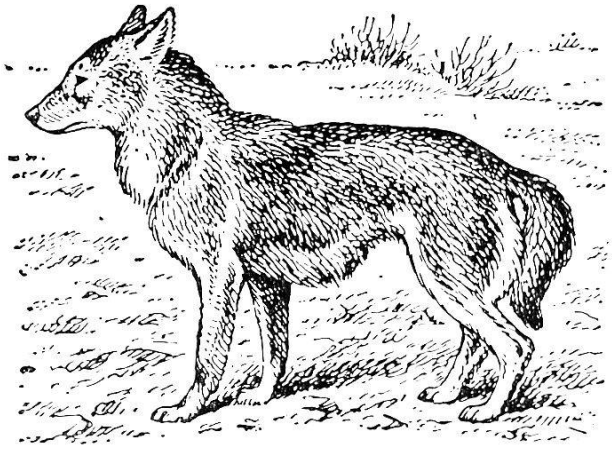

Fig. 2. Jackal, *Canis (Thos) aureus:* reservoir host of Kala-Azar in S. W. Asia. (From Soviet Encyclopaedia, 1957.)

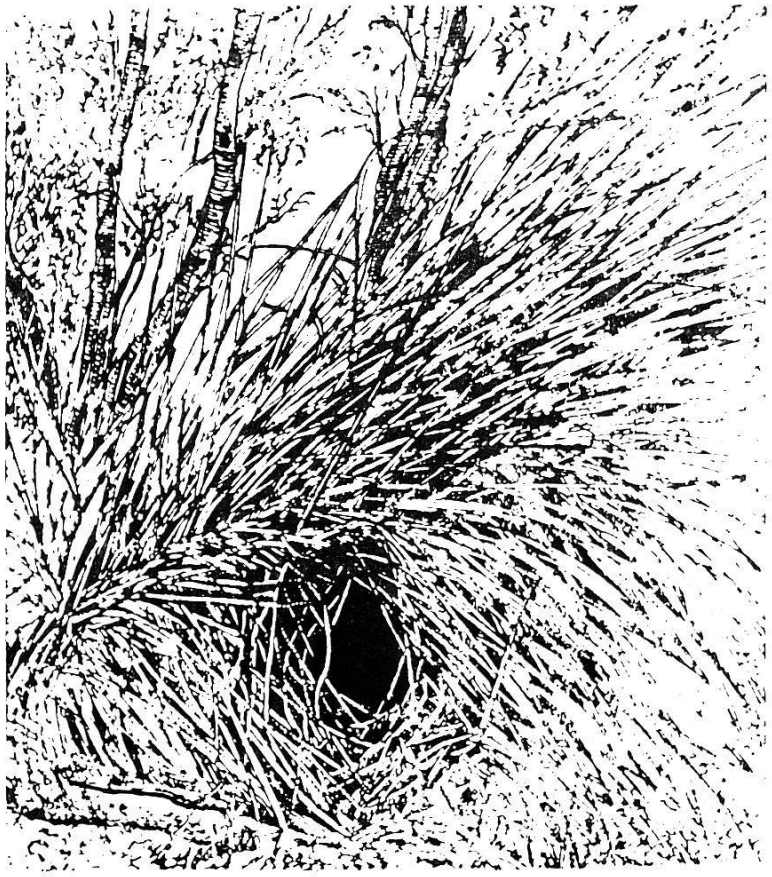

Fig. 3. Lair of jackal. (After JANKEVIC, 1954.)

demiological chain to rupture, bringing the outbreaks of human disease to an end. However, in other cases, represented by towns of Middle Asia and the Caucasus, where Kala-Azar is endemic, the disease had adapted itself to man as one of its hosts, while retaining its infectivity for domestic dogs, whose ancestors must have originally acquired the infection from their wild relatives, the jackals. It is conceivable that in the Mediterranean area dogs might sim-

ilarly have acquired their infection in the remote past, from some wild Canidae, e.g. foxes. In fact, the role of foxes as reservoir hosts of Kala-Azar in some parts of Middle Asia (Kirgizia) is already suspected (LATYSHEV, SHOSHINA & POLIAKOV, 1951), while in South America it has recently been reported that foxes (*Lycalopex vetulus*) (Fig. 4), captured in rural areas of Brazil where Kala-Azar is endemic, were naturally infected with *L. donovani,* whereas in the settlements the reservoir hosts were represented by dogs (DEANE,

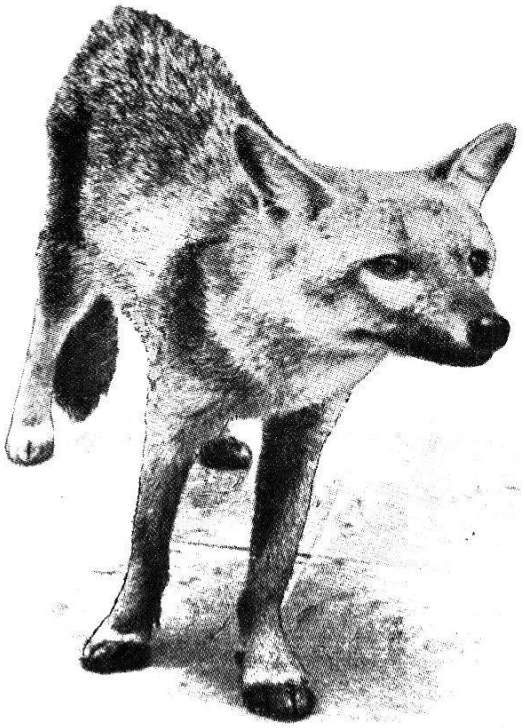

Fig. 4. Fox, *Lycalopex vetulus:* reservoir host of Kala-Azar in Brazil. (After DEANE, 1956.)

1956). However, in foxes the disease may run an acute course. Since it is thought that Kala-Azar in South America had been imported from Europe by the early settlers, this anomaly is probably due to the fact that the infection in foxes is not indigenous, but was acquired from dogs, during raids on human dwellings in search for food (DEANE & DEANE, 1962). Finally, there is strong evidence of the existence of wild animal reservoirs of human Kala-Azar in Kenya, where the disease is of the Sudanese type (HEISCH, 1954), for quite recently natural infection with *L. donovani* has been demonstrated in local ground-squirrels (*Xerus rutilis*) and gerbils (*Tatera*) (HEISCH, 1957; MANSON-BAHR, 1959).

The situation in India is still obscure, for all attemps to discover a reservoir host there have so far failed. However, it is difficult to admit that the epidemiology of Indian Kala-Azar is so different

from that in other types of leishmaniasis: it is conceivable that in India infection with *L. donovani* also occurs in some lower mammal— other than dog—but remains undetected (HOARE, 1945, 1954).

Trypanosomiases.

We now turn to the epidemiology of Human Trypanosomiases, represented by Sleeping Sickness in tropical Africa and by Chagas' Disease in America, to which may be added infection with *Trypanosoma rangeli* in South America.

Chagas' Disease.

As is known, Chagas' Disease, which occurs chiefly in South and Central America, is caused by *Trypanosoma cruzi,* and is transmitted by Reduviid bugs of the genera *Triatoma, Panstrongylus* and *Rhodnius*. This disease is a typical zoonosis. Since its discovery in 1909, it has been noted that infected bugs are encountered in most of the warm regions of the New World, including parts of the United States, where they are found not only in endemic areas of Chagas' disease, but also in unpopulated territories, where the bugs inhabit the burrows and nests of various wild mammals, especially armadillos (*Dasypus*), opossums (*Didelphys* spp.), wood rats (*Neotoma* spp.) and raccoons (*Procyon* spp.) (Figs. 5-9). All these animals can be spontaneously infected with *T. cruzi,* which does not produce in them any clinical manifestations.

Fig. 5. Armadillo, *Dasypus* sp.: reservoir host of Chagas' Disease. (After CAHALANE, 1947.)

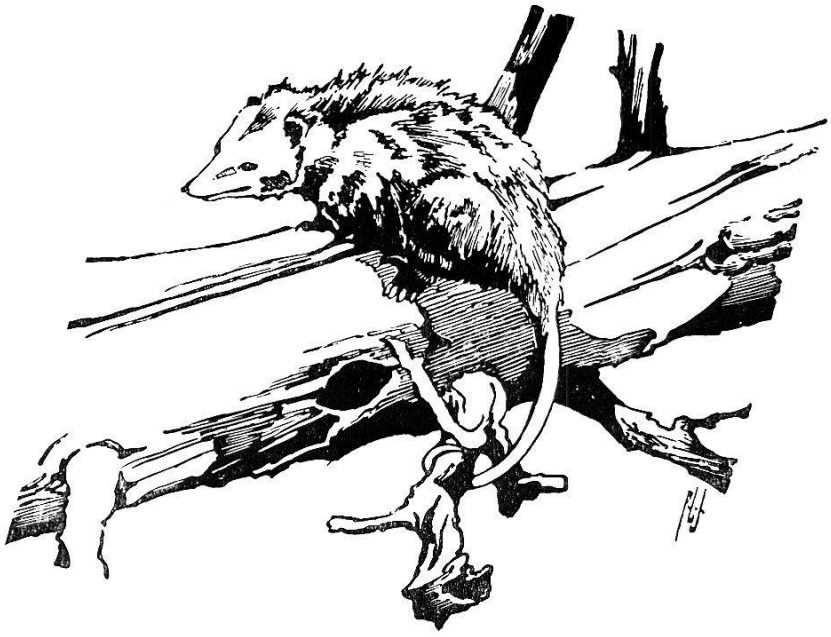

Fig. 6. Opossum, *Didelphys* sp.: reservoir host of Chagas' Disease. (After CAHALANE, 1947.)

Fig. 7. Wood rat, *Neotoma* sp.: reservoir host of Chagas' Disease in U.S.A. (After CAHALANE, 1947.)

The habitats of these animals thus represent natural enzootic foci of the infection, which circulates from the vector to the vertebrate host and back, quite independently of man. But, as in the case of the desert type of cutaneous leishmaniasis in Asia, if man intrudes into such a natural focus he may accidentally acquire Chagas' disease when attacked by "wild" bugs infected from the feral reservoir host (DIAS & CHANDLER, 1949; WALTON et al., 1958; MCKEEVER et al., 1958; HERMAN & BRUCE, 1962). It is interesting to note here that transmission of the infection is more effective in

the case of bugs feeding on the feral reservoir host than in those feeding on the human host, for the trypanosomes are always present in the blood of oppossums, whereas in man they appear there only periodically (ESPINOSA, 1953).

As regards the terrain in which natural foci of Chagas' disease occur, it varies with the habits of the reservoir host. Thus, the dens of armadillos are typically found among rock formations, covered with vegetation and situated near water. Opossums prefer mixed forest near water, but will also settle down in territories cultivated by man. They build their nests in hollow trees or in cavities among rocky slopes, but may also occupy empty burrows of ground

Fig. 8. Nest of wood rat. (Courtesy of Dr. S. F. WOOD.)

squirrels. Wood rats build large nests (Fig. 8) of dry twigs or grass in ravines and woods, as well as near human dwellings. Raccoons are encountered chiefly in forests, where they live in hollow trees (Fig. 9), but in the United States they frequently raid land occupied by man in search of food. Moreover, in cases where reclamation of virgin land by man has led to the destruction of the natural biotopes of raccoons (e.g. by cutting down trees and cultivation of fields), these animals adapted themselves to the new territory, where they find favourable conditions of existence (WHITNEY & UNDERWOOD, 1952). Cases when the feral reservoir hosts establish themselves in the proximity of man are examples of irradiation of

Fig. 9. Raccoon, *Procyon lotor:* reservoir host of Chagas' Disease in U.S.A. (After WHITNEY & UNDERWOOD, 1952.)

old enzootic foci into a new territory, where an endemic focus of Chagas' disease is created (PAVLOVSKY, 1948). All the feral reservoir hosts lead a nocturnal life, spending the daytime in their dens, which they share with triatomine vectors.

As already mentioned, man may acquire Chagas' disease accidentally, when visiting a territory where natural foci are present, but in those cases when the donor and vector settle near human dwellings the risk of infection increases considerably, since the winged bugs can fly into the houses. Although in some areas of South America feral hosts play a definite role as reservoirs of Chagas' disease (PESSÔA, 1958), the main source of human infection are the synanthropic Reduviid bugs, such as *Triatoma infestans* and *Panstrongylus megistus,* which have adapted themselves to life in houses and out-buildings, where they feed on human blood. In such cases, enzootic foci had irradiated into zones of human habitation, by migration of the vectors, which have established themselves there and become domiciliated. In South America the primitive shacks (Brazilian *cafúas,* Spanish *ranchos*) of the inhabitants provide ideal biotopes for the bugs, thousands of which live and breed in cracks of the walls, and attack the sleep-

ing inmates during the night. In such endemic foci the vectors, having lost contact with the feral reservoir hosts, also feed on the blood of domestic animals, which thus serve as domestic reservoirs of the disease. The most important reservoirs in endemic areas are dogs, cats and pigs, all of which have been found naturally infected with *T. cruzi* (DIAS & CHANDLER, 1949).

Such is the situation in South America. However, in North America the position is quite different. In spite of the wide distribution in the Southern States (Texas, New Mexico, Arizona, California, Florida) of triatomine vectors and reservoir hosts (represented by wood rats, opossums and raccoons) between which *T. cruzi* circulates under natural conditions, only two spontaneous cases of human Chagas' disease and two cases of experimental infection with strains isolated from local triatomine bugs have so far been reported from the United States (WOODY & WOODY, 1955; GOBLE, 1959; PACKCHANIAN, 1943). The reason for the scarcity of this disease in that country is not clear. It may be due to a higher standard of living than in South America, when there is less chance of coming in contact with the bugs, or to the fact that North American strains of *T. cruzi* are less virulent than South American ones (GOBLE, 1959). In the latter case it is conceivable that such strains cause only latent symptomless infections which escape detection (PACKCHANIAN, 1949; YAEGER, 1959). This is attested by the fact that in a recent survey, carried out in Texas by the complement fixation test (WOODY, DEDIANOUS & WOODY, 1961), Chagas' disease was detected in a number of persons living in farms. Their houses were infested with triatomine bugs (*Triatoma gerstaeckeri*), while opossums and wood-rats lived nearby. It has also been suggested (DIAS & CHANDLER, 1949) that the frequency of human infection might be influenced by the different habits of the local vectors. Thus South American triatomine bugs defecate as they feed, whereas North American ones—notably *Triatoma protracta*—defecate only after completing their meal and moving away from the site of the bite. In the latter case the vector is less liable to contaminate the wound or mucous membranes of the host, so that the chances of transmitting the infection are considerably reduced.

We now turn to the methods of control of Chagas' disease. Unfortunately this disease does not lend itself to chemotherapy, for up to the present no specific drugs have been found for its treatment. On account of the scattered distribution of the natural foci, the elimination of reservoir hosts is impracticable. In recent years the control of Chagas' disease has been directed towards the destruction of the vectors in endemic areas and to an improvement

of living conditions of the population. In this respect much has been done in Brazil: for instance repeated treatment of dwellings with hexachlorane has resulted, by 1957, in the eradication of bugs in 1½ million houses (N. P. DIAS, 1959; LIMAVERDE, 1959). In some endemic areas (e.g. in the town of Bambui) Chagas' disease was completely liquidated in this way, as shown by the absence of new cases of infection (E. DIAS, 1957).

Trypanosoma rangeli.

Another interesting trypanosome occurring in parts of South and Central America (Venezuela, Colombia, Guatemala) is *T. rangeli,* which commonly infects human beings and dogs, without causing any symptoms of disease in either of these hosts, and is transmitted by the triatomine bug, *Rhodnius prolixus.* This trypanosome has also been recorded from *Cebus* monkeys and opossums *(Didelphys),* which are probably the reservoir hosts of the human and canine infection (HOARE, 1953; PIFANO, 1954; FLOCH & FAURAN, 1954; ZELEDON, 1954).

African Sleeping Sickness.

In the case of African Sleeping Sickness, our knowledge of the epidemiological factors is less satisfactory (cf. ASHCROFT, 1959). As is known, Sleeping Sickness is represented by two forms of the disease: the chronic Gambian type and the acute Rhodesian type, but the causative organisms of both are closely related or even identical, *Trypanosoma rhodesiense* probably being a virulent race of *T. gambiense.* Moreover, both these species are morphologically indistinguishable from *T. brucei,* which causes Nagana in livestock.

The question regarding the reservoir hosts of Sleeping Sickness has not been fully elucidated (cf. HOARE, 1948), mainly owing to the fact that in the endemic areas tsetse-flies, on the one hand, and domestic or wild mammals, on the other, may be naturally infected with any of these trypanosomes, whose nature cannot always be established with certainty. Therefore, in most cases the identification of the trypanosomes detected in natural infections is based on indirect epidemiological data. Thus, trypanosomes found in animals from localities where the human disease is unknown are most probably *T. brucei,* while those occurring in areas where the Rhodesian disease is endemic might be either *T. brucei* or *T. rhodesiense,* their differential diagnosis depending upon the results of inoculation of human volunteers: if they become infected, the parasite is *T. rhodesiense,* if not—it is *T. brucei*

(HOARE, 1948). In endemic areas of the Gambian disease *T. brucei* can be differentiated from *T. gambiense* by its greater virulence for laboratory rodents. Apart from cases of spontaneous infection of wild ruminants with trypanosomes of the *Brucei* group, one of the main arguments pointing to the existence of reservoirs of Sleeping Sickness is the fact that the human trypanosomes can be passaged cyclically through wild and domestic ruminants in the course of many years (cf. DUKE, 1936), while in the case of *T. rhodesiense* it has been proved that this parasite had not lost its power to infect man after passages for 23 years (WILLETT & FAIRBAIN, 1955; ASHCROFT, 1959).

In the Rhodesian and Gambian forms of Sleeping Sickness, the part played by animals as reservoirs of human infection is different, because each of these diseases has its specific vectors, which have their own ecological requirements, including distinct biotopes and food preferences. Although vectors of the acute and chronic forms of this disease belong to different groups of *Glossina*, namely *morsitans* and *palpalis*, the mode of existence of all tsetse-flies has common features. They are shade-loving insects that avoid direct sunlight and live among bushes and trees, under the shelter of which they deposit their larvae in the soft and moist earth. Since the biotopes of tsetse-flies are also associated with certain plant communities, they have a diffuse distribution known as "fly belts", where the vectors spend all their life, emerging into the open in search of food only for a short distance. However, they may be passively transported beyond their habitat by food-animals (BUXTON, 1955).

The ecology of the vectors of the two types of Sleeping Sickness has the following features. *Glossina morsitans* and related species, which are the chief vectors of *T. rhodesiense*, inhabit savannah-like woodland (Fig. 10) where they are restricted to biotopes represented by groves with a definite type of woody vegetation (e.g. "miombo", comprising *Berlinia, Isoberlinia* and *Brachystegia* in various combinations). This type of country also abounds in game animals, especially antelopes, on which the flies feed. That these tsetse-flies and wild ruminants are linked in a food-chain was repeatedly demonstrated by the new precipitin and agglutinin-inhibition tests devised by WEITZ (1956a, b) for the analysis of blood ingested by these insects. Moreover, it has been demonstrated that antelopes in such country may be naturally infected with trypanosomes of the *Brucei* group, to which *T. rhodesiense* belongs. In the past there was considerable circumstantial evidence that man may acquire the infection from wild mammals. Thus, in certain parts of Tanganyika that are endemic for Rhodesian Sleeping Sickness, the entire

Fig. 10. Habitat of *Glossina morsitans*. (After GEIGY & HERBIG, 1955.)

population was evacuated some years ago and no one was allowed to enter these areas, where only game animals and tsetse-flies remained in occupation. Nevertheless, on a number of occasions persons who had wandered into these uninhabited localities became infected with *T. rhodesiense,* and there could be no doubt that the disease was acquired by them from tsetse-flies which had fed on infected wild mammals (FAIRBAIRN, 1948; JACKSON, 1955). There is also convincing epidemiological evidence of the existence in Tanganyika and Southern Rhodesia of enzootic foci of Rhodesian Sleeping Sickness (APTED et al., 1962).

The correctness of this hypothesis was recently confirmed in East Africa by experimental inoculation of volunteers: first, with trypanosomes isolated from bushbuck (*Tragelaphus scriptus,* Fig. 11) in Kenya (HEISCH et al., 1959), and, secondly, with a strain isolated from wild tsetse (SOUTHON & ROBERTSON, 1961). From these facts it is evident that Rhodesian Sleeping Sickness is a typical anthropozoonosis. Under natural conditions in the bush, the infection circulates independently of man between donor-antelopes, their vectors and recipient-antelopes, while in endemic zones the circulation of the parasite involves man as well, with the result that he becomes both donor and recipient of the infection.

Fig. 11. Bushbuck, *Tragelaphus scriptus:* reservoir host of Rhodesian Sleeping Sickness. (Courtesy Wellcome Museum of Medical Science.)

Vectors of the Gambian type of Sleeping Sickness are represented by *Glossina palpalis* and allied species. They are riverine insects that live among the trees forming the gallery forest along the edges of the waterside, to which their activities are restricted (Fig. 12). The zones occupied by *G. palpalis* are characterized by a scanty mammalian fauna, but are usually situated near well-populated places, the inhabitants of which frequently come in contact with the vectors when visiting the river-banks for water, or washing, as well as for fishing. Although under these conditions tsetse-flies of the *palpalis* group will attack man, their main food-hosts are reptiles, especially crocodiles. Evidence of intimate association between *G. palpalis* and crocodiles is provided by a number of facts. Thus, I have shown (HOARE, 1931, 1932) that this fly is the intermediate host of two protozoal parasites specific to the Nile crocodile: *Hepatozoon pettiti* and *Trypanosoma grayi*. I also found that the infection rate with *T. grayi* among the "wild" tsetse—i.e. under natural conditions—was comparable to that among experimentally infected

Fig. 12. Habitat of *Glossina palpalis.*

flies, hence it can be inferred that the crocodile is the main source of food for *G. palpalis.* Furthermore, the preference of this species of tsetse for reptilian blood was demonstrated serologically (WEITZ, 1956a, 1960), while COTT (1961) frequently observed these flies in the act of feeding on crocodiles in Uganda. This author also states: "That the tsetse prefers reptilian to mammalian blood is also indicated by the fact that where crocodiles are abundant, as at Magungu, *G. palpalis,* though plentiful, is hardly troublesome to man. On the other hand . . . in areas of the Ruzizi basin, where crocodiles were scarce, tsetse flies were less numerous but attacked man more vigorously" (*loc. cit.*, p. 310).

On account of these peculiarities of the biotopes of *G. palpalis,* it is thought that the disease caused by *T. gambiense* is essentially an anthroponosis, which is transmitted mainly from man to man, though there is both experimental and epidemiological evidence that some domestic animals, especially pigs and goats, living in close association with man in endemic areas, might serve as reservoir hosts of human infection (DUKE, 1928; VAN HOOF, 1947; FAIRBAIRN, 1954).

A clue to the genesis and evolution of Sleeping Sickness is provided by *T. brucei,* the causative agent of Nagana in domestic animals and also harboured in natural foci by antelopes, which are the reservoir hosts of this disease. Since *T. brucei* is morphologically indistinguishable from *T. rhodesiense* and *T. gambiense,* there can be no doubt about the close phylogenetic affinity between these three species. The only essential feature distinguishing *T.*

brucei from the other two species is its inability to infect man, a fact established by numerous unsuccessful attempts to infect volunteers. However, on one occasion VAN HOOF (1947) produced experimental infection in man with a Congo strain of *T. brucei,* but the infection was very slight and transient, lasting only 3 weeks. In assessing the value of these experiments it should be borne in mind that the susceptibility of the human organism to infection even with his own specific trypanosomes may vary according to the physiological state of the host, parasite or vector, and may also be influenced by other factors. It is therefore conceivable that in the past—or even at present—exceptional virulence of a strain produced by mutation or a lowering of resistance on the part of the human organism might have created conditions enabling *T. brucei* to establish itself in man. An example of such a case is provided by VAN HOOF's experiment; moreover there is some epidemiological evidence that sporadic cases of human infection with *T. rhodesiense* in the Zambesi basin must have been derived from *T. brucei* (ORMEROD, 1961).

From the foregoing facts, the genesis of Sleeping Sickness can be visualized as follows. Nagana is a purely animal infection maintained in natural enzootic foci, where it normally circulates between the tsetse-vectors and antelopes, but when domestic animals intrude into such zones they are also drawn into the circulation and become infected with *T. brucei.* As already pointed out, human beings exposed to similar conditions do not acquire an infection, but in those exceptional cases when this took place *T. brucei* probably caused in non-immune human hosts an acute disease, and became known as *T. rhodesiense,* which still retains its connexion with the game tsetse as vectors and with antelopes as reservoirs of the infection in enzootic foci. However, in waterside zones the trypanosome became better adapted to man and produced in him a chronic disease attributed to *T. gambiense.* In such endemic areas the role of vectors was taken over by tsetse-flies of the *palpalis* group, which are associated with reptiles as food hosts and do not depend upon wild mammals. The chronic course of the infection caused by *T. gambiense* indicates that in the Gambian form of Sleeping Sickness the parasite and host are better adapted to each other than in the Rhodesian form. Moreover, the different virulence of *T. gambiense* and *T. rhodesiense* is in some way correlated with the possession of distinct vectors—*Glossina* of the *palpalis* and *morsitans* groups, respectively. However, we are still in ignorance about many of the factors affecting the pathogenesis of Sleeping Sickness.

In the light of this hypothesis, *T. brucei* may be regarded as the

ancestral form, which gave rise first to *T. rhodesiense* and then to *T. gambiense*. Furthermore the evolution of the respective diseases apparently proceeded from a purely animal infection (Nagana) to an anthropozoonosis (Rhodesian Sleeping Sickness) and finally to a pure anthroponosis (Gambian Sleeping Sickness).

The choice of methods for the control of Sleeping Sickness depends largely on local conditions, on the cost of the operation, and on the comparative effectiveness of the methods employed. In general the measures are directed, on the one hand, against the pathogen and, on the other, against the vector (BUXTON, 1955). Mass diagnosis and prophylactic treatment with pentamidine, which are employed in the case of the Gambian type in former French and Belgian territories, have resulted in a considerable reduction of the incidence of the disease. However, preventive treatment is not suitable in the case of the Rhodesian type because of the existence of reservoirs among wild ruminants, which provide a permanent source of new infection.

In British territories the campaign is directed mainly against the vectors. In view of the vast area of distribution of tsetse-flies in Africa their extermination by insecticides or by trapping can only be applied on a limited scale, in isolated foci. The control of tsetse-flies is based essentially on a knowledge of their ecology. Its aims are, accordingly, first to break the contact between vector and man, secondly to modify the habitat of these insects in such a way as to render it unsuitable for their existence, and thirdly to deprive them of their sources of food. Moreover, the choice of methods depends not only on the ecological requirements of different species of *Glossina,* but also on local geographical conditions.

The control measures against the fly consist of cutting down or burning trees and bushes. In the haunts of the *palpalis* group, clearings made along the waterside in places frequented by people protect them against the attacks of the flies, since the latter avoid open spaces. In the woodland savannah areas of the *morsitans* group, the same result is obtained by clearing corridors through zones infested by tsetse-flies. This results in the formation of a protective barrier, isolating the biotopes of tsetse. However, in view of the rapid regeneration of tropical vegetation, these measures can have a lasting effect only if such corridors are reclaimed by man, since agricultural development causes the tsetse-flies to retreat. In addition to this purely mechanical clearing, some success has been attained by discriminative or selective removal from plant communities of particular species of trees that are essential to the well-being of *Glossina.*

Finally, in zones of flies of the *morsitans* group, which feed on

wild animals, the incidence of the disease can be reduced by the destruction of game, thereby eliminating potential reservoirs of the infection and depriving the tsetse of their main source of food. However, the mass extermination of wild ruminants which has been practised in some parts of Africa, presents a serious threat to its already dwindling fauna. It is therefore more rational to destroy selectively only those species of animals for which the tsetse-flies show a predilection, and which can now be determined by analysis of the blood ingested by these insects. Fortunately, there has recently been a great improvement in the situation, for it is now realized that the conservation of African game animals is potentially of economic importance. The vandalic policy of its destruction is therefore being largely abandoned, except in restricted areas, where it is combined with bush clearance, followed by agricultural settlement (HUXLEY, 1962).

Other Protozoal Infections.

In the case of human leishmaniases and trypanosomiases the zoonotic nature of the diseases is beyond doubt, but in some other protozoal infections the role of animal reservoirs has either not been fully elucidated or is still uncertain.

Toxoplasmosis.

The most important of these is Toxoplasmosis, a disease caused by *Toxoplasma gondii* (Fig. 13), a parasite of uncertain status,

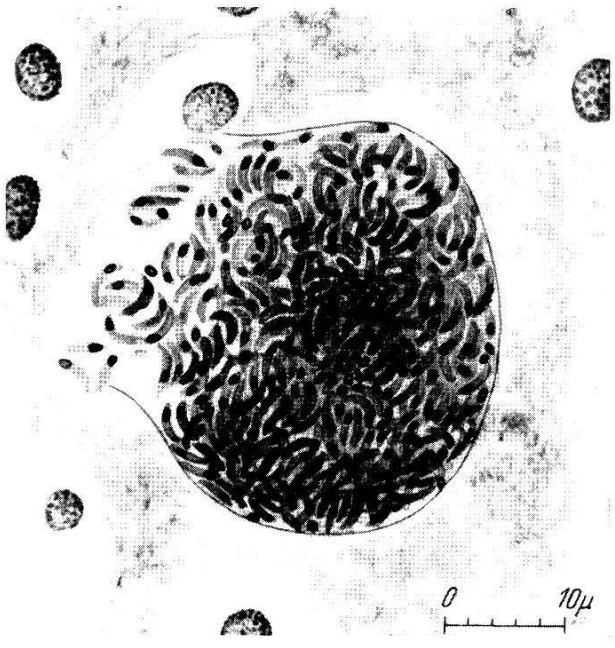

Fig. 13. Toxoplasma gondii, cyst in brain of child. (After PIEKARSKI, 1950.)

probably related to the Sporozoa. As is known, toxoplasmosis has a world-wide distribution with a relatively high incidence and an extremely wide host-range, which includes man, numerous mammals and some birds, between which the parasite is interchangeable, thus showing no host-restriction. Among the mammalian and avian hosts there are a number which are actually or potentially of epidemiological importance, as possible reservoir hosts of human infection, but since the natural method of transmission of toxoplasmosis has not been solved the role played by different animals is not yet clear.

Theoretically it is conceivable that any infected animal might be a source of human infection, but obviously the risk of infection is greatest from animals in the human environment, and especially those with which man comes in close contact, some of which can be regarded as potential reservoirs of human toxoplasmosis. Although no single animal species has so far been actually incriminated in the transmission of the disease to man, there is considerable circumstantial evidence that rabbits, dogs, farm animals, birds, and perhaps some game animals might act as reservoirs (HAVLIK & HÜBNER, 1958). Thus it has been demonstrated in England that the proportion of human cases with positive serological reactions was significantly higher among persons handling rabbits or their carcases professionally (e.g. veterinarians, abattoir workers, trappers) than in the general population (BEVERLEY et al., 1954). These findings are correlated with a high incidence of rabbit toxoplasmosis in that country (LAINSON, 1955). A number of observers have also demonstrated a definite correlation between human and canine infections in the same household (WESTPHAL & FINKE, 1950; COLE et al., 1953), and it has also been shown that toxoplasmosis is practically an occupational disease among persons handling dogs professionally (OTTEN & WESTPHAL, 1951). It is not clear, however, whether man acquires the infection directly from dogs, or both become infected from a common source, such as rabbits (JACOBS et al., 1955; LAINSON, 1955). Since toxoplasms may be present in the muscles of infected cattle and pigs, it is also conceivable that man may be exposed to infection by handling their carcases or by consuming undercooked beef or pork (SANGER et al., 1954; WEINMAN & CHANDLER, 1954). Among birds, suspicion has fallen on pigeons, a high proportion of which are naturally infected in the United States (MANWELL & DROBECK, 1951; JACOBS et al., 1952). As regards wild animals, it may be significant that, in outbreaks among hares and capercaillies in Sweden, it was found that the geographical distribution of human and game toxoplasmosis coincided (BORG, 1953).

Interstitial Pneumonia.

It is possible that the Interstitial Pneumonia of infants also represents an anthropozoonosis. Since the causative organism, *Pneumocystis carinii,* occurs commonly among various wild and domestic animals, it is conceivable that these serve as reservoirs of human infection (SASSUCHIN & SASSUCHINA, 1955; JIROVEC, 1959). However, the epidemiology of this disease is still obscure and in need of further investigation.

Malaria Parasites.

An interesting problem is presented by the malaria parasites of man and anthropoid apes (Fig. 14). Thus chimpanzees harbour under natural conditions three species of plasmodia which, although morphologically indistinguishable from the human parasites, *Plasmodium vivax, P. malariae* and *P. falciparum,* have been given separate names, *P. schwetzi, P. rodhaini* and *P. reichenowi,* for the Benign Tertian (B.T.), Quartan (Q.) and Malignant Tertian (M.T.) parasites respectively. The mutual relationship between the human and simian parasites was determined by cross-infection experiments, with the following results. It was demonstrated that the M.T. parasites of man and chimpanzee, *P. falciparum* and *P. reichenowi,* are strictly specific not only to their mammalian hosts

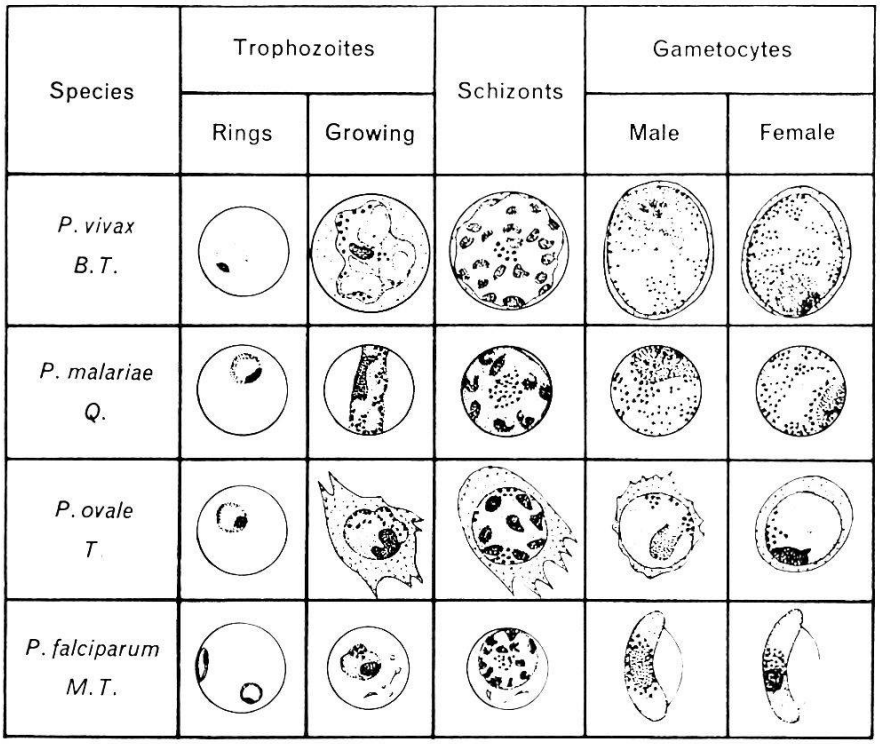

Fig. 14. Malaria parasites of man and chimpanzee.
(After C. A. HOARE from BROOM, 1942.)

but also to their Anopheline vectors, and can therefore be regarded as distinct biological species. On the other hand, the B.T. and Q. parasites of man *(P. vivax* and *P. malariae)* and chimpanzee *(P. schwetzi* and *P. rodhaini)* are interchangeable between these two hosts (RODHAIN, 1939; RODHAIN & DELLAERT, 1955; BRAY, 1956; GARNHAM et al., 1956). Hence it follows that the last two parasites are common to the Hominid Primates. But, in view of the absence of close contact between these hosts, apes cannot be regarded as reservoirs of human malaria: it is more probable that man inherited these parasites from his anthropoid ancestors in the course of evolution.

There is increasing evidence that man is also susceptible to infection with the malaria parasites of lower monkeys. Thus, it has been known for some 30 years (KNOWLES & DAS GUPTA, 1932) that the Quartan parasite of Indian macaques, *P. knowlesi,* could produce malaria in man, and at one time it was used in malariotherapy of General Paralysis of the Insane. It was also suggested (ANONYM., 1961) that some B.T. infections of man in the Amazon region of Brazil might be derived from *P. simium,* a parasite of howler monkeys *(Alouatta)* which resembles *P. ovale* (FONSECA, 1951).

Quite recently more concrete evidence was produced that some forms of human malaria might be in fact anthropozoonoses derived from monkeys. Thus, two years ago American workers (EYLES et al., 1960) reported accidental laboratory infection of man in the United States with *P. cynomolgi* (Fig. 15) isolated from

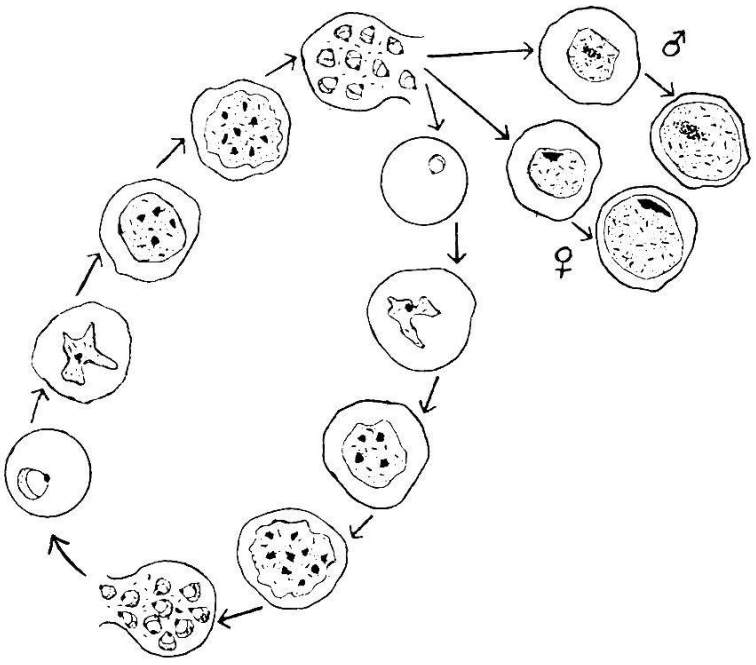

Fig. 15. Plasmodium cynomolgi of macaque monkeys. (After SHORTT, 1948.)

Rhesus monkeys (*Macaca irus*) in Malaya, while later (BEYE et al., 1961; COATNEY et al., 1961) the monkey strain was transmitted through the bites of infected Anophelines to a group of volunteers, who developed Tertian malaria, which was passaged further through a series of volunteers. Though this parasite adapted itself to man, it remained infective to monkeys. Final proof of the infectivity of this parasite to man was provided by recent experiments (CONTACOS et al., 1962), in which *P. cynomolgi* was transmitted in serial cyclical (*Anopheles freeborni*) and direct passages through 12 human volunteers, producing in them typical Tertian malaria.

It is now known (WHARTON & EYLES, 1961) that the natural vector of *P. knowlesi* in Malaya is *Anopheles hackeri*, and that the local vector of human malaria, *A. barbirostris*, also feeds on monkeys (REID & WEITZ, 1961), while the role of other Malayan anophelines (*A. maculatus*, *A. sundaicus* and *A. philippinensis*) was demonstrated experimentally (WARREN et al., 1962). Since certain malaria parasites are interchangeable between man and monkeys, it is conceivable that Malayans living in or on fringes of the jungle are frequently exposed to the bites of mosquitos harbouring simian parasites, and become infected with monkey malaria. However —owing to the resemblance of *P. knowlesi* to *P. malariae* and of *P. cynomolgi* to *P. vivax*—the disease in man is erroneously diagnosed as Quartan or Benign Tertian malaria, respectively.

These discoveries might have an adverse effect on the success of malaria eradication campaigns, for it will be necessary to consider the possibility that in enzootic areas man is liable to acquire monkey malaria. On the other hand, they may be of positive value in chemotherapeutic research, since for the first time malaria parasites of primates have become available for tests on antimalarial drugs.

Balantidiosis

Another example of anthropozoonoses is provided by Balantidiosis, which is a cosmopolitan disease caused by the ciliate *Balantidium coli* (Fig. 16). However, human infections are relatively rare, for only several hundred cases have hitherto been recorded throughout the world, but this ciliate is a common parasite of domestic pigs, over 90% of which may be infected in some countries. *B. coli* is also a natural parasite of monkeys and sometimes also occurs in rats (HOARE, 1949). Here it should be emphasized that while pigs are symptomless carriers of this ciliate, which leads a commensal existence in the lumen of their gut, in man it usually in-

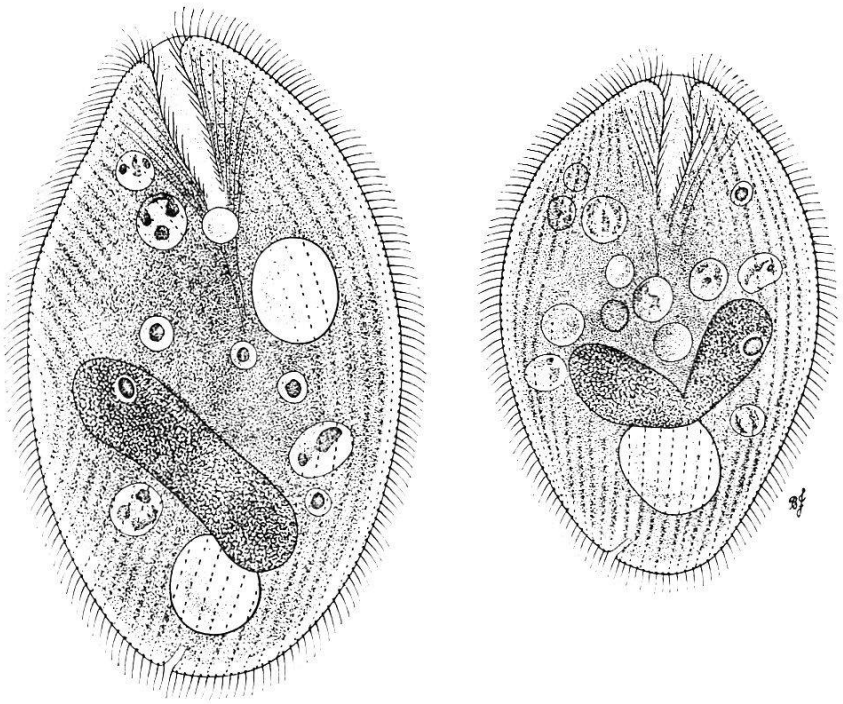

Fig. 16. Balantidium coli of man and pigs. (From WENYON, 1926.)

vades the wall of the large bowel, producing ulceration with symptoms of diarrhoea or dysentery.

There is convincing evidence that pigs act as reservoirs of human balantidiosis, for in most cases there is evidence that the patients had been in close contact with these animals, as shown recently in Kazakhstan (APPASOV, 1958), while in New Guinea (COUVÉE & RIJPSTRA, 1961), where pigs are the main livestock of Papuans, up to 28% of the population were found to be infected. In fact, balantidiosis is practically an occupational disease among pig-farmers, swineherds, slaughterers and sausage-makers. Moreover, from the relative incidence of swine and human infections it can be inferred that pigs are the principal hosts of *Balantidium*, whereas man is only an incidental host. This view is also supported by the fact that in countries where there is no contact between man and pigs for religious reasons—as among muslims in Egypt (HALAWANI & EL KORDY, 1948)—the incidence of balantidiosis among the population is exceptionally low. Nevertheless, there is some evidence that this disease can also be transmitted from man to man (SVANIDZE, 1959).

While the pig represents the domestic reservoir of human balantidiosis, the data regarding the role played by wild animals are very scanty. It is possible that in India, where man comes in close contact with macaque monkeys, the latter might serve as reservoirs of the infection: this is a question that stands in need of investigation. Furthermore, it is interesting to note that previous

reports of the finding of *B. coli* in wild boars (PAVLOVSKY, 1946; REICHENOW, 1952) were recently confirmed in Kazakhstan, where several cases of natural infection among boars were detected (APPASOV, 1958). It is therefore conceivable that there exist natural enzootic foci of balantidiosis among boars, but it is doubtful whether these animals play an important role in the epizootology of swine balantidiosis, for this disease is widespread among domestic pigs in countries where wild boars are absent. It is more probable that the domestic pig inherited the infection from its wild ancestors in the course of evolution. It should be pointed out that many authors erroneously refer the porcine parasite to a separate species, *B. suis,* in spite of the fact that LAMY and ROUX (1950) have clearly demonstrated that the smaller ciliates bearing this name are merely young stages of *B. coli,* resulting from its division; after conjugation, they grow to the normal size. There can therefore be no doubt that the ciliate common to man and pigs is represented by one species—*B. coli.*

Amoebiasis.

We may now turn to Amoebiasis. Although this disease is a typical anthroponosis, it is known that—in addition to man—*Entamoeba histolytica* commonly occurs in monkeys, especially in macaques, in which the infection runs a symptomless course, affording a good example of perfect adaptation between parasite and host. The identity of human and simian strains was demonstrated by cross-infections, which have shown that the amoebae of monkeys and man are interchangeable (DOBELL, 1931; KNOWLES & DAS GUPTA, 1934). It is therefore conceivable that in countries like India, where there is sometimes close contact between man and monkeys, these animals might serve as a reservoir of human amoebiasis. Natural infections with *E. histolytica* have also been reported from rats and dogs but, since there is some evidence that the infected animals had been in contact with human cases of amoebiasis, it is thought that they derive their infection from man. This view is supported by the fact that rats and dogs are highly susceptible to infection with human strains of the dysentery amoeba (HOARE, 1959).

Other Protozoa.

It remains to mention some other Protozoa common to man and lower mammals. One of these is the harmless intestinal amoeba, *Iodamoeba bütschlii,* which commonly occurs in domestic pigs and

in man throughout the world. In a recent survey carried out in Brazil (COUTINHO & RABELO, 1956) it was found that in the State of São Paulo 63% of the pigs were infected with this amoeba, as compared with about 14% of the human population examined. It is therefore highly probable that swine are the reservoir hosts of human *Iodamoeba.*

Another example is provided by the human coccidium, *Isospora hominis.* Although some authors still regard this parasite as an aberrant form of the better known *I. belli,* there can be no doubt about its independent status. The authenticity of this species, established by REICHENOW (1925) in Germany, was fully confirmed by MEIRA & CORRÊA (1951), who found, among 28 cases of human coccidiosis in Brazil, 15 infections with *I. belli* and 13 with *I. hominis.* As a rule, *I. hominis* is discharged with the stools in the form of mature spores, sometimes bound together by a delicate elastic membrane, which is characteristic of the oocysts of those coccidia that develop subepithelially in the intestine of their host. One of these is *I. bigemina* of dogs, whose mature oocysts are morphologically indistinguishable from those of *I. hominis* (Fig. 17). On account of this, some authors (HOARE, 1949;

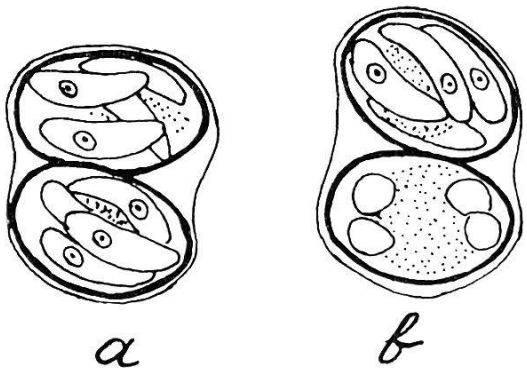

Fig. 17. Isospora (a) of man (*I. hominis*) and (b) of dog (*I. bigemina*). (Original.)

REICHENOW, 1953; CHEISSIN, 1957) have suggested that *I. hominis* is identical with *I. bigemina,* whose principal host is the dog, while man is a secondary or incidental host. However, in view of the rigid host-restriction of the majority of coccidia, this hypothesis is in need of experimental verification.

Finally, there is a remarkable instance of a specific animal parasite, the bovine piroplasm *Babesia bovis* (Fig. 18), producing infection in man in Yugoslavia (ŠKRABALO & DEANOVIĆ, 1957). In this case the patient had been living in close contact with infected cattle grazing in a field infested with ticks *(Ixodes* and *Dermacentor).* He had previously undergone splenectomy in connexion with a motor accident and examination of his blood revealed

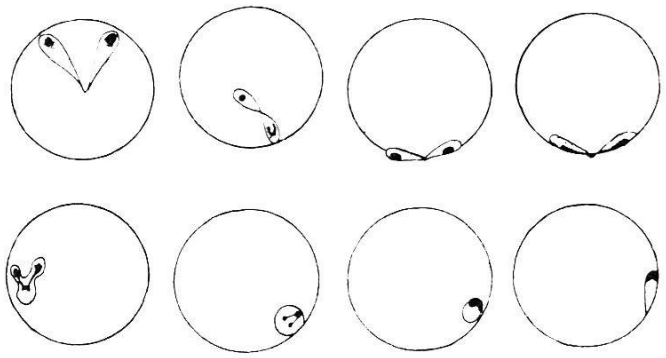

Fig. 18. Babesia bovis. (From WENYON, 1926.)

typical piroplasms, which produced an acute infection, terminating in the patient's death. On the other hand, no signs of this infection were found in other people inhabiting this enzootic focus. In order to throw light on this case, GARNHAM & BRAY (1959) inoculated chimpanzees with the bovine *Babesia* and demonstrated that only splenectomized animals became infected. It is therefore possible that bovine piroplasmosis is an anthropozoonosis, which produces an inapparent or latent infection in normal persons, but when their resistance is lowered—e.g. by splenectomy—the infection is activated, producing an acute disease, terminating fatally. In the light of these observations, it is conceivable that enzootic areas present a definite hazard to man, and one might have to reckon with the existence there of human piroplasmosis.

A different problem arises when parasites of lower animals establish themselves temporarily in man. This category is illustrated by two cases of human infection in Africa with *Trypanosoma vivax* (MACFIE, 1917; LAVIER, 1927). In assessing such cases we must recall the variation in human susceptibility to his own specific trypanosomes *(vide supra)*. Therefore the possibility cannot be excluded that the enhanced virulence of a strain of *T. vivax* or a lowering of the host's resistance might have created conditions enabling this trypanosome to set up a temporary infection in man. As already suggested, the evolution of *T. rhodesiense* from *T. brucei* might likewise have passed through such a phase.

Discussion.

From the foregoing account it is seen that zoonoses have a common pattern which not only throws light on the epidemiology of the diseases in question but also gives an idea of the genesis of the human infections in the historical process of their evolution (Fig. 19). The picture is especially clear in the case of protozoal

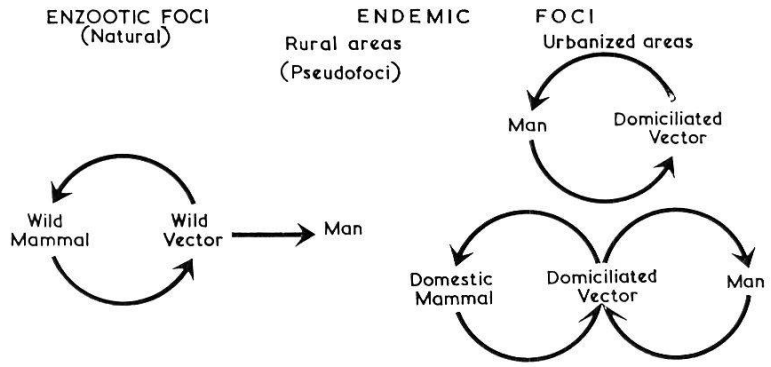

Fig. 19. Epidemiological patterns of zoonoses. (Original.)

infections transmitted by arthropods, where it is generally found that, in addition to endemic foci of human infection, these diseases have natural enzootic foci situated in the open country, where the infection circulates by insect-transmission from donor to recipient hosts, represented by wild mammals. One of the characteristics of these natural foci is their complete independence of man and his domestic animals, and it is conceivable that in some cases the infections in question existed among the wild animals long before man even came on the scene. However, when human beings temporarily enter such an enzootic locality, or settle under primitive conditions in its vicinity, they expose themselves to attacks of the wild vectors and may become infected. Since in such cases propagation of the infection in the community depends entirely on the introduction of the parasite from natural foci, settlements of this type represent merely "pseudofoci" (cf. BEKLEMISHEV, 1961).

With time, agriculture and general economic development lead to urbanization of these human settlements, bringing about various changes in the epidemiological situation. Thus, (1) contact between man and wild nature, with its reservoir hosts and vectors, may be broken, with the result that human infection disappears from the settlement; or (2) the wild vectors may establish themselves within the settlement and become synanthropic or "domiciliated" there, transmitting the infection directly from man to man (e.g. in urban Oriental Sore, Indian Kala-Azar); while (3) in other cases domestic mammals may replace the wild animals as reservoir hosts (e.g. Mediterranean Kala-Azar, Chagas' disease). The epidemiology and host-parasite relations in human leishmaniases and trypanosomiases provide the best illustration of the genesis of endemic foci by evolution from purely enzootic foci. In this connexion it should be emphasized again that wild animal hosts are typically symptomless carriers of the infection, whereas in man it usually produces clinical manifestations of disease. This fact points to a stable adaptation between the reservoir host and parasite, which reflects

the antiquity of their association in primitive enzootic foci, as compared with that in the more recently evolved endemic foci of human disease.

In zoonoses the reservoir hosts are either wild or domestic mammals, according to the local epidemiological situation. While in leishmaniases and trypanosomiases (and possibly in toxoplasmosis) we have examples of both types of reservoirs, human intestinal infections are associated either with domestic reservoirs (such as swine in balantidiosis), or depend upon man-to-man transmission (as in amoebiasis).

Within an enzootic territory, natural foci may have a discrete or patchy distribution, restricted to animal burrows and lairs in the case of leishmaniases; or their distribution is diffuse, as in the case of Chagas' disease and Sleeping Sickness. The distribution of such foci or biotopes depends upon the ecological requirements of the mammalian hosts and their vectors, which are adapted to special types of habitat.

Finally, the existence of natural enzootic foci of human diseases has obvious practical implications. Such foci may remain undetected and, as it were, dormant for indefinite periods of time, in fact as long as human beings do not intrude into them. They, therefore, constitute a potential epidemiological hazard, and it is important that their existence and localization should be recognized beforehand, so that they can be avoided or brought under control. Since such foci or biotopes are characterized by definite ecological peculiarities—determined by topography, climate, vegetation and other environmental factors—these can serve as indicators of the presence of certain diseases in such areas. A knowledge of the geographical background or terrain, which PAVLOVSKY (1948) calls "the landscape epidemiology", is therefore important in assessing the epidemiological situation and potential danger of unknown territories into which man is about to penetrate, e.g. in the course of reclamation work, during military operations or movements of troops, and when camping or settling in such places. Thus, in desert areas of Asia and North Africa, inhabited by burrowing rodents, the presence of Oriental Sore might be suspected; in thickets among rock formations of America containing burrows of armadillos, one might expect to encounter vectors of Chagas' disease; while in tropical Africa, woodland with big game or river banks with thick vegetation harbouring tsetse-flies might indicate the presence of Sleeping Sickness. If the potential danger of such places is recognised, they can either be avoided, or appropriate measures can be taken to protect human immigrants from infection.

Preventive Measures.

Among the preventive measures against zoonoses the most important are based on eradication of the vectors, either by insecticides or by ecological control, which aims at modifying the environment in such a way that it becomes uninhabitable by the insects. This method, of course presupposes an intimate knowledge of their ecology. In some cases the same object is attained by elimination of the reservoir hosts.

Zusammenfassung.

Ein Überblick über die menschlichen Protozoeninfektionen, die zugleich Zoonosen darstellen, wird gegeben. Sie sind charakterisiert durch das Vorhandensein von natürlichen Infektionsherden und von Reservoir-Wirten unter den Wild- und Haustieren. Für die cutane Leishmaniase der Alten Welt (*Leishmania tropica*) und der Neuen Welt (*L. brasiliensis*) sind verschiedene Nagetiere als tatsächliche und potentielle Reservoirtiere nachgewiesen worden, während für die viscerale Leishmaniase (*L. donovani*) wilde und domestizierte Canidae (Schakale, Füchse und Hunde) das Hauptreservoir sind. Im Falle der Chagas-Krankheit wurde festgestellt, daß zahlreiche wilde Säugetiere natürlicherweise mit *Trypanosoma cruzi* infiziert sind und daß Reduviiden, die die Höhlen und Nester zusammen mit diesen Tieren bewohnen, die Überträger sind. Beim Vorhandensein von natürlichen endozootischen Herden wird der Mensch zufälligerweise infiziert, während in endemischen Gebieten die Krankheit durch synanthropische Wanzen übertragen wird. Die Epidemiologie der Schlafkrankheit variiert je nach Art der Erkrankung und des Überträgers. Die akute Rhodesiense-Trypanosomiase ist im Savannen-Grasland verbreitet, welches für *Glossina morsitans,* den Überträger von *T. rhodesiense,* das Habitat bildet; hier ist die Antilope das Reservoirtier. Die chronische Gambiense-Trypanosomiase kommt in den besiedelten Flußgebieten mit nur spärlicher Säugetierfauna vor, und die Krankheit wird ohne Reservoir von *Glossina palpalis* direkt von Mensch zu Mensch übertragen. Es wird vermutet, daß die menschlichen Trypanosomen von der *T. brucei*-Gruppe stammen und daß die entsprechenden Infektionen sich von der rein tierischen Nagana durch Anthropozoonose (Rhodesiense-Trypanosomiase) zu einer reinen Anthroponose (Gambiense-Trypanosomiase) entwickelt haben.

Obwohl für Toxoplasmosis auch die Existenz von Reservoir-Wirten vermutet wird, so ist doch die Rolle, welche die verschiedenen Tiere für die menschliche Krankheit spielen, noch nicht abgeklärt. Es ist bewiesen worden, daß Malariaparasiten zwischen Schimpansen und Mensch gegenseitig austauschbar sind, und man vermutet, daß der Mensch diese Parasiten von anthropoiden Vorfahren geerbt hat. Es gibt auch Hinweise darauf, daß der Mensch in Asien Affenmalaria erwerben kann. Für Balantidiasis ist das Schwein, der hauptsächlichste Träger von *Balantidium coli,* das Reservoirtier. Im Falle der Amoebiase sind Macacus-Affen Träger von *Entamoeba histolytica,* die den Menschen infizieren kann, während die natürlich vorkommenden Infektionen bei Hunden und Ratten wahrscheinlich menschlichen Ursprungs sind. Von andern Protozoen, die beim Menschen und niedrigen Säugetieren gemeinsam vorkommen, werden *Pneumocystis, Iodamoeba, Isospora,* und *Babesia* erwähnt. Zum Schluß wird der allgemeine Verlauf der Zoonosen und die Entwicklung von enzootischen zu endemischen Herden diskutiert.

Résumé.

Une contribution est apportée à l'étude des infections humaines à protozoaires représentant les zoonoses. Celles-ci sont caractérisées par l'existence de foyers naturels et de réservoirs parmi les animaux sauvages et domestiques. Dans le cas des Leishmanioses cutanées de l'ancien et du nouveau monde (*Leishmania tropica* respectivement *L. brasiliensis*) divers rongeurs sauvages ont été reconnus comme réservoirs actuels ou potentiels de maladies humaines, alors que, dans le cas de la Leishmaniose viscérale (*L. donovani*), les canidés domestiques et sauvages (chacals, renards et chiens) jouent le rôle de réservoirs principaux. Dans le cas de la maladie de Chagas, plusieurs mammifères sauvages sont naturellement infectés de *Trypanosoma cruzi* qui est transmis par les Reduviidés partageant leurs gîtes et leurs nids. Dans un foyer enzootique naturel, l'homme peut être accidentellement infecté, mais dans les régions endémiques, l'infection humaine est transmise par des punaises synanthropiques, le rôle du réservoir étant assuré par les animaux domestiques. L'épidémiologie de la maladie du sommeil varie selon le genre de la maladie et des vecteurs. Le type Rhodesiense aigu se rencontre dans les régions de savannes boisées, habitées par *Glossina morsitans,* vecteur de *T. rhodesiense* ; dans ce cas l'infection humaine provient des antilopes représentant le réservoir de cette maladie. Le type Gambiense chronique s'observe dans les populeuses régions riveraines avec une faune mammalienne rare ; en l'absence d'un réservoir, la maladie est transmise d'homme à homme par *Glossina palpalis.* On suggère que la trypanosomiase humaine dérive de *T. brucei,* et que les infections correspondantes ont évolué de la pure Nagana animale à la pure anthroponose (type Gambiense) par l'intermédiaire d'anthropozoonose (type Rhodesiense).

Malgré d'évidents repères quant à l'existence d'hôtes réservoirs dans la toxoplasmose, le rôle joué par les différents animaux comme source de maladie humaine n'est pas clair. Il a été démontré que les parasites de la malaria sont interchangeables entre chimpanzés et homme, lequel a probablement hérité ses parasites de ses ancêtres anthropoïdes. Quelques observations suggèrent également la présence de malaria simienne chez l'homme en Asie. Dans la balantidiose, le réservoir est le porc qui est le principal hôte de *Balantidium coli.* Dans le cas de l'amibiase, le macaque héberge *Entamoeba histolytica* qui est infectieuse pour l'homme. Les infections naturelles des chiens et des rats sont probablement d'origine humaine. Parmi d'autres protozoaires communs à l'homme et aux mammifères inférieurs sont mentionnés *Pneumocystis, Iodamoeba, Isospora* et *Babesia.* Enfin l'évolution générale des zoonoses, ainsi que celle des foyers endémiques à partir de foyers enzootiques est discutée.

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