THIRD EDITION

INSECTS AND HYGIENE

The biology and control of insect pests of medical and domestic importance

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Preface to the third edition

It was gratifying to be invited to prepare a third edition of this book, which first appeared in 1951. Preliminary discussions with the publishers, however, revealed a considerable challenge in the present high costs of printing, so that changes and some improvements were clearly necessary to justify the venture.

It was immediately apparent that the chapter on chemical control measures would have to be substantially re-written, because of the great changes in usage due to resistance and the regulations introduced to prevent environmental pollution. Also, I decided to expand the scope of the book by increased coverage of the pests of continental Europe and North America, including some new figures and keys in the Appendix.

These two undertakings resulted in considerable expansion in length, with about 370 new references and 250 additional specific names in the Index. In order to avoid too alarming an increase in price, I decided to sacrifice three chapters from the earlier editions: those dealing with the structure and classification of insects, their anatomy and physiology, and their ecology. Readers who require basic biological information on insects should buy one of the various short introductions to entomology available.

A further small saving in length has been made by eliminating the various notes on historical curiosities. Those interested may care to obtain a complete account of this bizarre but fascinating subject in my recent *Insects, Hygiene and History*, (1976), Athlone Press, London, 262 pp.

Contents

CHAPTER ONE

Insects and hygiene

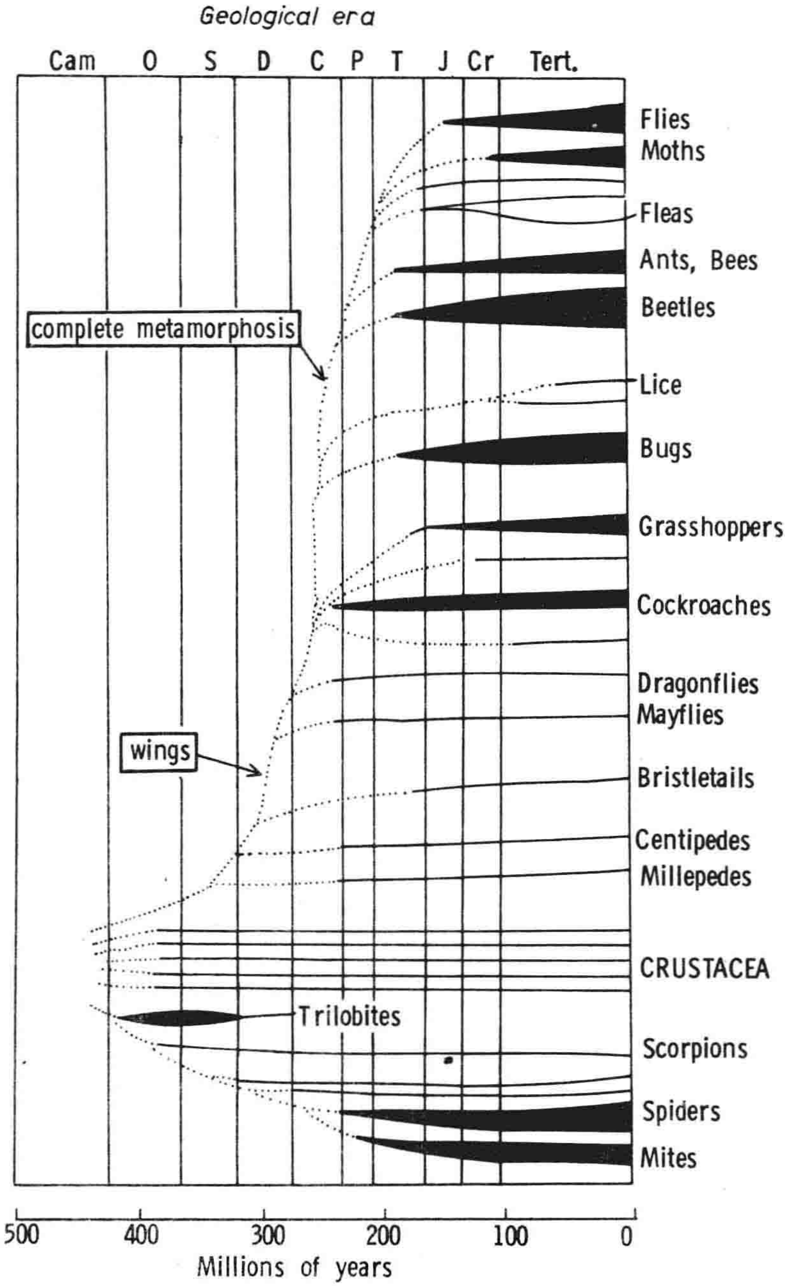
1.1 NUMBERS AND VARIETY OF INSECTS AND ACARINES

If numbers and variety are taken as the criteria of successful evolution, then insects are the predominant form of life on earth. Other terrestrial arthropods are also more numerous and varied than vertebrates. Thus, there are about 50 000 kinds of spider and perhaps 30 000 different mites, compared to a mere 4500 species of mammals and 8600 birds; but the insects far exceed all these figures, with an estimated number of species near to 900 000. This enormous proliferation is a consequence of their evolutionary history, which began far back in geological time (see Fig. 1.1).

The predominance of insects over other land arthropods is almost certainly due to the innovation of wings, which conferred immense advantages to such small creatures. All arthropods have to moult at intervals to grow, however, and the possession of wings renders this difficult. The evolutionary solution was to postpone the emergence of wings until the insect was a fully-grown adult, which can take advantage of them for migration and colonization. A further advance was the evolution of a life history with radically different larvae and adults, the former specialized for feeding and growing, and the latter for mating and dispersal. This 'complete metamorphosis' is familiar to all of us from the example of the caterpillar and the butterfly, and is common to most of the more successful types of insect.

Although the actual magnitude of the insect hordes is not generally realized, most people are familiar with the typical forms of the main orders. These include the following: Coleoptera (beetles) 360 000 species; Lepidoptera (moths and butterflies) 160 000; Hymenoptera (ants, bees, wasps etc) 150 000; Diptera (flies, gnats etc) 90 000; Hemiptera (bugs, aphids, cicadas etc) 61 000; Orthoptera (cockroaches, grasshoppers etc) 30 000; Mallophaga (biting lice) 3000; Siphonaptera (fleas) 2000; Anoplura (sucking lice) 250.

Although these vast numbers of insects have exploited every conceivable niche in the terrestrial environment, only a very small proportion of species (about 0·5 per cent) have become serious pests. Most of these attack plants or plant products. Human agriculture upsets the 'balance of nature' by planting large areas of unmixed crops and storing large quantities after harvest. These great supplies of food invite certain kinds of insect to proliferate excessively and become pests. Most of them belong to the orders Coleoptera, Lepidoptera and Hemiptera, and the losses caused by them are enormous.


Geological era
Cam
O
S
D
C
P
T
J
Cr
Tert.
Flies
Moths
Fleas
Ants, Bees
Beetles
complete metamorphosis
Lice
Bugs
Grasshoppers
Cockroaches
Dragonflies
Mayflies
wings
Bristletails
Centipedes
Millepedes
CRUSTACEA
Trilobites
Scorpions
Spiders
Mites
500
400
300
200
100
0
Millions of years

Relatively fewer forms of insect are harmful to man and his animals because of differences in their evolutionary time scales. At the time of the emergence of the first mammals, 200 million years ago, insects had already established themselves as the most successful arthropod group on land. Certain kinds (especially in the order Diptera) took advantage of the new sources of food provided by mammals by sucking their blood or by breeding in their excrement or dead bodies. By the Oligocene (20 million years ago) the insect's main evolutionary history was over, so that specimens trapped in resin and fossilized in amber scarcely differ from their present day descendants. The past 100 000 years, which saw the emergence of man, have been too short to attract the undivided attention of more than a very few species. Nevertheless, insects which attack man as well as other mammals are vectors of some of the most serious human diseases, such as malaria, yellow fever, sleeping sickness, plague and various forms of filariasis.

Most of this book concerns insect pests; but it is convenient to include certain mites and ticks of public health importance. Most acarines are very small mites and relatively few of the larger, exclusively blood-sucking, ticks. Most are harmless to man and, because of their small size and cryptic habits, seldom noticed. However, a small number are parasitic on man or his domestic animals and some of them transmit dangerous disease organisms. Again, however, scarcely any are specific to man and the diseases they carry are brought from other animals. Examples are mite-typhus, tick-borne relapsing fever and Rocky Mountain spotted fever.

1.2 INSECTS AS DISEASE VECTORS

1.2.1 EVOLUTION OF VECTOR TRANSMISSION

The micro-organisms which are involved in vector-borne diseases vary greatly, ranging from viruses to tiny nematode worms. The *viruses* are very small, from 10 to 250 nm*, the smallest being comparable to a large protein molecule. Next in size are the *rickettsiae*, extending up to the dimensions of a small bacterium, rather less than 1 μm*. Both viruses and rickettsiae (which are probably degenerate bacteria) are exclusively parasitic and cannot be cultured in non-organic media. Bacteria are a large and variable assembly, with free-living as well

* A nanometre (nm) is one millionth part of a millimetre; a micrometre (μm) is one thousanth part of a millimetre.

Figure 1.1 Some of the main branches of the arthropod family tree. The firm lines show the geological period from which the earliest fossils of various orders occur; dotted lines show putative relationships. *Key to geological eras*: Cam., Cambrian; O, Ordovician; S, Silurian; D, Devonian; C, Carboniferous; P, Permian; T, Triassic; J, Jurassic; Cr., Cretaceous; T, Tertiary. From Busvine [94], by permission of the Athlone Press.

as parasitic forms. Two representatives of the latter are the plague bacillus ($1{\cdot}8 \times 0{\cdot}6$ μm) and the spirochaetes of relapsing fever (8–15 μm long and 0·3 μm thick). Protozoa are slightly larger and a higher form of life, with a true nucleus and chromosomes. Representatives are the malaria parasite *Plasmodium* (2–4 μm) and the larger flagellates, such as the *Leishmania* of kala azar, and the long trypanosomes of sleeping sickness, which may be 12–40 μm long. Finally, there are the parasitic nematode worms known as filaria, of which the infective stages are about 300 μm long and 6 μm thick.

The largest of these pathogens must weigh only about 10^{-5} g; this compares with 10^{-2}g as an approximation for most of the insect vectors and 10^3g, the weight of a man. The very small pathogens have problems of existence very different from those of larger animals, especially the parasitic forms, which have to get from one host to another. Some animal pathogens solve this by passing to a new host during close social, familial or sexual contact. Others pass out in faeces with the possibility of contaminating food or drinking water. Still others may be transferred in droplets sneezed or coughed out by the host. The most curious and complex modes of transfer, however, have evolved in a series of adaptions involving two different-sized organisms: a large animal (or plant) and a small creature such as an insect. The advantages of the alternation is that it combines a large host with a longer life, constituting a lasting reservoir with a small mobile vector, which facilitates long-range transmission. This system seems to have developed both from forms originally parasitic on large animals and from those parasitic on arthropods, though it is not always easy to guess which. Some clues can be gathered from the degree of adaption of the parasite, which usually evolves from being a pathogen to a more or less benign parasite. Many of the vector-borne diseases affecting man seem to have begun as parasites of animals, which have evolved to a more or less harmless stage. The cycle of animal and vector continues in the wild and human cases are incidental offshoots. Their malign effects on man are evidence of recent extension to a new host. Sometimes, as in louse-borne typhus, a new insect vector seems to be involved and the parasite is lethal to the vector as well.

The various mechanisms involved in the alternating system allow for speculation on the ways in which the most efficient ones were evolved. Perhaps the simplest cycle is exemplified by the fortuitous transmission of enteric diseases which occurs when flies (or cockroaches) transfer pathogens from faeces or septic matter to food, by accidental contamination due to their habits. The advent of bloodsucking forms provided a new and efficient mode of transfer of blood parasites. This probably began through traces of infected blood on the biting mouthparts of the vector, which still occurs in some cases; but because the traces are so small and may dry up and kill the pathogen, it is not efficient. A more prolonged infection of the biting vector would be the next step; and at this point, began the obligatory association of each pathogen with a particular vector. The importance of this is obvious. Thus, malaria cannot be transmitted without anopheline mosquitoes; if they are exterminated, the disease is eradicated. But enteric diseases can and do continue (though possibly somewhat abated), if all flies and other potential vectors are controlled.

The first step towards parasitism of the vector may have been a gut infection, either of the foregut or the hindgut. Infection of the next host could either be by regurgitation at the next meal, or by passing infective faeces which could enter a scratch or mucous membrane of the next host. In the most complete form of parasitism of the vector, however, the pathogen passes through the gut wall into the vector's body cavity. A crude method of escape for the pathogen was by the vertebrate host swallowing the vector, which can often happen to parasitic insects when animals groom themselves. A human example in some primitive communities is the practice of killing lice by biting them, which can result in the transmission of relapsing fever. In this arrangement, the vector can obviously only infect one new host. A more efficient method of passing on the infection is at the next blood meal. Thus, filarial worms invade the insect's proboscis and burst out of it when the insect begins to feed. In the most highly-developed system, the pathogens invade the salivary glands and are injected with saliva during feeding. This is the mode of infection of a number of serious diseases, including malaria, sleeping sickness, yellow fever, dengue, mosquito-borne encephalitides and some forms of tick-borne relapsing fever (see Table 1.1).

In these more complex processes, the pathogen requires a period of development in the vector, after which the latter may be able to pass it on to more than one new host. This depends on the life-span of the vector. There are some long-lived arthropods, such as triatomine bugs or some ticks; and in some cases, their reservoir capacity may be prolonged by passing the pathogen (via the egg) to the next generation. However, they never approach the span of human life. Very often, especially with short-lived insects like mosquitoes, survival of the insect is critical, because the insect may not live long enough for the pathogen to develop to the infective stage. Such development will be prolonged by cold and, therefore, in temperate climates, the vector often dies before it becomes infective. This is one reason why diseases like malaria and yellow fever are so much more prevalent in the tropics. Another reason is that some of these disease cycles are not highly efficient, so that many bites of a vector species may be necessary before one results in infection. This may be achieved by the more frequent attacks of the numerous insects which breed under tropical conditions.

1.2.2 PREVALENCE OF VECTOR-BORNE DISEASE, ESPECIALLY IN TEMPERATE REGIONS

For reasons mentioned earlier, vector-borne diseases have always been more prevalent in hot countries. Some of them have never extended to northern temperate countries; but others have, and though they may be rare now, they are potentially able to return. The more serious epidemics (malaria, plague, typhus) have been largely eradicated from Europe and the U.S.A., though the vectors are still present. Other vector-borne diseases are indigenous, with reservoirs in wild

Table 1.1 Pathogens and vectors of some human diseases; (sg) indicates definite involvement of the salivary glands.

Pathogen				
Type	Designation	Disease	Vector	Mode of transmission
Viruses	WEE, EEE, etc	Equine encephalitides	Mosquitoes	Bite (sg)
	YF	Yellow fever*	Mosquitoes	Bite (sg)
	RSSE, CSE etc	Spring-summer fevers	Ticks	Bite (sg)
	SFN etc	Sandfly fevers	Sandflies	Bite
Rickettsiae	*Rickettsia prowazeki*	Typhus	Lice	Faeces
	Rickettsia rickettsi	Rocky Mountain Spotted fever	Ticks	Bite (sg)
	Rickettsia tsutsugamushi	Scrub typhus*	Mites	Bite
Bacteria	*Yersinia pestis*	Plague	Fleas	Bite
	Borellia recurrentis	Relapsing fever	Lice	Crushing lice
	Borellia duttoni	Relapsing fever*	Ticks	Bite (sg)
Protozoa	*Plasmodium* spp.	Malaria	Mosquitoes	Bite (sg)
	Trypanosoma spp.	Sleeping sickness*	Tsetse	Bite (sg)
	Trypanosoma cruzi	Chagas' disease*	Triatomid bugs	Faeces
	Leishmania spp.	Kala azar and Oriental sore	Sandflies	Bite
Filarial nematodes	*Wucheria bancrofti*	Filariasis*	Mosquitoes	Bite
	Onchocerca volvula	Onchocerciasis*	Blackflies	Bite

* Tropical diseases.

animals and not readily amenable to eradication; but these are relatively uncommon and sporadic in occurrence. The present status of some of these infections will be briefly reviewed.

(a) Protozoal diseases

(i) Malaria

The enormous range of malaria can be realized from the fact that some 3000 million people live in potentially malarious areas. With the introduction of DDT house spraying about 1950, a new simple and economical method of control became available, which was outstandingly successful in temperate and subtropical regions. This encouraged the World Health Organization to formulate a programme for the total eradication of the disease, which soon achieved remarkable progress in about 60 per cent of the malarious areas, mainly on the periphery of distribution of the disease. However, little or no progress was made in the intensely malarious parts of Africa. Even in the more amenable areas, technical difficulties (such as insecticide-resistant strains of vectors) slowed the advance about 1967. Since about 1970, the situation has actually deteriorated, with severe epidemics in Ceylon, India and Pakistan etc. The goal of world eradication has been abandoned for the forseeable future and countries are reverting to the more modest concept of control. Even this is hampered by rising costs of insecticides, combined with declining use of DDT, which is cheap and safe to use.

In the temperate zones, the story is more encouraging. The northern limits of the disease once extended up to 45 or 55 degrees of latitude and, in the 19th century, there were several hundred cases a year in England. In the U.S.A., as late as the 1930s, there were 6 or 7 thousand cases a year. For the past century, however, the range of malaria has been contracting. At first there was slow improvement, due to better farming practice, with drainage and with cattle barns remote from houses to draw away the mosquitoes. Finally, in the 1950s and 1960s, the use of modern insecticides virtually eradicated malaria from temperate regions. There remains, however, a risk of re-introduction of indigenous malaria by means of travellers from the tropics, because the vectors are still present here. In surveying this risk, the W.H.O. has suggested the following malaria terminology. (1) *Indigenous* (contracted in a malarious country); (2) *imported* (contracted abroad in a malarious area); (3) *introduced* (contracted by a local vector, from an imported case); and (4) *induced* (deliberately, for malaria therapy, or by blood transfusion, accidentally) [630].

Periods of exceptional risk in Europe followed the return of soldiers from World Wars. An analysis of the British experience suggests that about half a million soldiers contracted malaria in each of the World Wars. Many thousands returned infected to Britain (over 33 000 between 1919 and 1921; and some 14 000 relapsed). Local mosquito vectors were responsible for 480 introduced cases after the First War, but only 46 after the Second [75]. The improvement was due to better surveillance, better treatment and more effective anti-mosquito measures. In the U.S.A., there was a third wave of military infections during and after the Korean War. From 1959 to 1965, both military and civilian cases ranged around 50–100 per year. With the Korean War, military cases rose to between three and four thousand, with civilian cases slightly up around 150, per year. There was a welcome decline after 1970 and by 1972 the total for both types was only about 800. Throughout the whole period, introduced cases remained at the low level of 0–5 p.a. [305].

In more recent years, the hazards of introduced malaria has shifted to civilians [75]. The monitoring of such cases in Britain is carried out by the Malaria Reference Laboratory. During the 1960s, about 100 cases were recorded annually, but the numbers shot up in 1971–3 to over 500 p.a., probably because of more efficient diagnosis with serological methods. An analysis of these last three years showed that native travellers accounted for over 30 per cent, while immigrants were responsible for only 18 per cent of verified examples. There were 26 deaths among the 548 *falciparum* cases, due largely to delayed diagnosis.

(ii) Diseases due to haemoflagellates

Certain flagellate protozoans are responsible for serious diseases which, fortunately, do not extend into the northern temperate zone. For this reason, they will be discussed only very briefly.

Sleeping sickness, which is endemic over an immense area of tropical Africa, is due to *Trypanosoma gambiense* and *T. rhodesiense*. These trypanosomes are transmitted by various species of tsetse fly, as are related forms which cause the fatal disease *nagana* affecting horses and cattle.

Chagas' disease, which occurs in many parts of South and Central America, is due to *Trypanosoma cruzi*, which is transmitted by bloodsucking bugs of the family Reduviidae.

Kala azar (visceral leishmaniasis), which, is highly dangerous if untreated, and Oriental sore are due to *Leishmania tropica* and *L. donovani*, respectively. They are spread by sandflies of the genus *Phlebotomus*, in various parts of the tropics.

(b) Arboviruses

Viruses transmitted from one vertebrate to another by insects or acarines are known as arboviruses ('arthropod-borne viruses'). In the past decade, the number of examples of these viruses has risen to over 200. Three-quarters of them are transmitted by mosquitoes, a few by sandflies and the remainder by ticks. They are generally harmless to the vectors, but in the vertebrate they can cause high fever and various unpleasant symptoms. The most dangerous types tend to be haemorrhagic (with bleeding from gums, nose, kidneys etc) or encephalitic (with nervous involvement resembling poliomyelitis). The two types are not sharply distinct, however; and there are milder viruses which merely cause severe pains in joints and bones. Man is the sole vertebrate host in very few arboviruses; various wild or domestic animals and birds constitute the natural reservoir and are often little harmed by the virus. The infection cycle is complex, in that the degree and duration of the viraemia varies in different vertebrates and so does the susceptibility to infection in different vectors. The danger to man depends on the feeding habits and prevalence of the vector. In many cases, man is not very infectious and represents a dead end of the infection chain.

(i) Mosquito-borne arboviruses; mainly tropical

Yellow fever is the most important of the tropical arboviruses, being both widespread and potentially dangerous. For nearly three centuries, it decimated

European explorers in Africa and the New World; however, it does not extend into Asia. In the Americas, epidemics have extended into the temperate regions as far north as New York and even Quebec but, since the urban vector (*Aedes aegypti*) is fairly easy to control, the disease has been confined to the tropics for some 50 years. There, the virus persists in an enormous reservoir of forest monkeys in Africa and the Neotropics, and from them, the infection can be passed to men working in such areas. Since human cases of this disease are infectious to mosquitoes, they can carry it to towns and cities, where it can be further spread by bites of the urban mosquito vector.

Because of the reservoir of 'jungle yellow fever', total eradication of the disease is not feasible. However, about 1950, the Pan American Health Organization initiated a campaign to eradicate the mosquito *Aedes aegypti* from the Western Hemisphere, using DDT etc. Good progress was made for the first 15 years but eradication was not achieved in all the countries involved, so the project was quietly abandoned. However, despite intermittent infections of forest workers, there has been no threat of an urban epidemic and, in any case, the danger of this disease is greatly mitigated by protection by a simple and effective vaccination.

(ii) Other tropical arboviruses

Various 'break-bone' fevers due to mosquito-borne arboviruses occur in different parts of the tropics. Most widely distributed is dengue, which is mainly transmitted by *Aedes aegypti* (though other species of *Aedes* are involved in the Pacific region). This is normally non-lethal but, in South-East Asia, there have been epidemics of a more dangerous disease involving a similar virus, known as haemorrhagic dengue. This is an urban infection, especially serious in Asian children, causing up to 7 per cent mortality.

(iii) Mosquito-borne arboviruses in the temperate region

Several of these occur in North America, though their nature was only recognized about 1933. Three distinct forms, which are well known, are rather similar in that wild or domestic birds are the principal reservoir and are little affected. Passage from one wild host to another is by bird-feeding mosquitoes, which sometimes bite and infect man with moderate or severe results. Horses are also sometimes afflicted; and, because the encephalitis syndrome predominates, these diseases are often called 'equine encephalitides'.

Eastern equine encephalitis (E.E.E.) is most dangerous, with fatalities up to 75 per cent, but fortunately it is comparatively rare. Its main distribution is the Atlantic seaboard and the Gulf coast of the U.S.A., but outbreaks have occurred far inland. It is associated with swamps in which breed the vectors, *Culiseta melanura* and *Aedes sollicitans*; also *Mansonia perturbans* and *Culex salinarius*.

Saint Louis encephalitis (S.L.E.) has caused larger outbreaks than E.E.E., but it is less dangerous, though mortalities up to 10–30 per cent have been recorded. Its distribution ranges from a central area around St Louis (Missouri) and over the western half of the U.S.A. However, a few outlying outbreaks have reached Florida and even Trinidad. The main vectors in the west are *Culex tarsalis* in rural districts and members of the *Culex pipiens* complex in urban areas. In Florida, *Culex nigripalpus* and *Aedes crucians* were implicated.

Western equine encephalitis (W.E.E.) is less dangerous than S.L.E. It is distributed over the U.S.A. and Canada west of the Mississippi. The main vector is *Culex tarsalis*, but the virus has been recovered from several other mosquito species.

Another American disease of this type is Californian encephalitis (C.E.). It is less well studied, but appears to be spread by species of *Aedes* and the wild reservoirs are various rodents (squirrels, ground squirrels and foxes).

In the Far East there is Japanese B encephalitis (J.E.) which extends over the tropical and temperate region of Eastern Asia. Severe outbreaks have occurred in Japan. Many vertebrates, including pigs, horses, various birds, certain lizards and possibly certain bats are infected, maintaining a continuous reservoir. The principal northern vector is *Culex tritaeniorhynchus*, which breeds in rice fields. In man the disease can cause considerable mortality (up to 30 per cent) especially among children, and it tends to have harmful after-effects.

(iv) Tick-borne arboviruses in the temperate region

Only one tick-borne arbovirus is prevalent in the U.S.A., that is, Colorado tick fever (C.T.F.). It attacks people camping in the Rocky Mountain area (Colorado, Montana) and, although it is a relatively mild disease, it may cause symptoms of encephalitis in children. The vector is the Rocky Mountain wood tick, *Dermacentor andersoni* and the reservoir, various wild rodents (e.g. ground squirrels).

In the Old World, various tick-borne viruses occur, both those causing haemorrhagic and those causing encephalitis symptoms.

Tick-borne haemorrhagic viruses include Crimean haemorrhagic fever (C.H.F.) and Omsk haemorrhagic fever (O.M.S.K.). The former is an acute infection with up to 8 per cent mortality. It occurs in late spring or early summer in the steppes of south-eastern Europe, especially the U.S.S.R. The vectors are *Hyalomma plumbeum* and *H. anatolicum*, while various small mammals serve as the wild reservoir. O.M.S.K. occurs in the steppe forests of south-west Siberia where ticks of the genus *Dermacentor* act both as vectors and reservoirs. Though a milder human disease than C.H.F., it is highly pathogenic for some wild mammals.

The tick-borne encephalitides include Russian spring–summer encephalitis (R.S.S.E.) and Central European encephalitis (C.E.E.). The former is the most dangerous, with mortality rates reaching 30 per cent. It occurs in the thickly