MEDICAL ENTOMOLOGY

Robert Matheson

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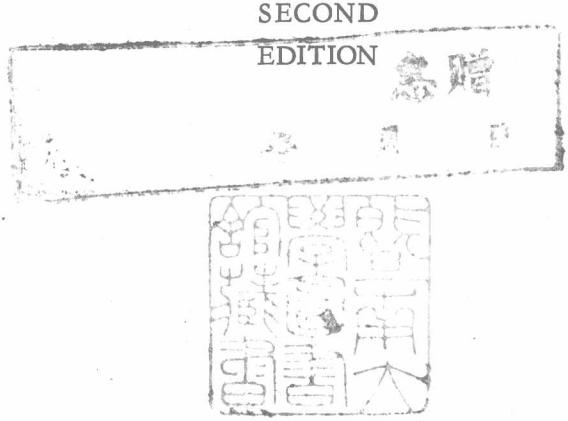

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Preface

MORE than seventeen years have passed since the first edition of *Medical Entomology* was published. In the original preface the important role played by insects and other arthropods in the transmission, causation, and spread of human and animal diseases was stressed. Today no such emphasis is needed, for the important role of insects in human welfare was fully demonstrated during World War II. Recognition of the effects of insect-borne diseases on the armies and navies of the belligerents has impelled our medical and entomological services and the governments of all nations to conduct extensive investigations on all phases of the problem. The results of many of these investigations, some of which are continuing, have not yet been published. In the present work the writer has attempted, with varying success, to bring together all data available by the end of 1948.

This completely rewritten text is offered to the physician, the entomologist, the public health worker, the student, and the layman in order to give them an authoritative survey of our present knowledge. The writer has not attempted to usurp the function of the physician, so the reader need not expect to find a discussion of treatment; he will find, however, a brief account of the best known methods of controlling the insects involved in disease transmission or causation. Here great advances have been made during the past few years. The reader is warned, however, that all the newer insecticides must be used with care and directions should be followed carefully.

The literature on insect-borne diseases is voluminous, widely scattered in many and varied journals, monographs, government publications, and other sources, and difficult to cover adequately. For this reason a list of journals, textbooks, and other publications that will enable the student to find the latest information is given at the end of the first chapter of the present work. Furthermore, each chapter is provided with a selected bibliography. Many of the references given have long bibliographies; these references are starred.

The writer gratefully acknowledges his indebtedness to the numerous

authors whose publications he has consulted or quoted. Wherever illustrative material is borrowed, full acknowledgment is given; if, by accident, such does not appear, due apology is hereby offered. To the many colleagues, friends, and students who have given suggestions, furnished material, and in other ways co-operated with him, the writer desires to tender his sincere thanks. He is under special obligation to Mr. Harvey I. Scudder for reading the galley proof, and to Mr. C. Y. Chow for checking the manuscript with reference to malaria in China.

ROBERT MATHESON

Ithaca, New York
September 1949

Plate II. Four great leaders in medical entomology. *Upper, left:* Sir Patrick Manson, M.D. (1844–1922), who first discovered the role of mosquitoes in the transmission of filariasis and propounded the theory that mosquitoes are the transmitters of malaria. *Right:* Sir Ronald Ross, M.D. (1857–1932), who first proved that mosquitoes are the vectors of malaria and laid down the principles by which malaria could be controlled. *Lower, left:* Major Walter Reed, M.D. (1851–1902), who brilliantly confirmed the proposition of Dr. Carlos Finlay that the tiger mosquito (*Aedes aegypti*) is the vector of yellow fever and who made possible the control of this disease. *Right:* Howard Taylor Ricketts, M.D. (1871–1910), who discovered that ticks (*Dermacentor andersoni*) are the vectors of Rocky Mountain spotted fever and contributed to the discovery that lice (*Pediculus humanus*) are the transmitters of typhus.

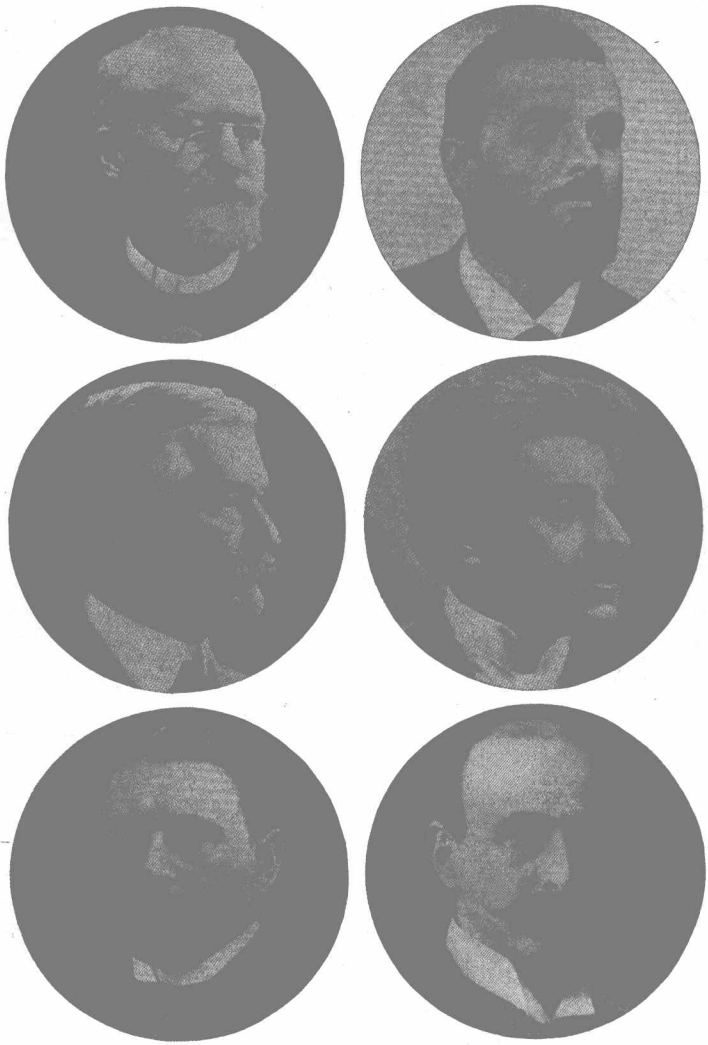

Plate III. Some noted leaders in medical entomology. *Upper, left to right:* C. L. A. Laveran, M.D. (1845–1922), noted French physician who discovered the parasite of malaria in 1880; G. Grassi, M.D. (1854–1925), who brilliantly confirmed Ross's work on the mosquito transmission of malaria. *Center:* Surgeon General W. C. Gorgas, M.D. (1854–1920), who carried out the great sanitation work in Havana and Panama based on the discoveries of Ross and Reed; Oswaldo Cruz, M.D. (1872–1917), director of the famous Oswaldo Cruz laboratory in Rio de Janeiro. *Lower:* F. V. Theobald (1868–1930), the author of the famous five volumes on the mosquitoes of the world; G. H. F. Nuttall, M.D. (1862–1937), who early stressed the importance of insects as vectors of human disease, who founded the Molteno Institute at Cambridge, England, and who throughout life conducted some of the most important researches on arthropods that serve as vectors of diseases.

Plate IV. Left: Dr. Leland Ossian Howard (1857–), who for nearly thirty-five years served as Chief of the Bureau of Entomology, United States Department of Agriculture, and who did more than any other American to establish the importance of insects as agents in the causation and spread of human disease. *Right:* Professor John Henry Comstock (1849–1931) in his old office in White Hall, Cornell University. By his work and teaching he gave entomology its present position in American universities.

Contents

CHAPTER I

Arthropods and Human Disease

THE phylum Arthropoda plays a role in human welfare that is little understood by the great majority of people. In the sea the dominant animal life is not the larger fishes, mammals, etc., but those tiny animals that constitute the greater part of the plankton—the free-swimming, minute Crustacea on which the others rely for food. As free-living vegetarians and scavengers they people the sea in vast numbers and perform their duties with admirable fitness, keeping great bodies of water cleaned of the dead and dying. On the land insects play a similar but more dominant role. For sheer vastness of numbers and incomparable adaptation for meeting the vicissitudes of life they far outrank any other animal or plant association. Who can count the ants that populate our fields and hillsides or the plant lice that suck their nourishment from our wild and cultivated plants? The part insects play in agriculture and commerce has been admirably portrayed by a number of writers and, at times, overemphasized, especially with respect to the vast losses agriculture suffers at their hands. It is not our purpose to enter such a discussion here; the reader will find references at the end of this chapter that will enlighten him on this phase of insect activity. Sufficient for our purposes is the self-evident fact that arthropods, and especially the class Hexapoda (insects), affect human welfare at every point and at times endanger man's very existence or hold in check his advances in the development of some of the most fertile regions of the globe. Medical entomology and parasitology have been recognized as important fields of study and research, not only for the zoologist, but for the physician, the veterinarian, and the layman. World War II amply demonstrated the great need for more knowledge of these subjects.

No more striking and dramatic story could be told than that of the remarkable interrelations which arthropods play in the spread and maintenance of plant, animal, and human diseases. Insects, long regarded and still regarded as unworthy of serious consideration by many of our scientists, have gradually forced peoples and governments to devote some of their resources to studies

too long delayed. Here only a bare outline of these studies can be offered and a tribute paid to those great medical leaders and others who have laid down their lives in the investigations of insect-borne diseases.

There are numerous early references to insects as distributors of disease—references made long before the parasitic origin of disease was established. To Mercurialis (1530–1607), an Italian physician, is usually attributed the first concrete observation that flies serve, in some unknown manner, to spread disease. During the plague (Black Death), which ravaged Europe in his day, he observed that flies may spread the disease by feeding on the internal secretions of the dead and dying and then depositing their feces on the food of the well. França states that Souza (1587) suspected flies of spreading yaws (framboesia); Bancroft (1769) propounded a similar theory from his observations in Guiana; and many years later Castellani (1907) demonstrated that flies do play a part in the dissemination of this disease—obtaining the organism (*Treponema pertenue*) from the sores of the sick and passing it on to the well.

It was not till many years later that well-defined theories of insect propagation of disease were promulgated. Such are those of Beauperthuy (1854) and Nott (1848) relative to the carriage of yellow fever by mosquitoes. Beauperthuy thought that mosquitoes brought the disease from decomposing matter and injected it into man and this was long before the discovery of pathogenic bacteria by Pasteur in 1857.

About the middle of the nineteenth century there was a remarkable development among German doctors and scientists in the study of helminths. Herbst in 1850 began the work of experimental parasitology when he fed trichinized meat to dogs and obtained the adult worms in his animals; Kückenmeister in 1852 discovered, by feeding experiments, that the "bladder worms" in rabbits were but a stage in the life cycle of tapeworms; in 1854–1856 he also showed that "bladder worms" in pigs were but a stage in the life cycle of human tapeworms; Virchow and Leuckart in the same decade determined the life cycle of *Trichinella* (*Trichina*) and Leuckart (1862) solved the mystery of hydatid cysts. All these and other experimental activities undoubtedly fired the minds and guided the thinking of the rising generation.

DISEASES DISCOVERED TO BE TRANSMITTED BY INSECTS

FILARIASIS: In 1863 Demarquay discovered a larval nematode in cases of chyluria; they were later seen by Wücherer in other cases, and Lewis (1872) discovered that the blood of man is the normal habitat of this filarial worm (*Filaria sanguinis hominis* of Lewis).

In 1866 Dr. Patrick Manson, a young medical man of imagination and

unbounded energy, left the shores of his native country, England, and took up heroic work first at Formosa and later (1871) at Amoy, China. He investigated anything and everything that came his way, developing a remarkable ingenuity for interpreting old and solving new problems. He found filaria abundant in the blood of his Chinese patients, established the "periodicity" of their appearance in the peripheral circulation, and in 1879 published the first account of an insect, *Culex fatigans* (the house mosquito of the tropics), serving as the intermediate host in the developmental cycle of a parasite. Though Manson traced the developmental cycle from the intestine through the thoracic muscles, he did not determine how the parasites reached a new host. He believed at that time that the life of the mosquito was short, the females dying after laying their eggs, and so he formulated the theory that man was infected by drinking the water in which infected mosquitoes died. It was not till 1900 that the true method was discovered by Low. Manson's work was the real starting point of medical entomology. In 1890 Manson returned to London, engaged in the practice of medicine, and urged the development of tropical medicine. In 1893 he evolved his mosquito theory of malaria. Though he never had an opportunity to test his theory, he so impressed his ideas on Dr. Ronald Ross that the latter eventually made his epoch-making discovery in 1897–1898.

Only one other contribution by Manson can be recorded here. *Loa loa,* the African eye worm, was long identified both in America and Africa, but nothing was known of its life cycle. In 1891 Manson reported a new filaria in the blood of natives from the Congo and Old Malabar, naming it *Filaria sanguinis hominis major* (later known as *Microfilaria diurna*). On account of its diurnal periodicity Manson predicted that some bloodsucking, day-feeding fly would be found to be the intermediate host. From talks with the natives of Old Calabar he suggested that the "mangrove flies," *Chrysops dimidiata* and *Chrysops* spp., would prove the correct flies. In 1912 Leiper confirmed this prediction, and Kleine (1915) worked out the methods of transmission in detail.

Another remarkable discovery should be recorded here; it, in fact, antedated Manson's work. Fedschenko (1869) demonstrated that *Cyclops* spp. (Crustacea) were the intermediate hosts of the famous "fiery serpent" of Moses, the dragon worm, *Dracunculus medinensis* Linn. (hence the name of the disease, dracontiasis). Manson (1894) confirmed and extended the work of Fedschenko.

MALARIA: In 1880 Laveran, working in Algeria, discovered the parasite of malaria in the red blood cells of his patients. More than ten years passed

before Laveran's organism was accepted as the causal agent of the disease. Though much had been learned about the parasite during this time, little progress was made till Manson evolved his mosquito theory and impressed it on Ronald Ross, a young British surgeon working in India. So farfetched appeared Manson's theory that he was dubbed "Mosquito Manson" by his distinguished medical confreres and regarded as rather fit for a lunatic asylum. Curiously enough, in 1883 an American physician, A. F. A. King, had also propounded a mosquito malarial theory, which, unfortunately, fell on deaf ears and unimaginative minds. Under Manson's urging Ross continued to work and in 1897 recorded his great discovery that "dappled-winged" mosquitoes served as the definitive hosts of species of *Plasmodium*. Ross's work was done under the most trying conditions and at a time when no one knew mosquitoes or their biology. His results were fully confirmed by Bastianelli, Bignami, and Grassi (1898, 1899), Manson (1898), and Sambon and Low (1900). This discovery by Ross is undoubtedly one of the great landmarks in medical history, for it has led to the reduction, and can lead to the elimination, of the most widespread and devastating of human diseases.

PIROPLASMOSIS: While the mosquito malarial theory came to fruition in India and Europe, Theobald Smith, working in Washington, D.C., discovered the causative agent of Texas or red-water fever of cattle, *Piroplasma bigemina,* a red-blood-cell-inhabiting protozoan. In 1893 Smith and Kilbourne published the results of their work. They demonstrated that the cattle tick, *Boophilus annulatus* Say, was the intermediate host. In addition, they showed that the parasite passes from the adult female ticks to their offspring and only young ticks (larvae) infect new hosts. This is the first instance of a protozoan passing by way of the egg to infect the young, which, in turn, transmit the disease to new hosts. Many other discoveries in the field of protozoan parasites of domestic animals have since been made and are of the greatest importance to animal husbandry. It would take us too far afield to discuss them here.

TRYPANOSOMIASIS: From about 1893 to the present time the most remarkable discoveries have been made in the field of insect-borne diseases. These can be reviewed only briefly. In 1895 Bruce discovered *Trypanosoma brucei,* the causative agent of nagana or tsetse fly disease of cattle in Zululand and demonstrated that the tsetse fly, *Glossina morsitans* Westw., could transmit the disease from the sick to the well. It was not, however, till 1909 that Kleine proved the developmental cycle in the fly and showed the true method of transmission. In 1901 Forde, in West Africa, observed a parasite in the

blood of a European patient suffering from Gambian fever; later Dutton (1902) recognized it as a trypanosome and described it as *Trypanosoma gambiense* Dutton; Castellani (1903) and Bruce and Nabarro (1903) proved this trypanosome was the causative agent of sleeping sickness and that *Glossina palpalis* R.-D. was the transmitting fly. In 1910 Stephens and Fantham described *Trypanosoma rhodesiense* as the etiological agent of Rhodesian sleeping sickness, and Kinghorn and Yorke (1912) proved that *Glossina morsitans* Westw. was the transmitter. In South America Chagas (1909) demonstrated that a trypanosome, *T. cruzi,* was transmitted by a bug, *Triatoma megista* Burm. This parasite is the etiological agent of South American trypanosomiasis or what has been called Chagas' disease.

YELLOW FEVER: While these African investigations were being developed, the American Army Yellow Fever Commission, consisting of Reed, Carroll, Lazear, and Agramonte, made a still more remarkable discovery. They demonstrated (1900) that yellow fever can be transmitted only through the agency of the "tiger mosquito" or yellow-fever mosquito (*Stegomyia fasciata, Aedes calopus, Aedes argenteus*—now known as *Aedes aegypti*). Though Carlos Finlay, a Cuban physician, had as early as 1881 propounded a mosquito theory for yellow fever and had extensive experimental evidence in support of it, yet it must ever redound to the glory of this band of devoted workers that, because of their discoveries, one of the most deadly of human diseases could now be controlled or even eliminated. Though Noguchi (1919) announced that *Leptospira icteroides* was the etiological agent and his work was accepted by many workers, his results have since been abundantly disproved. It is now known to be caused by a recognized virus, which has been studied in great detail. For over a quarter of a century it was firmly believed that the only transmitter of yellow fever was the "tiger mosquito" and that man was the only animal susceptible to the disease. On this belief prophylactic measures against yellow fever were based, and remarkable results were obtained in reducing and controlling outbreaks of the disease. However, in 1928 two most important contributions were made to the yellow-fever problem. Stokes and his associates, working in West Africa, demonstrated that monkeys, *Macacus rhesus,* were susceptible to the disease, and since then many more species of monkeys, both from the Old World and the New World, have been shown to be susceptible to yellow fever. In the same year Bauer, working in the same laboratory, proved that three other species of mosquitoes were capable of transmitting yellow fever. Since that date over thirty additional species of mosquitoes have been shown to be capable of transmitting yellow fever.

In 1933 Soper and his associates reported an outbreak, in parts of Brazil, of what has been designated as jungle yellow fever. Since then large areas in South America have been shown to be endemic centers of this disease. Jungle yellow fever is identical with classical yellow fever, but its epidemiology is remarkably different. (See pp. 353–356.) These and other discoveries have thrown new light on the yellow-fever problem. The development of an effective vaccine by the workers of the Rockefeller Foundation in 1932 has provided one of the most efficient methods to prevent and reduce yellow-fever outbreaks.

PLAGUE: In 1894 Yersin and Kitasato independently discovered the causative agent of plague, *Pasteurella pestis,* and Yersin demonstrated that the disease in man was identical with a plaguelike disease of rodents. Simond (1898) suggested that fleas were agents in the dissemination of plague, and his experiments showed that he was on the right track. In 1903–1904 Verjbitski demonstrated that fleas act as vectors of the plague bacillus, but his results were not published till 1908. The development of the plague bacillus in the gut of the rat flea was independently discovered by Liston (1905), and the role fleas play in the epidemiology of plague was fully determined by the British Plague Commission (1906–1908). Finally Bacot and Martin (1914) demonstrated the method of transmission of the plague bacilli by fleas.

DENGUE: Dengue or breakbone fever, a disease of unknown etiology, was shown by Graham (1902) to be mosquito-borne, and his results were confirmed by Ashburn and Craig (1907). Though the mosquitoes with which these investigators were supposed to have worked have since been shown not to be true vectors, their discovery was of great importance. The true vectors have since been shown to be *Aedes aegypti* and *Aedes albopictus* (see pp. 357–358).

PHLEBOTOMUS FLIES AND DISEASE: Pappataci fever (three-day fever or sand-fly fever), another disease of unknown etiology, was shown by Doerr, Franz, and Taussig (1909) to be transmitted by a sand fly, *Phlebotomus papatasii* (Psychodidae). Oroya fever, verruga peruana, or Carrion's disease, a disease of rather high mortality in parts of South America, was demonstrated by Townsend (1913–1914) to be transmitted by *Phlebotomus verrucarum,* and his results have been confirmed by Noguchi and his associates (1929). *Phlebotomus* spp. have also been proved vectors of kala azar, Oriental sore, and espundia (diseases known as forms of leishmaniasis, the etiological agents being species of *Leishmania*), but at the present time (1949) many actual transmitters still remain unknown.

SPIROCHETAL DISEASES: In 1903 a peculiar disease of fowls caused by *Spirochaeta marchouxi* Nuttall was shown by Marchoux and Salimbeni to be tick-borne, the common fowl tick, *Argas persicus* Oken, being the vector. Various recurrent fevers of man caused by *Spirochaeta* spp. have since been shown to be tick- or louse-borne. Ross and Milne (1904) first demonstrated that the tick, *Ornithodorus moubata,* is the vector of African relapsing fever caused by *S. duttoni.* These conclusions were confirmed and extended by Dutton and Todd (1905) working independently in the Belgian Congo. Since then various species of ticks (*Argasidae*) and lice (*Pediculus humanus*) have been shown to be the natural transmitters of the different relapsing fevers of man. Mackie (1907), working in India, first demonstrated the part played by lice (*Pediculus corporis*) in the dissemination of relapsing fevers.

TSUTSUGAMUSHI DISEASE, KEDANI FEVER, FLOOD FEVER, OR JAPANESE RIVER FEVER: A serious disease in parts of Japan, China, Formosa, and other parts of the Far East, tsutsugamushi was first diagnosed as a distinct disease by Bälz and Kawakami in 1879. This peculiar disease had long been believed by the common people to be associated with the bites of a red mite. Bälz and Kawakami concluded there was no such association. Kitasato (1891–1893), however, decided that the bites of a red mite did play a role in the causation of the disease. The mite theory of the transmission of the disease has since been fully confirmed by the work of Tanaka (1899), Kitashima and Miyajima (1909, 1918), Miyajima and Okumura (1917), and others. The etiological agent was isolated by Nagayo and his associates (1930) and described as a rickettsia, *R. orientalis.* During World War II this disease was found to be widespread in many Eastern areas. The so-called "Mossman fever" of Australia, "scrub typhus" of Malaya and other parts of the East, and "pseudotyphoid" of Sumatra were found to be kedani fever and transmitted by mites (*Trombicula* spp; see pp. 110–113).

ROCKY MOUNTAIN SPOTTED FEVER: This peculiar disease prevalent in Montana and certain other Rocky Mountain states was definitely proved by Ricketts (1906) to be transmitted to man by a tick, *Dermacentor andersoni* Stiles (*venustus* Banks). His results have been fully confirmed by various later workers, and Wolbach (1916, 1919) determined the causative agent to be *Dermacentroxenus rickettsi* (Rickettsia bodies, so-called). This disease is now widespread in the United States (see pp. 73–74).

TYPHUS FEVER: Though the head and body lice (*Pediculus humanus* var. *capitis* and var. *corporis*) have been closely associated with man in all his long career, it was not till 1909 that Nicolle, Comte, and Conseil, working in

Tunis, demonstrated the role played by the body louse (*corporis*) in the spread of the much-dreaded typhus or jail fever. These results were confirmed by Ricketts and Wilder (1910) working independently in Mexico. Da Rocha-Lima (1916) discovered the causative agent and named it *Rickettsia prowazeki*. During World War I (about 1915) a peculiar disease dubbed "trench fever" appeared among the troops of the contending armies and was definitely proved by various workers to be disseminated by head and body lice (see p. 208). Töpfer (1916) designated what is considered the causal agent as *Rickettsia quintana*.

TULAREMIA: A peculiar plaguelike disease of rodents was investigated by McCoy (1911), and the etiological agent, *Bacterium tularense*, was isolated and described by McCoy and Chapin (1912). In 1911 Pearse, in Utah, described a peculiar disease of man under the title of "insect bites," and this disease later became known as "deer-fly fever." Francis (1919–1920) recognized the identity of "deer-fly fever" of man and the plaguelike disease of rodents and named the disease tularemia. Francis and Mayne (1921) demonstrated that the deer fly, *Chrysops discalis* (Tabanidae), was the transmitting insect. Since then a large number of insects and ticks have been shown to be able to transmit the disease in nature.

ONCHOCERCIASIS: Recent contributions in the field of medical entomology have been the solving of the life histories of *Onchocerca volvulus* Leuck. and *O. caecutiens* Brumpt (Nemathelminthes, family Filariidae). The former species occurs in Africa and the latter in parts of Central America and Mexico. Blacklock (1926) determined that *O. volvulus* passes part of its life cycle in black flies (*Eusimulium damnosum*, family Simuliidae) while Hoffman (1930) and Strong (1931) demonstrated that *O. caecutiens* undergoes a developmental cycle in at least three species of black flies. Both these round worms produce diseased conditions in man. These two species are now considered to be one and the same, *O. volvulus*.

In recent years several important diseases have been demonstrated to be insect-transmitted. Poliomyelitis, long associated with some bloodsucking insect as a vector, has been shown capable of being disseminated by filth-loving flies, as the housefly, blowflies, and flesh flies. How important a part these flies play has not been determined. St. Louis encephalitis, a new virus that appeared in epidemic form in St. Louis during 1933 and 1937 and has since been isolated in other parts of the country, has been shown to be disseminated to man by mosquitoes. The reservoir of this disease has been found in birds, primarily fowls, and in the fowl mite, *Dermanyssus gallinae*. Japa-