INSECTS AND HUMAN WELFARE

LONDON : GEOFFREY CUMBERLEGE

OXFORD UNIVERSITY PRESS

INSECTS

& Human Welfare

AN ACCOUNT OF
THE MORE IMPORTANT RELATIONS
OF INSECTS TO THE HEALTH OF MAN,
TO AGRICULTURE, AND
TO FORESTRY

CHARLES T. BRUES
Professor of Entomology, Emeritus
HARVARD UNIVERSITY

REVISED EDITION
HARVARD UNIVERSITY PRESS
CAMBRIDGE, MASSACHUSETTS
1947

PRINTED IN THE UNITED STATES OF AMERICA

To my two children

AUSTIN MOORE BRUES

and

ALICE MOSSIE BRUES

whose interests have led them into other diverse branches of scientific inquiry concerning the human species

PREFACE TO THE REVISED EDITION

At the time this little volume was originally written we, as Americans, together with the greater part of Europe, were emerging from a war-torn world and turning our thoughts toward a peaceful era, which we naïvely saw as a permanent innovation. Twenty-five years later, like the cheerful insect, we have gone through another molt, and are again looking forward with some misgivings to a more or less protracted period of normal growth and development.

During World War I applied science was very much in the forefront, but advances in biology were not greatly accelerated. However, the following quarter-century witnessed widespread progress in the several pure and applied phases of biology. Among these entomology shared in the general prosperity, scoring many advances and technological improvements.

The presently ended conflict stimulated extensive research in the medical aspects of entomology. This was due mainly to the fact that this war was fought to a large extent in tropical or subtropical regions where the prevalence and severity of insect-borne diseases are generally far greater than in the colder parts of the world. With this incentive, finely organized groups of energetic and capable scientific men turned their attention to the very urgent problem of protecting the health of our armed forces. Their signal success is well-known and has gone far to impress on the public mind the altruistic viewpoint of science.

Twenty-five years have thus added greatly to our knowledge of the relations of insects to public health, so the chapter on this subject has required extensive revision, with the inclusion of much additional information.

By comparison, much less has been learned concerning the insects dealt with in the other portions of the book. Considerable change has been necessary, nevertheless, to bring the material up to date. Several important new insect pests have been introduced into our own country and much progress has been made in methods of control, as well as in the application of insects to the control of weeds and other noxious plants.

The illustrations have been reduced in number by the elimination of the photographs. Most of the charts are retained in revised form and a few new ones have been added.

The scientific nomenclature has required some revision, although, as previously, changes in Latin names have been adopted only when well established in current literature. A brief index has been added as an aid to convenient reference.

I am deeply indebted to Miss Ruth C. Dunn for painstaking editorial work on the revised manuscript, and later continued help in seeing the book through the press.

Charles T. Brues

Biological Laboratories
Harvard University
June, 1946

PREFACE TO THE FIRST EDITION

The present volume is an attempt to present some of the principles and practices of economic entomology in a form that will illustrate the biological relationships of insects to their environment. Like nearly all applied sciences, economic entomology was early developed as an art, with little reference to biology, aiming toward the empirical application of certain methods for the destruction or abatement of noxious insects.

The past few decades have witnessed great changes whereby the field of the entomologist has been greatly extended, and he has been compelled, not unwillingly, to improve his methods of investigation and to take advantage of the rapid progress made not only in zoology and botany, but in medicine and chemistry as well. He has naturally greatly improved his efficiency, and has been enabled to increase his usefulness to humanity manyfold.

The general public rarely appreciates fully the many economic problems in relation to insects which continually present themselves. Even the zoologist, be he morphologist, embryologist, geneticist or student of animal behavior, often regards the entomologist as a collector or cabinet naturalist, who spends the greater part of his time impaling specimens upon slender pins, and continually rearranging them in cork-lined boxes. Unfortunately, this means toward an end seems to be a bugbear from which the entomologist may never escape, since he has to deal with a wonderfully varied and extensive series of animals. This very fact makes it difficult to deal with insects in the brief and generalized manner applicable to other groups of animals. As a consequence, entomological books and treatises naturally tend to assume encyclopedic form.

In the following pages I have considered few of the details which may be found in many other carefully prepared volumes, but have rather attempted to avoid, as consistently as possible, matters not directly necessary for a brief consideration of insects as they affect human welfare.

Most of the material contained in the chapter on Insects and Public Health appeared in the *Scientific Monthly*, and in its recast and revised form is reprinted with their kind permission. The illustrations have come from several sources, the photographs almost entirely from negatives made by the author; of the maps, charts, etc., some have been made especially for the present book and others are redrawn or modified from various authors.

Owing to changes in nomenclature during the past few years, many of our common insects now have different Latin names. All of these changes have not been made in the present book, as the author feels that they should become well established before they are presented to the nonexpert reader.

Charles Thomas Brues

Bussey Institution
Harvard University
February, 1919

CONTENTS

ILLUSTRATIONS

INSECTS AND HUMAN WELFARE

INTRODUCTION

In his ceaseless strides toward domination of the material world man has encountered many obstacles. Some of these are palpably of his own making. For many of those presented by his living environment, man is responsible only in so far as he forms a part of the intimately interdependent myriad of organisms which make up that environment.

In his battle with the elements he has continually improved his condition, and he has seemingly mastered many problems which did not even disturb the minds of previous generations. This is most conspicuously evident in the remarkable achievements of modern synthetic chemistry, whereby a multitude of substances have been made available for an almost endless variety of useful purposes. Perhaps even more important in its power for good or evil is the release of atomic energy and the possibility of its use for peaceful purposes at a time when our natural resources of heat and power are dwindling at an alarming rate.

It is in relation to other animals and to plants, more like himself in their plastic constitution and powers of reproduction, that man has so far experienced the greatest difficulty in turning the balance to suit his fancy.

The great variety and usefulness of domesticated animals and cultivated plants that have been selected and developed show that there is much in man's living environment that may be diverted to useful ends. These have been sought out and remain, at least in their present state of improvement, only as unwilling guests, ready to depart, or to revert to their former savage state at the first opportunity. Most of them date back for many centuries, as only a very few have been added in recent times. The cultivation of microscopic organisms like the mold from which penicillin is prepared or the Torula yeast which serves as a food of high protein content is, of course, a recent innovation.

Another and far more extensive series of unbidden guests is made up of numerous other animals and plants, some originally associated with the human species, and some attracted to it as the result of changes wrought by civilization. The organisms of this class consist of various disease-causing microbes and parasites, and of living things that either find a more congenial environment where the face of nature has been altered, or have actually been transferred to parts of the world where they did not formerly exist in the orderly arrangement of nature.

This great train of undesirable animals and plants is continually augmented by new arrivals, mainly through extensions in the distribution of those already affected by a changed environment. A quite considerable part of this motley assemblage consists of insects, which enter into our life and activities in many ways. This group of animals really vies with the mammals, and with man in particular, in its threat to dominate the animal world. With this end in view, insects have several points in their favor which must not be forgotten at the outset, although they are dealt with at greater length in the succeeding chapters. There are many more different kinds of insects than there are of other animals, and it follows from this, if for no other reason than as a matter of chance, that they will cross our path at many places. They are small, extremely tenacious of life, and endowed with such great powers for reproduction and multiplication that the abundance of any particular species responds very rapidly to changes in food supply or other variable factors in their surroundings. Although in great part terrestrial or aquatic during their preparatory stages, they are typically winged and adapted to an aerial life in their mature condition. In addition, some are parasites of various plants, animals, and even of other insects, till it would seem that about every method of earning a living, or of securing it otherwise, may find its counterpart in some insect. Thus the actions of the busy bee, the industrious ant and the cheerful, chirping cricket have been more or less accurately cited as exhibiting certain traits desirable in human behavior. The activities of others, like the rapacious praying mantis, the ant-decapitating fly, and the slave-making Amazon ant recall the levels of depravity to which our species may at times descend. Endowed also with a great fixity of purpose dependent upon their purely instinctive behavior, insects do not respond readily as a class to our efforts to thrust them aside out of our way.

What can be more persistent than the well-directed flight of the hungry mosquito in its search for blood? The same constancy prevails among the vegetarian insects as they seek out their favorite food plants with great acumen and precision. Much has been learned concerning the hidden dangers that lie in the wake of the mosquito bite, but little has been accomplished toward banishing the mosquito tribe. Quite properly, no biologist has entertained the idea that the instincts of the mosquito, or for that matter of any other insect, could be altered in the least. The only remedies which can be proposed at the present time for dangerous, annoying, or destructive insects depend upon completely destroying them, preventing their reproduction, or actually imprisoning the objects that might be damaged, as we do for ourselves with barricades of fly screens and mosquito nets. Crude as such methods may appear to be in general principle, their application is by no means as simple as might appear at first sight, and in practice they are becoming much more efficient from year to year.

Unfortunately the vast group of insects has furnished almost no species that are directly useful to man. Only two stand out in sharp contrast: the honeybee and the silkworm. Like some of our higher domesticated animals and cultivated plants, they have been associated with man for many centuries. Indeed, the Chinese silkworm has its origin hidden in antiquity and like our familiar plant, Indian corn, is now not to be found in the wild state. Through selection, several improved races of the honeybee have been evolved, and apiculture as now followed in many countries has added greatly to the material wealth of the world through its extensive production of honey and beeswax.

The silkworm is likewise an extremely valuable insect, although its cultivation is limited to a smaller part of the world. All the real silk of commerce is produced by insects, although certain kinds are spun by other caterpillars than the true silkworm (*Bombyx mori*). Like the honeybee, the true, or Chinese, silkworm is known in several races with special characteristics of cocoon-color and rate of development, brought about by selection and inbreeding. For many centuries the silkworm has produced not only a vast amount of valuable material for clothing and other purposes, but has added immeasurably to the glitter of personal adornment. Quite recently the product of the silkworm has been supplanted by materials of similar appearance produced by the chemical treatment of wood fibre and certain animal proteins. Of these, nylon appears to be actually superior for the manufacture of fishing lines and women's stockings. Nevertheless, the glamor of true silk still remains, at least in the feminine mind.

Shellac is also the production of an insect—a product of considerable commercial importance for which so far no acceptable substitute has been evolved. It seems very probable, however, that the lac insect may become obsolete, to be replaced by some synthetic resin or plastic. Such a fate overtook the cochineal insect. The latter was formerly important as a source for carmine and the red dyes made therefrom, but has been replaced by inferior, though more cheaply produced, chemical colors. It is still indispensable to the biologist as a source of permanent microscopic stain.

Few other insects are directly useful to an extent that makes them of general economic importance, and so much has been written of the species just mentioned that they will be omitted from the following account. Our attention will be restricted to the insects which bear a less pleasant relation to man, and to those which are secondarily beneficial in so far as they may regulate the abundance of the primarily destructive species.

For convenience we may group insects in their relation to human welfare into several categories, as has been done in the following chapters. In their association with various diseases of man and of the higher animals insects are of very direct importance, and this aspect stands more or less clearly apart from the others. As enemies of various cultivated plants, the depredations of insects are a serious menace in so far as they interfere with agricultural production, decreasing the supply of foods and of other less useful and necessary, although valuable, materials. Their influence upon the forests is similar to the last in many ways, but, as will appear on closer examination, presents different problems from the practical standpoint.

Many insects, some of far less real importance than those of less sociable habits, will be considered under the caption of household insects. These creatures, of many diverse sorts, have taken up their abode with man and are continually intruding themselves upon his attention. Some are dealt with elsewhere as they are related to diseases or have otherwise striking economic relations; the remainder, no worse than nuisances, show many interesting and surprising adaptations.

CHAPTER I

INSECTS AND THE PUBLIC HEALTH

Almost exactly half a century has elapsed since the scientific world entertained its first suspicion that certain human diseases might be spread through the agency of insects. Several years later that suspicion became an established fact, and since then so much has been learned concerning the pernicious activities of these small animals in disseminating disease-causing organisms among man and the higher animals, that the science of preventive medicine can now be applied to many important diseases which were before utterly beyond its reach. Almost every year brings forth fresh evidence that insects are important factors in relation to public health, and adds to the list of diseases that are partially or entirely dependent upon certain insects for their spread.

A brief statement of the nature of communicable diseases and of the general habits of the kinds of insects that are implicated in carrying disease will serve to define roughly the field of medical investigation which is open to the entomologist. Communicable diseases are invariably due to parasitic organisms or viruses in the body which are capable of inducing similar symptoms in other persons or animals if transferred from diseased individuals to susceptible healthy ones. Many conditions modify the transfer of communicable diseases; some individuals are more easily infected than others; some may be immune as the result of a previous attack; and, on the other hand, the virulence of pathogenic organisms often varies greatly in accordance with conditions to which they have previously been subjected. A simple method of spread occurs with many diseases, for example, typhoid fever and pulmonary tuberculosis. With the former, *Eberthella typhosa,* which is the disease-producing organism, is present in the dejecta of an infected person and may find its way from these to food, carried by flies or otherwise; ingested by a susceptible person, it may quite likely multiply and induce a second case of typhoid. With tuberculosis, the tubercle bacillus from desiccated sputum may enter the lungs of a healthy person with dust and there reproduce the disease. As we shall see later, certain insects are commonly associated with the spread of diseases of this type, although from the very nature of such diseases, insects are not exclusive factors, and may be referred to as contaminative carriers.

A second type of communicable diseases differs from the one just mentioned in that the organism which causes the disease must live for a time in the body of some other animal to undergo certain definite changes before it can again induce the disease in another individual. Many of the most important insect-borne diseases belong to this type, for in the case of man and domestic animals, certain insects and ticks act as the secondary host animals for the organisms that cause numerous diseases. Thus yellow fever is spread through the agency of certain mosquitoes, for only in them can the yellow fever virus exist and undergo the changes that are necessary before it can be introduced into another patient by the bite of an infected mosquito. Malaria belongs to the same category, for it spreads only through the bite of certain mosquitoes that obtain the organisms with their meal of blood, and then afterwards inject into the blood of another person a later stage of the malarial parasite which has developed meanwhile within the mosquito. These disease-causing parasites are quite diverse. Many are bacteria; others are protozoans; some, known as rickettsias, are bacteria-like but of dubious relationships; and others are known as viruses. The last are ultramicroscopic, but seem to be enormous chemical molecules having the ability to multiply and reproduce their kind like living organisms.

The importance of insects as detrimental to public health is well known to professional zoologists, medical men, and laymen alike, but is usually emphasized only under the stress of particular circumstances, such as the safety of armies in time of war, or of unusual outbreaks or epidemics.

Insect-borne diseases present a constant menace to the world, and aside from the actual toll of lives which they exact they impair its efficiency by enfeebling the health of its human population. Their direful influence is more pronounced in the tropics, where it has been most commonly proclaimed, but our own country is by no means exempt, although its cooler climate causes it to be less severely affected.

No other insects can compete with the mosquitoes as persistent annoyers of man, and none, with the possible exceptions of the rat flea and the louse, holds over him such power for evil. Practically no part of the globe that can serve for human existence is free from mosquitoes, and large areas from the tropics to the arctic are periodically invaded by them in varying abundance. Even where irrigation has made the "desert blossom like the rose" it has often also produced a crop of mosquitoes to annoy or even afflict with disease the inhabitants of the garden.

On account of their blood-sucking habits, and particularly their fondness for man, mosquitoes have always been heartily detested, even by the entomologist, but only their known association with diseases brought them to the serious attention of zoologists. With this incentive a vast amount of work has been done by entomologists and medical men and an enormous mass of literature has been produced bearing on every conceivable aspect of the subject. We now know that mosquitoes are responsible for many deaths, much human misery, and great economic loss through their activity as disseminators of malarial fevers, yellow fever, dengue fever, filariasis, and so forth.

In all of this, several of the more important relations of mosquitoes to public health stand out very clearly. (1) Some very important diseases of man are transmitted by certain specific mosquitoes, the latter being absolutely necessary for the continued existence of these diseases. (2) The disease-bearing mosquitoes are most widely distributed in the tropics, whence they extend into portions of the temperate zones. (3) The range of mosquito-borne diseases is not necessarily coextensive with the distribution of their insect carriers, but is dependent upon other factors as well. (4) Mosquito-borne disease may be combated either by the elimination of the mosquito responsible; by the protection of the population from its bites; by the careful screening of human patients to prevent them from infecting mosquitoes; or by a medical prophylaxis or immunization of the susceptible population. (5) Remedial measures are applied preferably against only the specific mosquitoes responsible, not against mosquitoes in general. The last is primarily a matter of economy, that the most vital needs of the community be fulfilled first; often the public evinces more willingness to coöperate in fighting the most annoying or abundant species of mosquitoes than in fighting the ones most deleterious to the public health.

Of these procedures, the elimination of the mosquito responsible has proved to be most generally applicable, preferably in combination with the protection of the population by screening, particularly the screening of infectious patients. Medical prophylaxis alone has usually not proved to be generally practicable. It can be applied only in the case of some diseases like malaria where quinine, atabrine, or other drugs are specific remedies, or with those like yellow fever and plague where immunization is possible.

One of the most widespread and best-known insect-borne diseases and one which is of great importance in many parts of our own country is malarial fever, variously termed ague, chills and fever, etc. This was the first human disease traced directly to insect carriers and gave the impetus which has led to the unraveling of the facts connected with other insect-borne diseases.

The protozoan blood parasites that cause malaria were first demonstrated many years ago, in 1880, by a French surgeon, Laveran, who discovered them in the blood of persons suffering from malaria. Five years later an Italian, Golgi, distinguished three kinds, each associated with one of the more familiar types of malaria. They were found to go through a regular life cycle in the red blood corpuscles and, from analogy with other known Protozoa, it was suspected that in addition to their non-sexual generations in the human blood there must be a sexual development in some cold-blooded animal. The British physician, Sir Patrick Manson, was led to suspect that some insect might be the secondary host, and, working on this hypothesis, Ross in India first found the human malarial parasites in a certain kind of mosquito in 1898. He had worked for nearly three years on a common mosquito belonging to the genus Culex without result, but finally, in a species of the genus Anopheles, was able to trace the development of the parasite. His epoch-making discovery has since been amply confirmed and extended by experimental proof, till we now know that the various types of malarial blood parasites complete their life-cycles in anopheline mosquitoes, the latter acting as the sole carriers of the disease.

The details of growth and development of these parasites, which belong to the protozoan genus Plasmodium, are extremely interesting, but far too complicated to discuss briefly. In general it may be said that the blood of persons suffering from malaria contains the parasitic organisms, and that these, on being taken into the stomach of the susceptible anopheline mosquito, undergo certain changes and later penetrate the wall of the stomach to form vesicular swellings. Within these they multiply, and finally on the bursting of the nodule are set free as spores in the body, whence they find their way to the salivary glands. When the parasites are ingested by other species of mosquitoes they fail to continue their development and die without passing beyond the stomach.

After becoming infected, a period of twelve to twenty days is required for these changes to take place in the body of the host mosquito. Then for a period of several weeks the virulent organisms remain in the salivary glands, and if the mosquito bites a second person the parasites are introduced with the salivary secretion, through the puncture, into the circulating blood. Here, after a brief intracellular stage, they multiply in the red blood corpuscles and produce another case of human malaria, which develops from ten days to three weeks after inoculation.

At the present time malaria in its several forms is the veritable scourge of the tropics. It also extends generally into the subtropics and warmer temperate regions and is prevalent over a considerable part of the southern United States. In our country its range is roughly coincident with the moist austral zones east of the 100th meridian as defined by zoogeographers. Aside from this main area, there is a small area in southern New England and another in central California; there are also a few isolated localities scattered through the country where malaria is thought to be endemic (Fig. 1). At least three species of Anopheles are known to act commonly as carriers in the United States. Barring various areas where suitable breeding places do not exist, the distribution of these taken together covers practically all parts of the country. As these malarious regions include a population of about fifty million people, it will be seen that the importance

FIG. 1. Distribution of malaria in the United States. In the larger blackened areas it is endemic and presents a real public health problem. Elsewhere it is sporadic and comparatively rare, although the mosquito carriers are very generally present in varying abundance in nearly all sections of the country.

of malaria from the standpoint of public health is very great indeed. It must be remembered, however, that the incidence of malaria varies widely, being greatest in the large southeastern area, and very much less in the more densely populated northern districts. A generation ago malaria was a most serious menace to health in the endemic areas. In Mississippi about eighty cases of malaria per thousand of population were reported during 1918, or 158,000 for the entire state.

Other southern states did not report the disease so thoroughly and it is difficult to estimate to what extent they were affected. It would seem, however, that one million cases each year would be a conservative estimate, especially as von Ezdorf found in 1913 in a portion of one mill town in the endemic area that over 13 per cent, or one person in seven, harbored the malarial parasite in the blood, while 233 out of 500, or nearly 50 per cent, reported having had chills and fever during the summer preceding his examination. Although the death rate from malaria outside the tropics is not very great (nine per thousand calculated on the data for Mississippi cited above), it is by no means inconsiderable in the mass. On the other hand, the economic loss is enormous, due to inability to work during the acute attack of the fever and to a loss of efficiency during prolonged periods following. That malaria responds quickly to antimosquito work and quininization is shown by the result following an application of these measures to the mill town mentioned. The report states that measures were inaugurated to get rid of mosquito breeding places and to encourage the use of quinine. A year later the town was again visited and the blood of 780 persons examined. Of these only 35, or 4.5 per cent, showed infection. The health officer reported at this time that for several months his visits from among the mill employees had averaged not over one a day, and that many of these were undoubtedly for old infections lasting over from previous years. The malaria rate had continuously decreased during the months when it was usually at its worst. The health officer of the town in his report for 1914 stated that, while during the summer of 1913, prior to antimalarial work, the mills were constantly short of help on account of the large numbers of employees sick with malaria, during the summer of 1914 there had not been a day when the mills did not have sufficient help. The manager of one mill stated that the improvement in the regularity and efficiency of the employees had been such that the amount ($1,000) which the mill had contributed to the fund for antimosquito work was more than regained in one month's operation. The work was thus fully worth its cost.

While these conditions were those of one of the most severely affected districts, they were nevertheless repeated very generally throughout the entire area, especially in the lowlands, for the hilly or mountainous and better-drained sections suffer less. The continued application of antimalarial measures over the years of the last several decades has steadily reduced the incidence of malaria, although it has as yet by no means been eradicated (Fig. 2). It is generally believed that the recession of malaria in our own country has been influenced by other factors than direct control measures, since its disappearance does not seem to have been very highly correlated with such measures. It may, of course, be expected to flare up again at any time, particularly as a result of the introduction of chronic cases, for example, among returning veterans of the war. The great reduction in immigration from southern Europe during recent years has been one factor in lessening the morbidity from this disease, especially along the Atlantic seaboard. In tropical countries, where malaria is a much more dreadful scourge, even more conspicuous progress has been made in its suppression. Thus over widespread areas in Africa, Malaya, the Philippines, the Dutch East Indies, and in the South

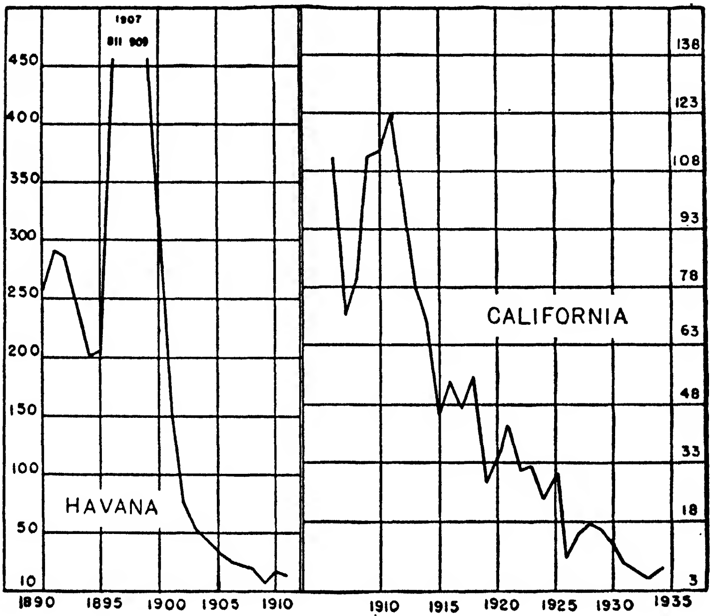

FIG. 2. Recession of malaria following the active application of measures to reduce the abundance of mosquitoes. Anti-mosquito work began in Havana in 1901, and in California in 1910, after which it was greatly expanded. Vertical columns at left and right indicate the number of deaths per year.

American republics, malaria has been greatly reduced, but in such countries the work is far more difficult and expensive.

As mentioned above, several species of Anopheles mosquitoes are concerned in the transmission of malaria in the United States. Till very recently only one species, *Anopheles quadrimaculatus*, has been thought to be of much importance. We now know that the closely related European *Anopheles maculipennis* occurs also in North America, where it is in some localities an important malaria carrier. Some very surprising and interesting facts have recently been learned concerning this European species. It is widespread in the warmer portions of Europe but is abundant in many places where malaria is not prevalent. Hackett, Bates, and other workers of the Rockefeller Foundation have shown that there are some seven forms or races of this species, some of which bite man much more frequently than others, and readily act as malaria carriers, while others do not. Thus, although they can be distinguished readily only in the egg stage, their relations to malaria are very different, and the situation becomes extremely complex. It is now known that the same is true of a number of other species in different parts of the world. Several other common North American Anopheles, all of which are malaria carriers but of less importance, are *A. punctipennis*, *A. crucians* and *A. pseudopunctipennis*.

All these species readily enter houses and are persistent biters, although no more so than some other mosquitoes. Both *quadrimaculatus* and *punctipennis* breed in stagnant water, usually that of permanent nature containing algae or other plant growth. They commonly occur near together, with *punctipennis* usually more abundant. Larvae of the latter species also occur rarely in temporary puddles, and both are occasionally to be found in the growth along the sides of slowly flowing streams. The breeding grounds of *A.*

crucians are mainly restricted to regions adjoining the salt and brackish marshes along the coast, although the larvae are most abundant in fresh water. Two Anopheles occurring on the Pacific coast region, *A. pseudopunctipennis* and *A. maculipennis freeborni*, have habits similar to those of *quadrimaculatus*. As is the general habit among adults of Anopheles, these mosquitoes feed mainly at twilight, and malaria is acquired by persons who expose themselves to their bites after nightfall. Occasionally they bite during the daytime, but since malaria appears never to follow such bites it seems probable that only newly-emerged females, and consequently non-infected ones, bite at this time, as appears to be the case with the yellow-fever mosquito.

The phenomenally rapid increase in airplane travel between the continents threatens to spread mosquitoes widely into regions where they do not naturally occur. One such case has already caused great concern. In 1930 a most notoriously dangerous carrier of malaria, the African *Anopheles gambiae*, was accidentally imported into eastern Brazil, where it became firmly established over a rather extensive area near the coast. After the vigorous application of measures for its eradication over the course of a few years, it was apparently completely exterminated. In 1942 this same mosquito spread in great abundance into parts of Egypt, and during the next year no less than 130,000 deaths from malaria resulted from the epidemic which followed. Vigorous measures were again successful and by 1945 the gambiae mosquitoes had been eliminated there. The technique of control consisted in the treatment of the breeding places with Paris green to destroy the larvae and the use of DDT in boats, trains, and other means of transportation to kill the adult mosquitoes. Such occurrences are best avoided by strict inspection

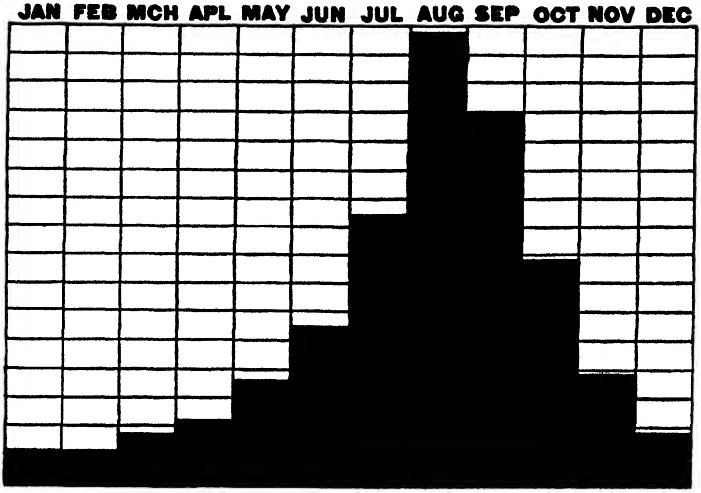

FIG. 3. Seasonal prevalence of malaria in the United States, based on accumulated data from 1900 to 1920.

of incoming vehicles, rather than by reliance on the very difficult or even hopeless task of extermination once the insects have established themselves.

Like other insect-borne diseases, malaria shows in its prevalence a close relation to the seasons, undergoing a period of quiescence during the winter and attaining a sudden maximum in late summer, after which it rapidly declines (Fig. 3). This is in response to the increasing abundance of Anopheles during the summer, coupled with a relatively high temperature favorable for activity on the part of the mosquito and for the development of the malarial parasites in its body. Under the conditions of temperature prevailing in the United States the malarial parasites do not persist through the winter in hibernating mosquitoes but must winter over in the human host, whence the Anopheles secure them the following season. In tropical regions, where there are usually alternating wet and dry seasons, mosquitoes naturally increase during the rainy period and gradually drop off as the dry period progresses, responding to the amount of water available for the growth of their larvae.

The larval or preparatory stages of anopheline and practically all other mosquitoes are passed in the water of small quiet ponds, puddles, exposed vessels containing water, rain-barrels, etc., and it is during this period that they are most easily controlled. This is accomplished by oiling the water with either crude or refined petroleum or with some miscible oil. The petroleum forms a film over the surface of the water through which the larvae cannot extrude their breathing tubes into the air and thus they are suffocated. The application of miscible oils is efficacious but attended with some danger, since it destroys fish and predatory insects such as dragonflies which are themselves some of the most important natural enemies of mosquitoes. Very frequently even oiling is not necessary, for much swamp land may be permanently freed from mosquitoes by very simple systems of drainage ditches to prevent the accumulation of the stagnant water in which the larvae occur. It is not probable that DDT or similar insecticides can be adapted for routine use to kill mosquito larve as they are also highly poisonous to practically all forms of aquatic life. The use of DDT dissolved in some highly volatile liquid like freon was introduced during the war. Using this solution loaded, together with other insecticides, in "bombs" from which the material may be sprayed in vaporized form, the destruction of adult mosquitoes in houses can be safely and almost instantly accomplished.

As pointed out above, the permanent reduction of malaria in communities is accomplished most readily by the application of measures aimed mainly at the breeding places of the mosquitoes. Such work is being extensively carried on by the Federal government, by many state boards and commissions, and by certain private or semi-private institutions in widely scattered parts of the country. Through their individual and collective efforts an enormous amount has been accomplished, although painfully little in comparison with what could well be spent upon the problem, still of great importance to public health in the United States.

Another mosquito-borne disease which has aroused more interest in America on account of its spectacular appearance and higher mortality is yellow fever. This is due to a filterable virus, concerning the nature of which we can only speculate at the present time, although enough has been ascertained through experimental work to demonstrate that the virus undergoes a development of quite definite periodicity generally in mosquitoes of only a single species, known as *Aëdes aegypti.* This mosquito enjoys a very wide distribution in many parts of the world, mainly in the tropics, but also extends into the warmer temperate regions. Yellow fever is not so extensively distributed, being absent in many places where this Aëdes occurs, but it is nevertheless present in parts of the American tropics and in western equatorial Africa, and all that is necessary for the development of a possible epidemic in a region where the mosquito carrier occurs is the introduction of a human case in the early stages of the fever.

The larval habits of *Aëdes aegypti* are in quite marked contrast to those of Anopheles. The adults are strictly domestic mosquitoes and occur almost entirely in the neighborhood of human habitations. Their larvae develop in the same places, breeding preferably in vessels containing small amounts of water, rain barrels, cisterns, stray tin cans filled with rain water, etc. On this account, extermination work against the yellow-fever mosquito resolves itself primarily into the examination and treatment of cities, towns, and the immediate environs of smaller settlements.

One of these mosquitoes feeding upon the blood of a person suffering from yellow fever becomes infected only during the first three days after the onset of the fever; later than this mosquitoes do not obtain the virus. An incubation period of at least twelve or fourteen days is necessary before the mosquito can infect a second person, after which it remains infectious for a long period and may be responsible for a series of new cases. These facts were first discovered during the summer of 1900 by a Yellow Fever Commission consisting of Drs. Reed, Carroll, Lazear and Agramonte, of the U. S. Army. Two of these men, Carroll and Lazear, allowed themselves to be bitten by infected mosquitoes. Lazear died from a severe case of fever contracted during the course of the experiments, and Carroll nearly succumbed to a case resulting from the bite of an experimentally infected mosquito.

Little further has since been learned of the etiology of yellow fever, but wonderful strides have been made in the application of these simple facts for its eradication. In Cuba, where the commission conducted its investigations, the first attempts were made, and in 1902 yellow fever had been practically eliminated from Havana. Other West Indian islands were formerly badly infested, but at the present time there is little more danger from this disease there than in the United States. Rio de Janeiro was once a hotbed for yellow fever, but it too yielded to the destruction of mosquitoes and the screening of patients, till after a six years' fight the fever vanished. Still more remarkable were the results accomplished in the Panama Canal Zone under the direction of Colonel Gorgas. Here the warfare against yellow fever went hand-in-hand with antimalarial work, and the isthmus was transformed from a veritable death-trap to a condition which compares favorably with that of any region on earth. In 1913, when the writer visited Guayaquil, Ecuador, to study this and other insect-borne diseases, yellow fever was still rampant there, but it finally yielded to vigorous repressive measures. So completely have conditions changed that this city, formerly regarded as the worst pesthole in the Western Hemisphere, was later included in the itinerary of vacation cruises until the war temporarily eliminated such travel.

Our own country has suffered from yellow fever in the past, mainly in the South, but extending as far as southern Illinois in 1878, to Philadelphia in the terrible epidemic of 1793, and even to Boston and into interior New England towns in colonial days.

Yellow fever no longer causes serious concern to residents of any part of the United States or, for that matter, to those of most parts of the American tropics. Many of the older generation can recall very clearly in the not-too-distant past, however, the terror and demoralization which accompanied its periodical appearance in our southern ports. The yellow-fever mosquito is still abundant and widely distributed throughout the Southeastern states and sometimes becomes temporarily established further north during the summer. There is no yellow fever, except an occasional stray case from the tropics, which does not get beyond the keen eyes of the Public Health Service, and consequently our population of yellow-fever mosquitoes remains free from this disease. In this case several factors have combined to make possible the elimination of the disease without more than temporary and local eradication of the mosquito. In our Southern states the disease cannot survive the winter and chronic human carriers do not exist, so that past outbreaks have been due to fresh introductions and have been terminated by cold weather. During the last epidemic that occurred in New Orleans, in 1905, vigorous antimosquito measures were necessary, but, due to the greater severity of the disease, the consequently greater ease with which it is recognized, the limited area to be dealt with, and the absence of chronic human carriers, the eradication of yellow fever without permanent mosquito repression has been easy in comparison with the control of malaria. The success of this campaign has undoubtedly sounded the death knell of the yellow-fever epidemic and panic in the United States, for New Orleans amply demonstrated what may be accomplished in the control of an epidemic by an efficient group of workers, backed by a sympathetic public and supplied with reasonable funds. Even in parts of the tropics where cases occur throughout the year it has rapidly been eliminated. Indeed, for a time it bid fair to be the first disease actually to become extinct as a direct result of human discovery and applied science. During recent years, however, in certain areas in South America where it had apparently been entirely eliminated, it has been noted that human yellow fever would appear unexpectedly and spread through the population of lowland urban communities. This is now known to result from the persistence of the virus in various animals other than man which act as reservoirs. This form of the disease, occurring in forested areas, is known as jungle yellow fever. It is carried by other species of mosquitoes and its control presents great difficulties. With this unexpected turn of events, it appears that the complete eradication of yellow fever cannot be expected in the near future.

This same mosquito is responsible also for the transmission of dengue fever or "break-bone" fever. Dengue is a mild (that is, non-fatal) disease which causes great distress and temporary disability. It is therefore a factor contributing to lack of efficiency and goes hand in hand with malaria in this respect. Like malaria, dengue is tropicopolitan in range, particularly prevalent on many Pacific islands, and extends into the warmer parts of our southern states. Here it sometimes appears in extensive epidemics, but in a much more erratic way than malaria, which has the well-deserved reputation of appearing year in and year out in the same districts. This difference is probably due to the absence of chronic human carriers and the fact that *Aëdes aegypti* does not breed in permanent water, but is an almost truly domesticated species which breeds in temporary water near human habitations, and under the climatic and other conditions of our country does not find uniformly suitable opportunities for breeding from one season to another. In consequence of their separate breeding grounds, measures designed to control malarial mosquitoes have no effect or practically none upon the dengue mosquito. It must be dealt with mainly by education leading to individual effort and coöperation in communities. Aside from its pathogenic possibilities, this species is a rather persistent biter, which is another argument for its control.

Another tropicopolitan, semidomesticated mosquito which extends quite widely into the warmer parts of the United States is *Culex quinquefasciatus.* This species is commonly responsible for the transmission of a parasitic disease of the tropics known as filariasis. The direct cause is a nematode worm belonging to the genus Wuchereria (Filaria) which is present in the circulation and lymphatics of the infected person. In the late stages of the disease the microscopic larval worms occur abundantly in the blood. For some unexplained reason they remain in the deep-seated blood vessels during the day, but usually appear more abundantly in the peripheral circulation during the night. Here they are readily obtained by mosquitoes with their meal of blood. In the alimentary canal of the mosquito the larval Filaria discards a sheath-like envelope which has previously invested it and works its way through the wall of the stomach into the thoracic muscles, where it increases greatly in size and finally migrates to the base of the proboscis. From two to three weeks are necessary for this metamorphosis, and for some time longer the Filaria may remain in the proboscis awaiting its opportunity to enter another person through the skin when the mosquito bites. Once they have been transferred to their human host the parasites enter the lymphatics, where they attain sexual maturity and give rise to the abundant microscopic larval filarias. These enter the circulation, where they may remain alive for long periods awaiting ingestion by another susceptible mosquito.

Filariasis is of wide occurrence in equatorial regions, but extends less commonly into the subtropics. It is particularly prevalent in Samoa and other islands of the southwestern Pacific, and was one of the diseases against which our armed forces had to be guarded during the war with Japan. The parasites themselves do not ordinarily cause great inconvenience, but their presence in the lymphatics may clog these vessels and give rise to large swellings. These commonly develop in the testes or legs, resulting in conspicuous deformities known as elephantiasis.

Very recently still other common mosquitoes have been incriminated as carriers of a virus that causes equine encephalomyelitis. Although primarily a disease of horses, it also affects man sparingly in parts of the

United States. As this is a serious malady, any threatened increase in its prevalence must be viewed with apprehension.

Less directly detrimental to public health are other mosquitoes not associated with any human disease, but making life miserable at some season of the year for human beings in practically all parts of the world. Although the United States supports an extensive mosquito fauna, a very few species aside from those already mentioned make up the bulk of those annoying man. Two in particular are widespread, abundant, and, on account of their strikingly different habits, perhaps worthy of mention in this connection. The first of these is the house mosquito, *Culex pipiens,* a palearctic species, now common throughout the eastern states, which breeds in rain barrels, cesspools, sewers, catch basins, puddles, or practically anywhere, no matter how foul the water. The other, *Aëdes sollicitans,* the salt-marsh or "Jersey" mosquito, breeds only along the coast in salt marshes. Broods of this mosquito follow the lunar calendar, developing after high tides flood the meadows and fill the pools in which the larvae live. The eggs of this form are laid on the mud and hatch quickly when submerged in water. It is generally believed that all the eggs laid by this mosquito must pass the winter before hatching and that the successive broods are only installments of eggs induced suddenly to hatch in turn by successive wettings. This is a true migratory mosquito, which invades the country for many miles adjacent to the salt marshes. Such incursions follow the appearance of each brood.

Much attention has been given to the control of this mosquito in New Jersey and the territory surrounding Long Island Sound, and its numbers have been marvelously lessened through the drainage of marshes by ditching. In the case of this species reforms have been easier than with the malarial mosquitoes, for an expectation of relief from the great personal discomfort of myriad mosquito bites exerts a stronger appeal to the average person than the much more important health problem of malaria. In the public mind, the latter unfortunately is not usually regarded as so immediately personal, since the fever and the bite are not coincident.

At some time during the insect season, usually in the spring, many districts are visited by swarms of small humpbacked flies which viciously bite man and animals alike. On account of their dark color these have been called black flies. They pass their developmental stages almost entirely in swiftly moving brooks and streams, where the larvae and pupae are attached to stones and other objects in the water. Wherever there are suitable streams in which they can breed, these pests appear abundantly, and may be present occasionally far from streams, where they would not be expected. They cause great annoyance to hunters and fishermen in the North Woods, often persisting there until the end of the short summer.

It has been found also that they act as secondary hosts for certain nematode worms of the genus Onchocerca that are parasitic in man. The Onchocerca undergoes partial growth in the thoracic muscles of the Simulium flies, after the manner just described for the mosquito-borne Filaria worms. In the case of one Central American species they find lodgement in the eyes, causing blindness in the affected persons.

Minute flies, somewhat like mosquitoes, which are vicious bloodsuckers, are often present in great abundance over widely distributed areas in both tropical and temperate regions, appearing particularly when the air is still, for they are very weak fliers. These insects belong to several genera, developing from aquatic larvae inhabiting fresh water and also brackish water along the seacoast. They are generally crepuscular, biting most abundantly at dusk, and are persistent at that time, causing a stinging sensation out of all proportion to their almost microscopic size.

The regions surrounding the Mediterranean Sea are the centers of distribution for a very interesting but not dangerous insect-borne disease known as phlebotomus fever. In this case the carriers are minute gnat-like flies of the family Psychodidae known as Phlebotomus. These insects are semiaquatic in the larval condition, occurring in damp situations, drains, cellars, etc., where they feed on plant matter. The adult is a vicious biter in spite of the fact that it is scarcely over one millimeter in length. It rarely bites except at night, following the habits of certain mosquitoes in this respect. The specific cause of phlebotomus fever is an invisible virus. At the present time it is impossible to state whether other insects may play a part in its transmission, although such does not seem probable. We have at least one species of Phlebotomus in the United States and it is possible that it might act as a vector should the disease be introduced into our country, although it would seem that such a possibility would have been realized already if it were likely to occur, for cases of this common European fever must undoubtedly have been imported.

Certain species of Phlebotomus are also known to transmit leishmaniasis, a disease due to flagellate protozoan parasites of the genus Leishmania. Variously known as oriental sore, kala-azar, or dum-dum fever, this is of wide occurrence in tropical countries, especially in India and eastward. Very little is known of our native species of Phlebotomus, but there is the possibility that they might spread leishmaniasis in our own country if the disease should be brought back with our troops returning from the Far East.

It is also believed that Oroya fever, a highly fatal disease of the Peruvian Andes, may be spread through the agency of *Phlebotomus verrucarum*, a species which acts in that region as the carrier of verruga, a form of oriental sore prevalent among the native population. Both of these diseases range over the otherwise delightful western slope of the Andes at elevations of from 4,000 to 6,000 feet.

The common housefly (*Musca domestica*) is an agent in the spread of certain infections which are often grouped under the term of fly-borne diseases. Of these it may be urged that, strictly speaking, there are none, at least in the sense of mosquito-borne diseases. The housefly is not known to be wholly responsible for the transmission of any disease and its relative importance in disseminating several infections of man is still a moot question. By some it is strongly urged as the main means of transmission for several enteric diseases in certain communities; by others it is cast aside without reasonable consideration as a sort of entomologist's nightmare.

We cannot believe that either course is justified; each seems to be based on prejudice due to lack of knowledge, either respecting the fly or relating to other channels of infection.

The housefly is more truly domesticated than any other insect; it lives and flourishes wherever man establishes himself, but does not thrive elsewhere. It has evidently been associated with him from the remotest antiquity, but has by no means failed to adapt itself to changed conditions. It still develops in the animal and vegetable refuse which accumulates about his habitations and still invades his dwellings to partake of his food. In short, it is practically ever-present, for its preferred larval food, horse manure, is usually to be found, and, if not, substitutes are available in greater or less abundance.

Several other species of flies appear regularly in houses, but in far lesser numbers, and none exhibit to such a marked degree the peculiar tastes of the housefly, which wanders back and forth from filth to food, feeding on each in turn. In this method of feeding lies the danger of infection; houseflies are equally fond of clean and filthy materials, and their frequent migrations from one to the other multiply their opportunities to pick up pathogenic organisms that may be later deposited upon foods. The frequency with which this actually happens is of course the vital point, and it is upon this that it is very difficult to obtain concise data.

It has been shown rather conclusively that adult flies do not retain in the alimentary tract bacteria which they may have ingested as larvae that have developed and fed in material containing, for example, the bacillus of typhoid fever. On the other hand, adult flies readily obtain this bacillus from contaminated substances and may retain and later deposit it in a living condition on food designed for immediate human consumption. There can be no question but that this occurs commonly under many circumstances, particularly in communities where there is no adequate system of sewage disposal. That these bacteria should be more attenuated than those occurring in drinking water does not seem probable. Many other facts support the conclusion that flies are a very important factor in the dissemination of typhoid fever. The greater frequency with which persons on country vacations contract the disease is very striking, although this may, of course, be attributed in part to contaminated water supply. Other opportunities for infection, aside from the fly, are, however, no greater there than in the city. In other parts of the world where the water supply is reasonably good, for example, certain South American cities, typhoid flourishes to an alarming extent, due undoubtedly to excessive soil pollution, where flies can almost instantly transfer material from typhoid carriers to food, while the latter is abundantly exposed on the streets for sale to be eaten on the spot. In our own country the seasonal incidence of typhoid fever corresponds to some extent with fly prevalence, and still more significant was its greater summer prevalence in rural or semirural areas where systems for sewage disposal were not so generally installed as at the present time. This disparity is shown on the accompanying chart (Fig. 4), which gives data for two of our eastern states, New York and Alabama, and one western state, Washington. The greater uniformity throughout the year in New York, where the opportunities for fly-borne infection are curtailed, is very marked. Another way in which the housefly can aid in the spread of typhoid

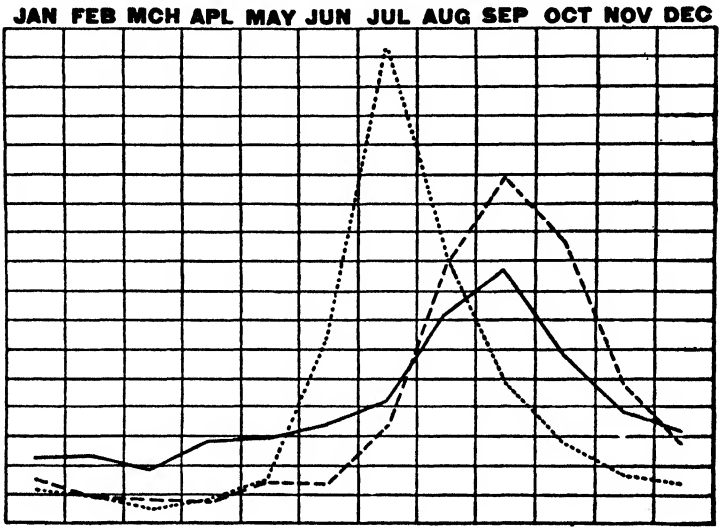

FIG. 4. Seasonal prevalence of typhoid fever in several states for 1916. Solid line, New York; dotted line, Alabama; dashed line, Washington.

is through infecting milk on dairy farms where carriers are present and offer the flies an opportunity to become infected.

Flies are also responsible, and to a much greater extent, for the prevalence of infantile diarrhea or summer complaint, and here their relation is very easily seen.

There is also the possibility that houseflies may be concerned to some extent in the transmission of infantile paralysis or poliomyelitis. This is as yet unproven, but deserves mention as a matter of great public interest. Although it has been prevalent in epidemic form for several decades, especially in our own country, we are still as ignorant of its method of spread as we were concerning malaria, plague and yellow fever toward the end of the last century. Poliomyelitis is due to a virus which invades the motor regions of the central nervous system, often resulting in paralysis of the muscles involved, sometimes terminating fatally. The virus is excreted from the alimentary tract of persons suffering from the disease, and has been recovered from contaminated sewage, as well as from flies that have presumably acquired it from such a source. As poliomyelitis occurs in a mild or abortive form as well as in the acute paralytic form, it seems probable that such non-paralytic cases which are characterized by gastro-intestinal disturbances may be due to infection by mouth carried by flies, as occurs in typhoid and infantile diarrhea. We shall mention poliomyelitis again in a later paragraph, as it seems probable that fleas may play an important role in transmitting the acute form.

Other activities of houseflies detrimental to public health are of far less importance, but by no means negligible. They can carry the eggs of parasitic worms as well as many bacteria and other microörganisms present in the several types of unsavory food upon which they indiscriminately feed.

Recently much progress has been made in methods of abating the housefly nuisance. It has been found that certain substances, notably borax, hellebore, and a fertilizer consisting of calcium cyanamid, acid phosphate and kainit, are highly destructive to fly larvae in horse manure (whence the great majority of our houseflies come), and that these substances do not ruin the manure for agricultural purposes. Practical traps whereby fly larvae in stored manure may be caught and destroyed before transformation have also been devised. Richardson has shown that housefly larvae can develop only in alkaline material, and some substances may thus be acidified to eliminate them as larval food. Most promising of all is the use of DDT, which is admirably suited for the destruction of the adult flies.

The people of the United States spend great sums of money for fly screens, flypaper, flyswatters, and flytraps and suffer much sickness and death as a result of the ubiquitous housefly. As yet no great reduction of houseflies has been accomplished, but even the uninformed public regards them less and less as harmless creatures, and should soon be in the proper mental state to launch a decisive campaign against them.

Cattle, horses, and other domestic animals, and more rarely man himself, are troubled in nearly all parts of the world by a small blood-sucking fly resembling the housefly in size and general color. On account of its great abundance about horses and cattle it has been termed the stable fly, although its larvae breed mainly in fermenting vegetable material rather than in manure. The adult flies readily bite human beings, particularly in damp weather, and this habit has given rise to the popular idea that houseflies bite before a shower. The stable fly is most important as a pest of animals, as it has not been definitely proved to be more than an accidental carrier of any disease affecting man. It is a native of the Old World, but is now practically cosmopolitan, and particularly abundant along the shores of lakes or ocean beaches. There the larvae find suitable breeding grounds in the rotting vegetable material cast up by wave action. The writer has encountered them as an equally unmitigated nuisance in the subarctic lakes region of western Canada and the lovely sandy beaches of our own southeastern seaboard.

One of the most important insect-borne human diseases which does not exist in the New World is African sleeping sickness. During recent decades this malady has decimated the native population in certain parts of eastern equatorial Africa and any extension of its range would be most serious. It seems very unlikely that America will ever have to face an epidemic, for the introduction of sleeping sickness together with its carriers is not at all probable, and the possibility of its becoming established, even after introduction, is still more remote. As is well known, sleeping sickness depends for its spread entirely upon certain biting flies known as tsetse flies belonging to the same family as our common housefly and stable fly. The genus Glossina in which these flies are included is restricted to the African continent, but is represented there by a number of species, several of which have been shown to act as carriers for trypanosome diseases of animals. These organisms are flagellate Protozoa which live free in the blood stream of the mammalian host. The disease then develops over a period of many months, the trypanosomes invading the lymphatics and certain internal organs, finally leading to complete debilitation and death. In the Glossina flies the organisms multiply in the gut, later reaching the salivary glands whence they may gain entrance to the mammalian host when the Glossina takes its meal of blood. *Glossina palpalis* carries the common trypanosome of human sleeping sickness (*Trypanosoma gambiense*) and another species, *Glossina morsitans,* acts as the vector of Rhodesian sleeping sickness, caused by a closely related trypanosome. The disease appears to have been originally epidemic only in West Africa, but was found in eastern equatorial Africa something over forty years ago, and it is especially in this latter region that its ravages have been so pronounced. Owing to certain peculiarities in the habits of the tsetse flies, the distribution of sleeping sickness is limited to very definite areas in the region where it occurs. The fly, which has a sharp, needle-like beak for sucking blood, resembles our own stable fly in general appearance but is considerably larger, measuring about half an inch in length. It is found only in the dense brush which grows along the edges of streams, ponds and lakes. In such places persons and animals may be bitten by the flies, and it is through such bites that the insects obtain the protozoan parasites of sleeping sickness from the blood of persons or animals suffering with the disease. Should the fly obtain a meal of blood containing trypanosomes, these may multiply in the body of the fly, although not always, for only about one in twenty of such flies becomes infectious. A considerable period, usually about thirty days, must now elapse before the infected fly is in condition to inoculate a new patient, but after this it may remain infectious for many weeks, and may introduce the trypanosomes into the blood of any animal upon which it feeds during this period.

The tsetse flies develop in a very different way from most insects. The female does not deposit her eggs, but a single egg develops to the fully grown larval condition before being deposited. This larva soon pupates in the shade beneath brush bordering the water where it has been dropped by the parent fly, and later emerges in the winged adult condition. The pupae require such moist shade, and it is apparently for this reason alone that the flies never occur away from the immediate vicinity of water. As a result of its method of development, the tsetse flies do not multiply rapidly, and under favorable conditions only one larva is produced in a ten-day period. Nevertheless, they are abundant where they occur.

The trypanosome of sleeping sickness was discovered by Dutton in 1901, and two years later the role of *Glossina palpalis* in its transmission was proved by Bruce. Since then much energy has been expended in attempting to stamp out the disease by every possible means. It was thought at first that by moving all the natives back from the edges of the water the flies, thus left without opportunities for reinfection, would become free from trypanosomes, and that by isolating and treating cases of the disease in fly-free areas it would be possible to eliminate it entirely. In conjunction with this, the cutting of brush, especially about boat landings and watering places, was practiced as far as possible. Contrary to expectations, it was found that even after three or four years infected flies still occurred along the uninhabited shores. This led to experimentation upon animals, and it is now generally believed that various wild antelopes as well as certain domestic animals may act as reservoirs for sleeping sickness, which may thus persist in the complete absence of any human subjects. Another trypanosome disease of man and other animals, prevalent in tropical America, is known as Chagas fever, or barbiero fever from the Brazilian name of the blood-sucking bug (Triatoma) which acts as the insect host.

Louse-borne diseases have come into prominence during the two world wars in Europe owing to the prevalence of typhus fever among the armies and civilian population, notably along the eastern front and also in Italy.

Human lice or "cooties" belong to two species, the body or head louse (*Pediculus humanus*) and the crab louse (*Phthirius pubis*). Both are strictly human parasites and do not occur upon animals, although some close relatives of the head louse infest certain American monkeys. These lice are of great importance since they act as the vectors of typhus fever, spreading it among human populations often in the form of terrible epidemics. It is a very serious disease with a high death rate, and those who recover are commonly incapacitated for long periods.

Typhus fever has been well known for many years and regarded as a disease characteristic of filthy surroundings. It is caused by a very minute type of organism to which the name of Rickettsia has been given. During our own Civil War it claimed many victims among the inmates of army prisons, and has been endemic though not generally very prevalent in many parts of the world in times of peace. Through the researches of Ricketts and others we know that typhus is spread by the body louse, and its epidemiology is at once made clear. When it broke out in Serbia in 1915 in severe epidemic form, knowledge of the method of its transmission made control possible, even under extreme difficult and unfavorable circumstances. During the second World War it again came into prominence, but immunization against it is now possible and the destruction of lice is more readily accomplished by the use of the recently discovered DDT. Consequently it did not reach such serious proportions. Difficulties are encountered, however, especially among the personnel of armies in the field and among the peoples of war-torn countries. During the first World War the delousing of extensive groups was a complicated matter requiring considerable time, space, man power, and mechanical equipment. It was necessary to delouse the individuals, to sterilize their clothing separately, and finally to reassemble all in their original combinations. During the Italian campaign in the last war, when an epidemic of typhus threatened, delousing was accomplished by means of a blowgun dispensing diluted DDT powder beneath the clothing without further preparation or treatment. This incomparably simplified method proved eminently satisfactory.

It is generally believed that the epidemic form of typhus fever originates as a disease of rats, from which it is carried to man by fleas. The epidemic form then develops with the louse as vector. Several other apparently distinct types of typhus are known, carried by very small mites. One of these, known as tsutsugamushi fever in Japan is carried by mites similar to the "red-bugs" of our own southern states. It is a virulent disease due to another species of Rickettsia, and occurs also generally in the Malay States and nearby islands. A mild form of endemic typhus in the United States is also mite-borne, although frequently carried by rat fleas and commonly known as murine typhus.

The louse is also responsible for the spread of relapsing fever in Eurasia, North America and northern Africa, but the most important carriers of this disease are certain ticks. Relapsing fever is due to a very minute corkscrew-like organism known as *Spirochaeta recurrentis,* together with a considerable series of other scarcely distinguishable species or strains. This disease is endemic over very extensive areas and is a common malady in the warmer parts of both hemispheres. Tick-borne relapsing fever is carried by ticks of the genus Ornithodoros. A very abundant African species, *O. moubata,* has been recognized for many years as the common vector on that continent, and more recently several American species have been shown to act in the same way. In the New World the disease is restricted mainly to tropical regions, but extends into Texas and California and rarely even farther northward. The spirochetes are acquired by the tick during engorgement of its blood-meal and later migrate generally throughout its body, whence they may reach their human host through the bite of the tick or scratching the skin. Once infected, the ticks are able to transmit the spirochetes to their offspring through the eggs. Ticks of the second generation thus become potentially dangerous previous to feeding on an infected host. Ornithodoros occurs mainly on various rodents, but very readily bites the human subject.

Rocky Mountain spotted fever is the only exclusively tick-borne human disease that is widespread within the confines of the United States. In 1902 Wilson and Chowning suggested that ticks might carry this disease, and four years later Ricketts definitely proved such to be the case. Rocky Mountain spotted fever is most common and severe in the far western and northwestern states, whence nearly three thousand cases and over four hundred deaths were reported during the years 1930–1939. Over half of these occurred in Idaho, Montana, and Wyoming. As shown by the fatality rate, the disease is most virulent in western Montana and northern Idaho, where the mortality may on occasion reach 70 or 80 per cent. A species of tick, *Dermacentor andersoni,* common in these regions is known to act as the vector. The Dermacentor ticks occur abundantly in the younger stages on various small wild mammals, mainly rodents, and as adults also on domesticated animals, such as cattle. Certain rodents are susceptible to the disease, and a tick thus infected in the nymphal stage can retain the disease organism till it becomes adult. The virus may then reach its human host through the medium of the tick, and thus be continued without any mammalian host. It had long been noticed that infection from tick bites rarely occurred unless the tick had been attached for a number of hours. Recently it has been found that during this period the virus becomes activated through the action of the blood the tick has ingested and is then able to establish itself more readily in the mammalian host. The virulence of Rocky Mountain spotted fever varies greatly in different localities and also when carried by two other species of tick, the dog tick (*Dermacentor variabilis*) and the rabbit tick (*Haemaphysalis leporis-palustris*). Protective vaccination is possible, although as yet not entirely satisfactory. It appears that this is the ordinary way in which human cases have their origin, that is, through the bites of adult ticks, although the newly hatched "seed ticks" derived from eggs laid by infected mother ticks are known to contain the organism also.

Although Rocky Mountain fever is of minor importance at present, it is feared that it may increase its range at any time, since other ticks of wider distribution can act as carriers. Whether this may happen is by no means certain, however, for the disease has been endemic for at least many years in the eastern United States (Fig. 5).

Still another disease, due to a bacterial organism (*Pasteurella tularensis*), is carried by ticks, among other carriers, although the most important carriers are the blood-sucking flies of the genus Chrysops. These flies were the first arthropod vectors to be detected. This is primarily a disease of rabbits, but may also be acquired directly by man, as by cuts or scratches acquired when skinning infected rabbits. It is quite widespread in North America, affecting various rodents, including the beaver.

Fleas are domestic insects which were looked upon only as a nuisance until it was shown that certain kinds of fleas are agents in spreading bubonic plague. The most terrible epidemics of which we have any historical record have been those of plague, or "black death." One swept from Egypt in the sixth century before the

Christian era and invaded Europe and Asia, where it raged for sixty years. A similar one spread through the whole known world in the fourteenth century and is thought to have caused over twenty-five million deaths

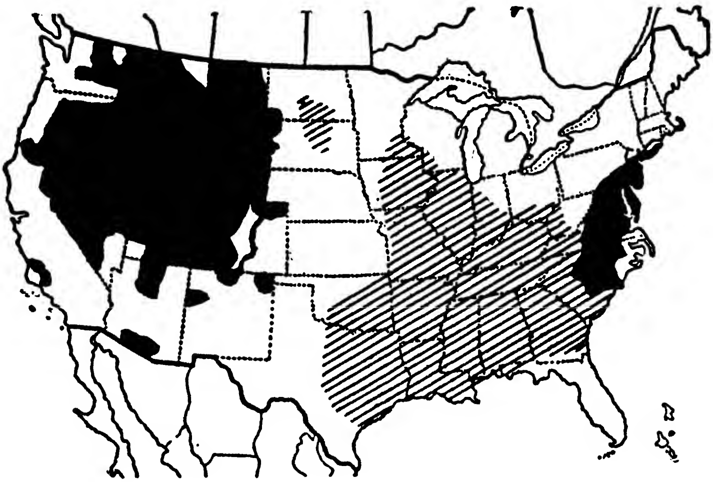

FIG. 5. Distribution of Rocky Mountain spotted fever in the United States, to August 1940. In the areas shown in black it is generally prevalent. In the shaded areas it is less frequently met with. (Redrawn in more generalized form after Philip, 1940.)

before it subsided. In 1898 Simond proved that fleas can act as agents in the spread of plague, and his work was corroborated through the researches of Verjbitski and the Indian Plague Commission. Plague is primarily a disease of rats and certain other rodents, and is usually carried to man by the bites of fleas which have become infected from plague-stricken rats. Another form of epidemic plague, caused by the same organism and affecting the respiratory tract, is known as pneumonic plague. This manifestation is not carried by insects and appears in extremely cold climates. From 300,000 to 400,000 cases of bubonic plague are reported from India every year, over half of which terminate fatally. At the present time it is most widespread and abundant in tropical countries, although by no means confined to them, and is excluded from our own country only by dint of repressive measures administered with the greatest thoroughness. Within the past few years it has appeared only sparingly in the United States, but at several times has given rise to temporary apprehensions lest it pass beyond control. That it has not done so shows that the probability of future danger is remote.

At the present time it is endemic only in a restricted area centering about southern California, where it has been established in the native ground squirrel.

Nevertheless there are other good reasons why we should spare no efforts in reducing the number of rats. They are said by Nelson to destroy annually $200,000,000 worth of our foodstuffs and other property; they constitute a fire menace, and besides, they can hardly be considered as deserving our hospitality from an esthetic standpoint. In short, war against rats is important for many reasons, one of which is the security against plague which it entails, and gradual repression through local effort is much easier than intensive campaigns necessitated by the advent of plague in a community.

Rats thrive in thickly populated communities. Towns and cities as well as rural districts generally harbor them in large numbers, variously estimated as equal to or exceeding the human population. They are not easily driven out or exterminated, but the recent discovery of a new and highly efficient rat poison (alpha naphthyl thiourea) which is nontoxic to man holds the promise of a really satisfactory solution of the problem imposed by these pests. Still newer and better materials have just lately been produced, and we may expect additional ones in the near future as the result of elaborate experimentation and the examination of a long series of products.

The relation of the flea to the transmission of plague is due to the fact that rats are regularly infested by fleas that may become infected with the bacillus of plague, if it be present in the blood of the host upon which they are feeding. These bacilli remain in a viable condition for some time in the gut of the flea and may be transferred to a human subject bitten by an infected flea. Thus, when a rat dies of plague, its fleas leave it to search for a new host; if they attach themselves to a rat, that animal is liable to infection, or if they feed upon a human being, as they frequently do, the disease may become transferred to man. Two species of fleas are commonly concerned in the transfer, one in tropical and subtropical regions and another in temperate regions. The tropical rat flea, *Xenopsylla cheopis,* is thus of greatest importance in the warm countries where it is most abundant, and the other, *Nosopsyllus fasciatus,* in cooler countries. Both occur in the United States, neither specifically associated with plague except as previously outlined; other fleas may act as carriers equally well, but are not so abundant on rats and do not bite persons so frequently.

The plague bacilli (*Pasteurella pestis*) appear only in fleas which have bitten affected persons or rats twelve to twenty-six hours previous to death, for after this time the bacilli do not occur in the blood. The vitality and virulence of the bacilli are preserved for nearly a week, at least, and sometimes fully a month; there is actually an increase in their number during the first few days. Infection from these insects may then occur through their bites, and may occur also if the insects are crushed *in situ* after they have punctured the skin.

As mentioned on a previous page, fleas are also concerned in the spread of typhus fever among rats.

There are many reasons for believing that infantile paralysis may be an insect-borne disease, and a few further words in regard to this baffling disease may not be amiss. Its summer prevalence (Fig. 6) is well known and its general distribution and occurrence are similar to those of the insect-borne diseases, particularly bubonic plague. That it may prove to be spread by the rat flea is not improbable, and if so, would be another strong argument for the reduction of our rat population.

The reasons for suspecting fleas and rats as vectors of poliomyelitis are mainly epidemiological. It is evidently not contagious through personal contact, but epidemics gradually spread, although not necessarily along the lines of human travel. It is more prevalent both in the squalid parts of cities and in rural communities, but in its very erratic distribution frequently appears in the most unexpected places. Although typically a summer disease, it persists well into the autumn, and winter outbreaks are not unknown. In these aspects and others its epidemiology is extremely like that of bubonic plague. Until recently only man and monkeys were known to be susceptible, but certain strains of the virus

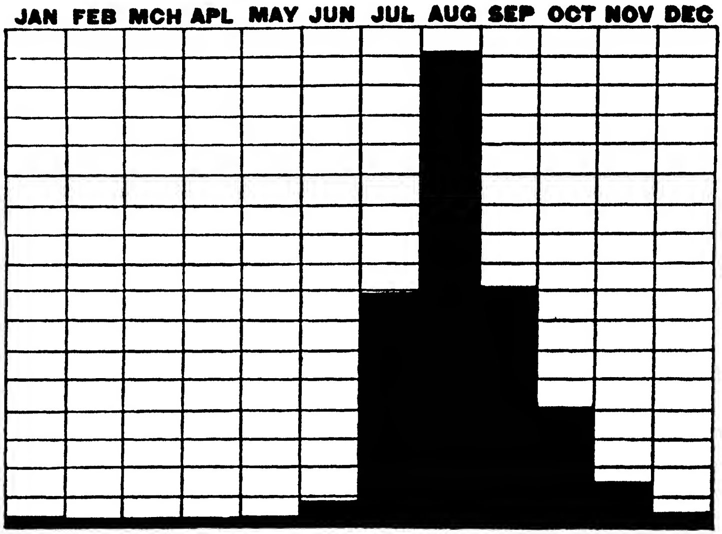

FIG. 6. Seasonal incidence of infantile paralysis (Poliomyelitis) in the United States, based on data for 1912 to 1916—the period of its greatest prevalence.

can now be propagated in some rodents, notably the cotton rat. However, in spite of a vast amount of study by many workers over several decades we cannot yet make any more positive statements.

No account of insect-borne diseases, however brief, could be complete without some reference to animal diseases. A few of these have already been referred to incidentally as affecting both man and animals, and it is quite likely that other human diseases whose etiology is at present obscure will in the future be shown to bear some relation to those of animals. Apart from this, the economic loss occasioned by such affections of domestic animals is enormous, although it is in great part preventable.

A widespread disease of cattle in the southern part of the United States, known as splentic fever or "Texas fever," is the most important insect-borne animal disease that occurs in this country, and is particularly interesting since it was the first disease of any kind shown to be carried exclusively by insects or ticks. It occurs very generally throughout the Gulf states as far north as the thirty-sixth parallel of latitude and is the cause of immense pecuniary loss to this region, not only on account of the cattle that die, but as a result of the greatly weakened condition of the animals in general. Southern cattle are usually immunized by an attack at an early age, but northern-bred stock die in large numbers when exposed to the disease.

Theobald Smith and Kilbourne showed in 1893 that the protozoan blood-parasite, *Babesia bigemina,* which Smith had discovered several years earlier to be the cause of the disease, is carried by ticks. The common cattle-tick of the southern United States, *Boöphilus bovis,* acts as the exclusive vector, becoming infected during its period of engorgement when feeding on the blood of a diseased animal, and then transmitting the Babesia through its eggs to the young ticks of the next generation. To accomplish this the parasites pass through the wall of the gut, reach the ovaries of the tick, and enter the eggs. Before these hatch the next season the Babesia has undergone a development similar to that of the malaria *Plasmodium,* and spores are present in the salivary glands of the new-born ticks. These may feed on healthy animals the next season, conveying to them the parasites that have been handed down from the mother tick.

Several similar, probably identical, diseases of cattle occur in other parts of the world. They are prevalent in Africa, Australia, Malaya, the Philippines, South America, West Indies, and other warm countries, known under various names as redwater, East Coast fever, Rhodesian fever, etc. Zebu cattle are immune, and this is usually true of hybrids between the Zebu and our own domestic cattle.

Spirochetosis in animals, due to organisms similar to those producing relapsing fever, is well known. The most familiar example is probably a disease of fowls which is carried by *Argas miniatus,* a common tick which infests these birds.

Among bacterial diseases of animals, anthrax may be mentioned as one which is sometimes transmitted by biting flies, the insects acting as mechanical or contaminative carriers only. Anthrax occasionally occurs in man, often entering the body through cuts in the skin or from the bites of animals, such as infected cats. When prevalent among cattle, human cases may arise through the bites of stable flies or horseflies whose mouth parts have been accidentally contaminated by feeding on the affecting animals.

The foregoing enumeration of insect-borne diseases is by no means complete. Indeed, it would be well-nigh impossible to make it so, in view of the progress being made at the present time toward a knowledge of these many problems which bear on the question of public health. While it is difficult to see how the fundamentally important revelations of the past twenty years can be equalled in the near future, we should be very unwise to predict that they will not be exceeded.

CHAPTER II

INSECTS AND THE FOOD SUPPLY

It is a widely recognized fact that insects consume much food material that might otherwise serve for human consumption. The truth of this assertion has been repeatedly brought home to all who have attempted in a modest way to supply their own household needs by means of vegetable gardens, as well as to those engaged primarily in agricultural pursuits. Following the spirit of the times, the home vegetable garden became successively the war-garden, the conservation-garden, and finally the victory-garden. Meanwhile agricultural production in America has grown apace. This growth has not been consistent, however, for during the past few years there has been wide fluctuation resulting from governmental schemes designed at first to raise and later to lower the market price of food products. Finally, the crying need for a greatly increased world food supply created by the recently ended war has stimulated agricultural production, in the main with cheerful acquiescence on the part of federal boards and agencies.

These immediate changes have not affected the fundamental relations existing between insects and food plants, nor have they influenced their economic expression to any noticeable extent. They have, however, served to impress upon the entomologist his responsibility as an interpreter of insect activities insofar as these relate to the production of human foodstuffs.

The matter is far less simple than might appear at first sight. In the first place, it depends upon many of the factors which determine the so-called "balance of nature," and secondly it involves the abnormal and rapidly changing environment which has resulted from agricultural development.

The extent of the loss occasioned by insects to growing agricultural crops and to edible products in storage can be estimated with some degree of accuracy by persons familiar with agricultural practice and with insect depredations over wide sections of the country. Several times the Federal Bureau of Entomology has gathered together statistics which give an adequate idea of the proportion of vegetable food products actually lost through insect injury, and the consequent monetary loss to the people of the United States. From their estimates it appears that fully 10 per cent of our agricultural production is annually destroyed by insects, or, in other words, that our food supply from this source is only 90 per cent of that which would be available if insects were not a factor in limiting the yield. Some crops regularly suffer a greater loss, others less, and there are considerable variations from year to year as well as from place to place. These are unpredictable as they are dependent upon many circumstances, including weather conditions. I think all entomologists will agree that this 10 per cent reduction is an underestimate rather than an exaggeration, and since the annual value of the products in question is well over ten billion dollars, it follows that agricultural insect pests rob the country of more than a billion dollars annually. This omits, of course, such important crops as cotton, tobacco, etc., having no food value, or of which the food value is secondary as is the case with cotton, which is grown primarily for the lint although the seed forms an important part of the rations of food animals like cattle, which in turn are utilized for human food. It includes, on the other hand, the loss of products in storage such as flours, meals, rice, beans, etc.

The table below differs somewhat from others of similar nature that have been published, but is essentially similar, and is, I believe, as close an approach to accuracy as can reasonably be expected. I have not attempted to bring it up to date within the past decade, since during this period a number of causes have conspired to increase the cost of food in our country, and it does not appear that anything approaching stability has been reached. The devaluation of our currency increased first the cost of imported foodstuffs and secondarily the cost of domestic kinds. The shortage caused by the enforced curtailment of production aggravated this movement. In addition, vastly increased amounts of foods were required by our armed forces. Other supplies placed in storage to maintain prices at high levels have successfully fulfilled this purpose. Finally, the widespread establishment of subsidies has not only boosted costs, but has even made it difficult to determine them, and has made it utterly impossible for any individual to know what he actually pays for his daily food. Consequently the figures given are not in very close agreement with those in recent publications. Whether our present difficulties with food are tem-

TABLE SHOWING ESTIMATED DAMAGE TO VARIOUS PRODUCTS CAUSED BY INSECTS IN THE PERIOD 1930–1940, BASED MAINLY ON PRICES CURRENT DURING THOSE YEARS

Product	Value	Loss
Cereals	$2,890,000,000	$231,150,000
Hay	775,000,000	85,000,000
Cotton	1,300,000,000	143,000,000
Tobacco	250,000,000	25,000,000
Truck & garden crops	1,043,000,000	92,700,000
Sugars	102,000,000	15,350,000
Fruits	530,000,000	56,500,000
Forests (farm)	110,000,000	11,000,000
Miscellaneous crops . .	97,000,000	9,700,000
Animal products	2,500,000,000	125,000,000
Stored products	1,200,000,000	300,000,000
Forest products	100,000,000	10,000,000
Total	$10,897,000,000	$1,104,400,000
Food total[1]	$ 7,797,000,000	$ 998,000,000

porary exacerbations, destined to subside like many of the invasions of insects detailed later in this volume, only time can tell.

When we consider that insects are, with the exception of the Protozoa and certain marine invertebrates, the most abundant animals on the earth, it is not surprising that no plants appear to be free from insect enemies. I have usually assumed that about one-half of the 800,000 described, living species were phytophagous

[1] Omitting tobacco, farm forests, and forest products entirely, and cotton and animal products in part.

in habits, feeding directly upon the tissues of various plants. That this proportion is probably not far amiss is shown by a tabulation made by Weiss of the food habits of the 10,000 insects of New Jersey enumerated in Smith's list. He finds (Fig. 7) that 48.2 per cent of these are phytophagous; that 16 per cent are predatory, feeding mainly on other insects; that 17.3 per cent are saprophagous, living as scavengers; that 12 per cent are entomophagous parasites, developing in the bodies of other living insects; and that of the small residuum of 6.5 per cent, 2.4 per cent are epizoic parasites of vertebrates. Only 2.1 per cent appear to be of negligible interest, so far as we can judge at the present time. Studies of the insect faunas inhabiting several other areas show similar proportions of these several types.

Of course, the great majority of phytophagous insects affect plants never or rarely utilized by man, and bear no immediate relation to food production. However, agricultural plants show no immunity to insect attack, but quite decidedly the opposite—they are especially susceptible; and this is undoubtedly due to several causes which I shall attempt to enumerate.

The species of plants suitable for cultivation as sources of food are naturally those which produce more than average amounts of food material in some part of the plant body. This may develop in the roots as in carrots, in the stem as in sugar cane, in the foliage as in spinach, in the seeds as in beans, in the tissue enveloping the seeds as in many fruits, or more rarely in special organs. On this account alone such plants are unusually acceptable to insects, as they are to ourselves. Another reason for the great susceptibility of agricultural plants to insect injury depends upon the removal of certain barriers to insect multiplication which follow necessarily as a result of all agricultural procedures. Under natural conditions, plants almost al-

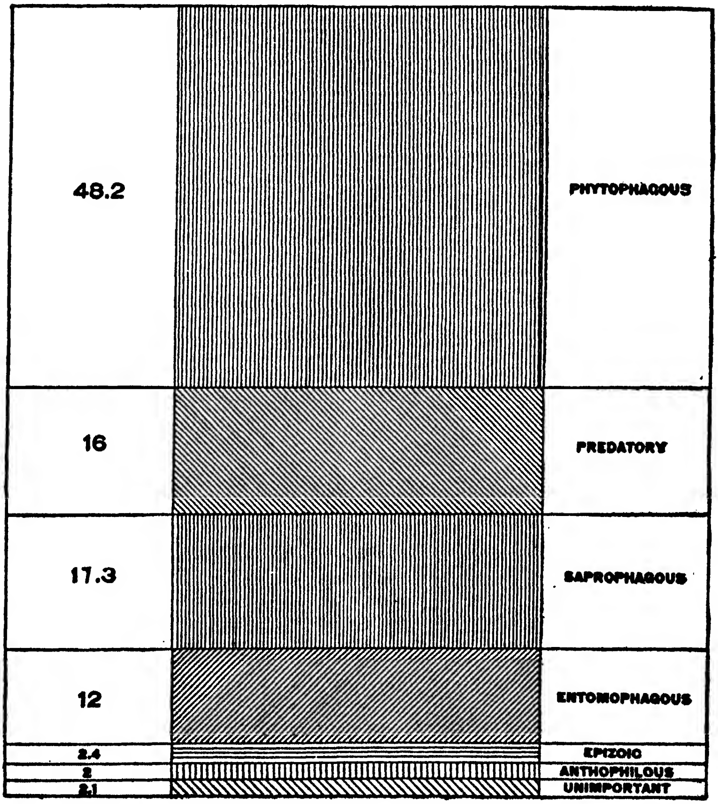

FIG. 7. Diagram illustrating the comparative abundance of various types of food habits in insects. The figures at the left indicate the percentage of species exhibiting the several types of habits. This chart is based on the recorded fauna of a limited area (New Jersey) which includes about 10,000 species. (Modified from Weiss.)

ways occur in complex associations of numerous species, of which one or several may be noticeably dominant, and many of the others are capable of assuming a temporary dominance when for any reason the more abundant species decline. Such a stable, gradually changing, or temporarily shifting condition is reached through the struggle for existence among the plants and the balance of nature maintained by the action of adverse conditions in their environment, of which the insect population is one factor. So far as the insects dependent upon plants are concerned, the innovations of agricultural development represent a cataclysm in their environment. When an extensive area is planted to some particular crop two alternatives present themselves to the original insect inhabitants of the area. With their natural food plant eliminated more or less completely they may become suddenly extinct, or nearly so; this will be the fate of the great proportion and it is of practically no human concern that it is so. Others (in very rare cases, but nevertheless important ones) may turn their attention to the newly arrived plant, and find it a satisfactory substitute for their former diet.

The proportion of these two classes of insects determines to some degree the extent of the damage which the farmer will find has been inflicted upon his crop by the end of the season.

In order to understand more fully the relations of these classes it is necessary to inquire rather closely into the degree of association exhibited by plant-eating insects to their host plants. A few insects avail themselves of very many plants as food, and such polyphagous forms, including certain locusts (Fig. 8),

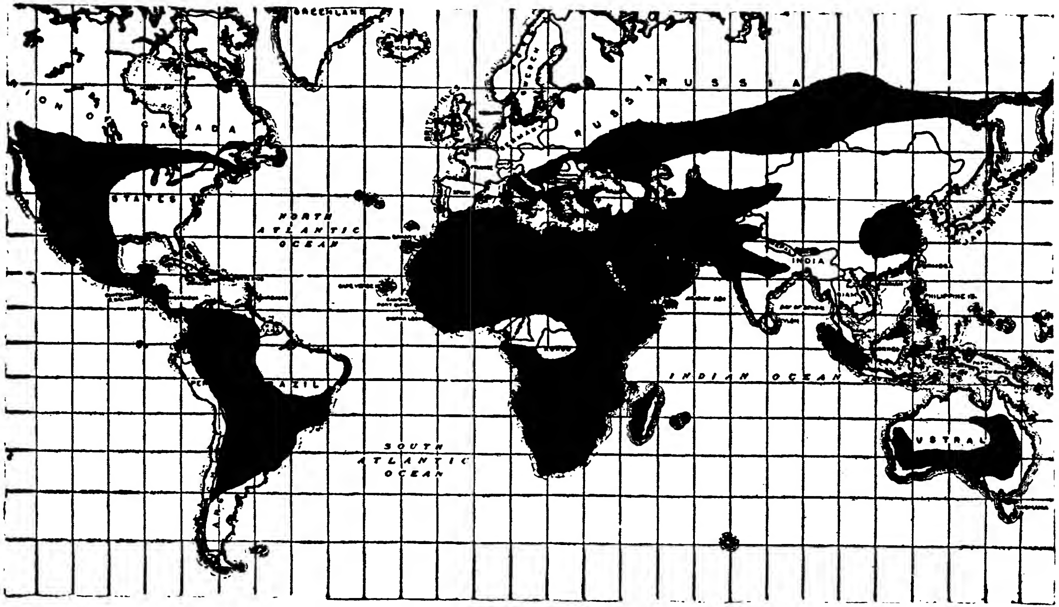

FIG. 8. World map showing (in black) the areas subject to invasion by migratory locusts and other destructive grasshoppers. Although extremely erratic in occurrence from year to year, owing to a variety of circumstances, the average value of agricultural products destroyed by these insects is of the order of $40,000,000 annually. To this must be added the cost of remedial measures now required to hold the destruction at present levels. (After Uvarov, redrawn from the Smithsonian Annual Report for 1944.)

grasshoppers, crickets, and the like are a constant menace, whose varying abundance depends upon factors not yet mentioned. Numerous other forms, which may be called oligophagous, depend upon several, usually related, species of plants for their sustenance. Still others appear to be monophagous, or restricted to a single food plant, like the Mexican cotton-boll weevil. The more closely the habits of insects are observed, the more apparent it becomes that nearly all are closely restricted in their choice of food. Thus many apparently omnivorous and ubiquitous grasshoppers are really highly oligophagous, or even monophagous in the case of a few species.

From the agricultural standpoint, monophagous insects feeding upon the crop plants are usually the most destructive. If present in the locality where cultivation takes place, they seek out their host plant with unerring accuracy to find enormous opportunities for development and multiplication, a condition which, like the vacuum, would be abhorred by nature, but which is a corollary of all agricultural development. Further, the same crop is planted and carefully cultivated during succeeding years, to give never-ending opportunities for increasing hordes of insects. The economic entomologist has no criticism to make of such a method of agricultural procedure, since he cannot, except perhaps within very narrow limits, propose a better one. He cannot, however, hold himself guilty when it is pointed out to him that insect ravages are constantly increasing in spite of his feeble efforts to reduce them.

The situation is still further aggravated by the constantly increasing number of foreign insects which find their way to our shores and become established, to spread gradually throughout those parts of our agricultural regions that enjoy a suitable climate. Such insects, of which a very considerable number could be

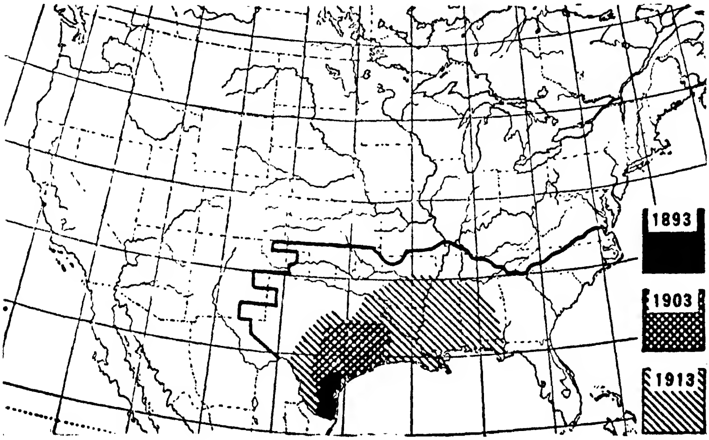

FIG. 9. Map showing the spread of the Mexican cotton-boll weevil (*Anthonomus grandis*), introduced into the United States from Mexico in 1892. After about thirty years it had spread over the most productive cotton-growing areas of the United States. After 1913 its range was still further extended, and by 1923 it was practically coincident with the limits of the cotton belt, indicated by the heavy line. (After the Bureau of Entomology, U. S. Department of Agriculture.)

enumerated, are our most destructive pests. They are, of all species of animals, the most fortunate. They are suddenly dropped in the midst of plenty; they are unhampered by the enemies and parasites of their native land. That they immediately make the best of their opportunities and proceed to exploit the country is seen by the phenomenal injury done by the Mexican cotton-boll weevil, or picudo (Fig. 9), to the cotton crop, the gipsy moth, or grosse Schwammspinner, to deciduous trees, the Hessian fly to the wheat crop, the cabbage butterfly (Fig. 10) to various cruciferous crops, and many other naturalized insects to various other cultivated plants.

Undoubtedly a great many foreign insect pests are accidentally imported but fail to establish themselves, even though the climate and other conditions appear to be suitable for them. If such were not the case, we would be far worse off than we are. A quarantine against foreign insects is difficult to carry out, and at best the search for stowaway insects is literally like searching for the proverbial needle in a haystack. Eradication, once the insects have become abundant, is next to impossible, although it has been accomplished in rare instances.

One of these instances, relating to a fruit pest, the Mediterranean fruit fly (*Ceratitis capitata*), may be appropriately mentioned at this point. This fly is native to Africa, but derived its name from the damage caused to citrus and other fruits in southern Europe. It is now widely distributed in many tropical countries, and was noticed in Florida in 1929 after it was already present in countless numbers over a wide area. Vigorous repressive measures were at once undertaken and after the lapse of several years the fruit fly had completely disappeared. The entomological world was in an uproar over this signal success in freeing the Florida citrus industry from certain destruction. Still there is a lurking suspicion in the minds of some that natural causes, not fully understood, played a major role in this venture.

The explanation for the abnormally rapid multiplica-

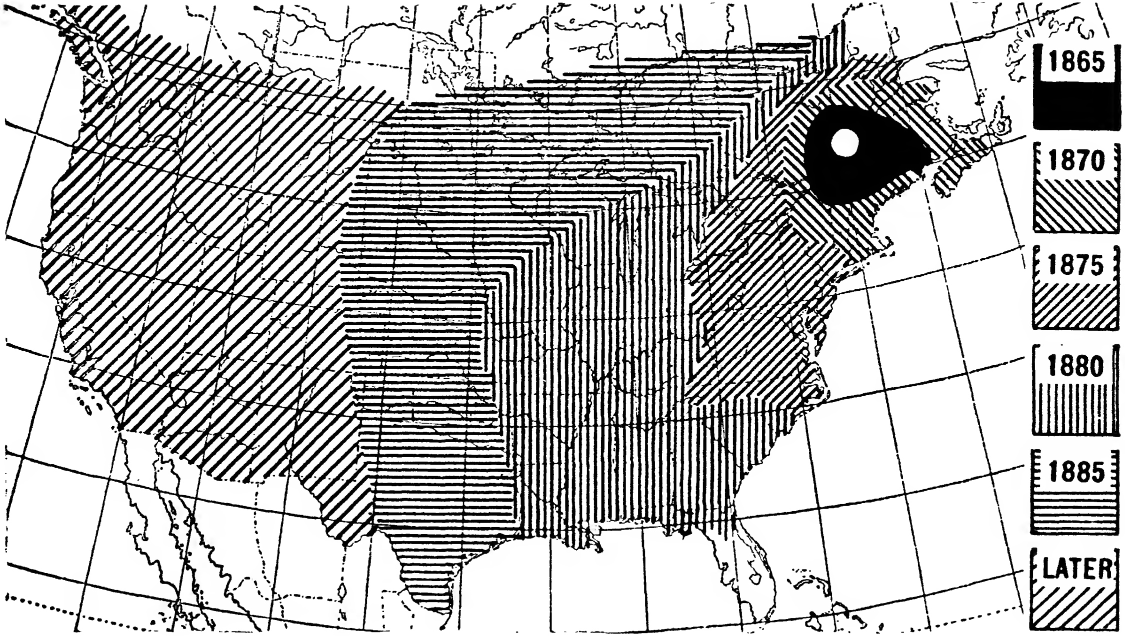

FIG. 10. Map showing the spread of the European white cabbage butterfly (*Pontia rapae*) following its introduction near Quebec (indicated by white spot) in 1860. This insect, which spread with great rapidity, feeds in the larval state upon cabbage and other closely related plants. (In part after Scudder.)

tion of imported insects is not far to seek, and depends upon principles well recognized by all biologists. As was previously pointed out, approximately one-sixth of our insects are entomophagous parasites, passing their developmental stages within the bodies of other living insects. Some of these parasites prey upon other parasites, but a goodly portion affect phytophagous insects, which they destroy before completing their growth. Like the plant-eating forms they are restricted to definite hosts, generally few in number, with which they show a very definite association. In fact, so fixed are their instincts to restrict themselves to the same host that they ordinarily avoid any insects which they do not normally parasitize. With this in view, if we consider for a moment the conditions surrounding an insect pest introduced from another part of the world, we see that it is no longer at the mercy of the entomophagous parasites that would affect it in its native land, and that the parasites with which it is now associated will leave it unmolested. Hence, compared with many of our common native insects having a dozen or more well-known parasites which may frequently produce death rates of from 50–90 per cent in a single season, the far greater danger of rapid multiplication by parasite-free imported pests is easily realized.

A parasitic insect of the entomophagous sort may be defined as one which passes a part of its developmental stages (usually the larval and often the egg or pupal stage also) upon or within the body of another insect or in its eggs, from which it derives its entire food supply and which it almost invariably kills before attaining its full growth. There are a great many species of parasitic insects, and there are probably very few or perhaps almost no predaceous or phytophagous insects which are not subject to their attack. Even parasitic insects themselves are quite frequently destroyed by other species known as secondary parasites, and in at least a few cases the secondary parasites are known to be infested with others known as tertiary parasites.

A parasite stands in contrast to a predaceous species since it cannot feed upon whatever suitable prey it may discover, but has a certain host species or restricted series of hosts which it always selects to the exclusion of others. From generation to generation these same hosts are always chosen with most extraordinary persistence, for reasons which are at present in most cases obscure. Nevertheless such appears to be almost invariably the case, although some species of parasites have been found to attack a much larger series of hosts than others, and a very few appear to be somewhat indiscriminate in their tastes. Predaceous insects frequently show similar preferences for particular prey, being much less catholic in their tastes than most other predatory animals. Consequently their relations to the abundance of noxious insects are closely similar to those of the entomophagous parasites. Some of the more generally important predaceous insects include the lady-bird beetles (Coccinellidae), which eat plant lice and scale insects, the larvae of various Neuroptera, the praying mantises, many ground beetles (Carabidae), and even a few caterpillars.

Parasitic species belonging to a number of the different orders of insects are known, and from our knowledge of the relationships of the different groups it is evident that the phenomenon of parasitism has arisen independently in each group. By far the most important from an economic standpoint are those included in the Hymenoptera and Diptera. The parasitic Hymenoptera have the greater significance, and include a vast complex of species of the most varied habits, included in a long series of families. Of these the Ichneumonidae and Braconidae attack the larval or more rarely the pupal stages, the female ordinarily depositing her eggs within the body of the insect, and the larva feeding upon the blood and tissues of its host, which it finally leaves for pupation, or destroys entirely by consuming the vital organs. In the former case, an affected host larva may perhaps survive under exceptional circumstances, but ordinarily succumbs to the attack. According to the comparative size of the host and parasite, one or a series of parasites may be nourished by a single host. The members of a series of families belonging to the wasp-like superfamily Chalcidoidea, which includes a vast number of small or minute species, are parasitic in habits, some of them attacking their hosts like the previously mentioned families. Others present a most remarkable phenomenon of paedogenetic, or precocious, multiplication known as polyembryony in which a single egg of the parasite deposited in the host egg gives rise to a series of larvae (often several hundred) which develop within the host larva. Still other very minute species are egg parasites, completing their entire growth within the eggs of larger insects, into which the female deposits her own minute eggs. The superfamily Proctotrypoidea includes several families of minute species which are egg parasites, developing in much the same way within the eggs of other larger insects. To this group belong also some other families with habits more like those of the Ichneumonidae, which attack the later preparatory stages of their hosts.

Second in importance are a large series of Diptera belonging to the family Tachinidae, parasitic during their larval development within the bodies of other insects, mainly the caterpillars of various Lepidoptera, although they by no means restrict their attacks to insects of this order. The Tachina flies are in some ways less specialized in their habits and as a rule do not have such definite host relations as the parasitic Hymenoptera, most species attacking a larger and more varied series of hosts. On the other hand, the methods by which the larvae gain access to the host show highly developed adaptations. Some deposit large, oval, white eggs directly upon the caterpillars or other insects within which they may develop, and the larvae on hatching bore through the cuticle to gain entrance into the visceral cavity. Others thrust maggots directly through the skin of their victims, while still other types deposit large numbers of minute eggs or larvae on the foliage upon which the host insects are feeding. In the latter case the eggs or maggots are ingested with the food, whereupon the eggs hatch and the larvae, perforating the wall of the alimentary tract, reach the visceral cavity. One or many larvae may live at the expense of a single host according to their relative sizes, and on attaining full growth, the larvae usually quit the host through orifices they make in its body wall and enter the soil for pupation, later to emerge as adult flies.

It seems probable, at least in regard to the Tachina flies, that the parasitic habit has been derived as a modification of the habit of feeding upon recently dead insects, which has been transferred to living ones and has since developed its most remarkable adaptations as seen in the group at the present time. With the parasitic Hymenoptera the derivation of the parasitic habits is far more obscure, and doubtless of much more ancient origin.

Ever since scientific methods of investigation were applied to the problems of economic entomology the importance of parasites has been recognized as a factor involved in the natural control of insect pests, but it is only within comparatively recent times that their full significance has been realized. With the recent introduction of several injurious insects into our own country a minute comparison of the controlling factors here and in the country of origin has brought clearly to light the prime importance of insect parasites. Highly successful attempts have been made to colonize the parasitic enemies of several imported pests in the United States, and similar experiments have been undertaken by foreign entomologists. One of the most extensive is that aimed at the control of the gipsy moth, which is discussed on a later page. The same condition prevails generally in regard to the diseases of insects caused by fungi, nematode worms, bacteria and other microorganisms, but this matter has been carefully investigated in only a few cases.

Several diseases of the silkworm and honeybee are well known, but as these insects are useful our efforts are directed toward the maintenance of health. Diseases due to nematodes are well known also, and have been used in the control of the Japanese beetle (*Popillia japonica*). This insect, native to Japan, was introduced into the eastern United States, where it has caused great damage to a wide variety of plants. The larvae are subterranean, feeding on roots, and the adult beetles indiscriminately eat foliage, green fruits, and even flowers, especially roses. Gratifying success has attended the propagation of the nematode parasite (*Neoplectana glaseri*) and also of a bacterial disease. The number of fungus parasites of insects is legion and although they often cause great mortality their artificial propagation has not generally met with any great measure of success.

Predatory insects also play an important part in reducing the abundance of phytophagous insects. In habits they are directly comparable to the beasts and birds of prey among the higher animals, which destroy the weaker and more timid members of the fauna. They do not show the same close correlation to their prey exhibited by insect parasites, and can only rarely be depended upon to restrict their depredations to any particular insect pest. Quite frequently, however, they are a great aid in combination with parasites, and several exotic forms introduced into the United States have aided in the control of the gipsy moth, scale insects, etc.

Perhaps the most generally useful predatory insects are the familiar, brightly-colored lady-bird beetles briefly mentioned on a previous page. Both the larvae and the adults feed almost entirely on plant lice and scale insects, which they consume in prodigious quantities. They are ever present and are a great natural asset in practically every garden, large or small.

Another factor which must not be overlooked relates to the provenience of our agricultural crop plants. These are the results of selection during the course of many centuries, and have been gathered together from the most diverse parts of the world. Thus most of them are grown to a very great extent outside of their natural habitats and consequently find themselves frequently and to varying extents free from at least some of their original insect pests. With the gradual and continuous growth of world commerce and the great innovations in ease and rapidity of transportation, insects are more easily carried over natural barriers, and the aggregation of agricultural pests is continually becoming more homogeneous. As was mentioned in the previous chapter in connection with insects that transmit human diseases, the great increase in air travel has hastened this dissemination. As the agricultural pests usually travel in association with their food plants, they may not be expected to take so generally to world tours, except where their favorite foods are carried as freight or in the impedimenta of human passengers.

As was mentioned before, cultivated plants are often attacked by insects which have previously fed on related plants, and such occurrences, although uncommon, are by no means rare. Many of our most important food plants belong to a very few of the natural families of plants and it is noticeable that these plant groups are usually very widely distributed ones with many representatives. Thus the grasses or Gramineae furnish us with wheat, maize or Indian corn, oats, rice, rye, barley, and sugar cane; the Leguminosae with beans, soy beans, chick peas, peas, and cowpeas; the Solanaceae with the potatoes, tomatoes, sweet peppers, and eggplants; the Umbelliferae with carrots, parsley, celery, and parsnips; the Curcurbitaceae with pumpkins, squash, vegetable marrow, cucumbers, and melons; the Cruciferae with cabbage, cauliflower, Brussels sprouts, kohlrabi, mustard, turnips, and radishes; the Compositae with salsify, lettuce, and the Jerusalem artichokes; the Polygonaceae with buckwheat and rhubarb; the Liliaceae with asparagus, onions, leeks, garlic; the Araceae with taro and breadfruit.

There are, of course, very numerous exceptions to this, as is the case in food plants like the beet, sweet potato, yam, etc., but these only modify the general principle that the utilization of numerous related plants is the common practice. It is noticeable also that a good many of these plants are of tropical or semitropical origin, and that they are commonly cultivated in climates far more rigorous than those in which they have originated. This is true of a large variety of well-known food plants like corn, potatoes, tomatoes, pumpkins, okra, and others.

As might naturally be expected from the foregoing, we actually find that some of our pests of wheat are species feeding on, and probably original enemies of, native American grasses, several of which are very closely related to the cultivated wheat plant. A still more interesting case is that of the Colorado potato beetle, a well-known and very destructive enemy of the potato (*Solanum tuberosum*). We have good evidence that this is a Neotropical insect of Mexican or

Central American origin, which extended its range within historic times into the Middle West as far as Colorado, following the probably northward migration of its original food plant, *Solanum rostratum,* which is a common roadside weed. In the late sixties of the past century it was first noticed feeding on the foliage of cultivated potatoes, and within twenty-five years it had encompassed the entire United States east of the Rockies, breeding upon potato plants everywhere, and even invading Europe, where most of its incipient colonies were wiped out.

This same group of plants, the Solanums, also illustrates nicely the vagaries of numerous insects in relation to food plants. Thus we find that the Colorado potato beetle now feeds upon *Solanum rostratum* far less commonly than upon potatoes, and that it practically never occurs on the tomato and rarely on eggplant, both species of the same genus, although it occasionally affects tobacco.

Another interesting case is that of another Mexican beetle which has recently invaded our southwest and spread rapidly by its own migratory habits as far as New England. This is the Mexican bean beetle (*Epilachna corrupta*), which devours the foliage of various sorts of beans. It is now a pest of major importance throughout its newly extended range, even in the cold north. Since these valuable plants are grown extensively and in considerable variety both as field and vegetable crops, they combine to offer almost unlimited opportunities for the bean beetle to thrive and multiply. Thus, although this insect restricts its diet closely to a few related species of plants, it happens that one or more of these are to be found in practically every cultivated area.

On the other hand, the tomato is frequently injured by a large caterpillar known as the tomato-fruit worm (*Heliothis obsoleta*), which does not occur on the eggplant or potato, although it is a common enemy of tobacco, known as the budworm, and is moreover a very important enemy of both corn and cotton, two totally unrelated plants. On these latter it has been called the corn-ear worm and the cotton bollworm, but it is identical and feeds on these several plants without much apparent choice. Several of our most destructive insect pests of cotton are, however, entirely restricted to this plant or to very closely related species, such as okra. They are the Mexican cotton-boll weevil, the cotton caterpillar, and the pink bollworm. Only the cotton caterpillar is native. The pink bollworm, which feeds in the seeds, occurs in the Old World, but appeared in Texas during the first World War, just at the time when this crop was in great demand. It has since spread into several adjoining states. Another recently imported enemy of corn, the European corn borer (*Pyrausta nubilialis*), which prefers corn to other cultivated garden crops, attacks also a great variety of common weeds, the caterpillars feeding in burrows which they excavate in the stems. First noticed less than thirty years ago near Boston, it has now encompassed the whole northeastern part of our country. Because of its fondness for weeds, it is especially difficult to keep under control.

Insects of these types point out clearly the fallacy of any statement that related plants always have the same or related insect pests. That they quite generally have the same enemies or nearly related ones with similar life history and habits is, however, ordinarily quite true. Some of these discrepancies are due to the fact that the essential oils or other odorous chemicals which attract the specific insects occur most generally in related plants, but occasionally are found also in widely different plants. By no means all of the peculiarities of food selection may be explained on this basis, however.

How this damage can be abated or lessened is the natural inquiry from the nonacademic mind. We have seen that a return to natural conditions would speedily reduce insect injury and bring into play the forces of nature which would maintain a more or less stable condition. Such a return would not take place, however, if human influence were simply removed; it is true that a stable condition would result, but it would be very different from that which existed in the original flora and fauna. Indeed human ingenuity could not again make things as they were, even if it were desired to do so at the cost of discarding all agricultural progress. It is possible, however, by an additional disturbance to approach in some respects a natural biological association without any change in current agricultural practice.

This partial return to the native environment can be achieved to some extent by the introduction of parasitic insects and other organisms such as nematode worms, fungi, and bacteria, and this biological method of combating imported insect pests has proved itself of value in many cases. Up to the present time the importation, colonization, and distribution of such enemies has been accomplished in this country with the parasites of the gipsy moth, European corn borer, brown-tail moth, Japanese beetle, and with those of certain other serious insect pests. The method gives great future promise, but there are many technical difficulties to be overcome. Its great advantage lies in the fact that it insures permanent relief once it has been put into operation, and that its limitations are in a broad way determined primarily by the insect species against which it is directed. Aside from the repeated application of poisons and other insect-destroying materials, it is the only feasible means except those which entail changes in agricultural procedure.

Of the latter methods, there are several which can be employed without seriously disturbing agriculture, and at least one of them is, in fact, only a slight modification of the principle of the rotation of crops, which had its origin not in relation to insects, but as a practice to delay or prevent the loss of soil fertility.

We have already seen how the continued replanting of a crop plant in the same place from year to year served to augment insect depredations. Since many different crops have insect enemies in common, it follows that when such crops follow one another on the same area, the opportunities for insect multiplication are not conspicuously less than if there were no rotation. Thus the planting of cotton and corn in alternate years is obviously of no advantage in lessening damage by the cotton bollworm (alias corn-ear worm), since this species may then breed uninterruptedly from season to season. Similarly the planting of newly plowed grassland to corn, wheat, or other grasses courts disaster in the same way, since a great many corn pests feed also on various wild grasses. Rotation practiced with insect injury in mind, however, where the crop plants are without important enemies in common, serves to reduce insect injury at least to some extent, dependent mainly upon the ability of the insects concerned to migrate, and it need in no way impair the other advantages derived from the process. Agricultural entomology has now reached such a condition that reliable advice with reference to many insects can be given in rather definite terms.

A concrete example of the utilization of this method in the control of certain insects that are difficult to combat otherwise has recently been demonstrated. In this case the insects are the large grubs of May beetles, which feed on the roots of many plants. They are particularly injurious to corn in the northern middle states, but do not injure clover nor deposit their eggs in soil that is covered by a stand of clover. In this region corn is commonly planted in rotation with timothy, oats, or barley, but if clover is grown the year before a field is to be planted to corn, few grubs will be present in the cornfield. As the beetles require two years for their life cycle, appearing most abundantly in alternate years, crop rotation can be planned in relation to the insects. Where feasible, the use of clover, cowpeas, or other leguminous crops as alternates in rotation is especially advantageous since these plants improve the soil through the action of the nitrogen-fixing bacteria that develop in nodules on their roots.

The growing of substitute crops is really this method applied in a somewhat different way, and has the further advantage that the original crop is not removed to a distance, but is more or less completely eliminated. This is a rather fundamental agricultural change and it must be taken for granted also that a substitute is something less desirable. As some of us have become rather enthusiastic over substitute foods forced down our throats during the past few years, it may be of interest to point out that two potato substitutes, the dasheen in the South and the edible sunflower root or "Jerusalem artichoke" in the North, are plants which so far do not appear to be severely affected by insects, and for this reason, at least, are worthy of encouragement.

Recent successful attempts to produce "vegetable meat" by growing certain microscopic yeasts (Torula) in large quantities have failed to arouse any permanent interest among the public at large. Nevertheless, such procedures hold great promise of future developments if they can be put on a rational basis, since they make possible the mass production of protein foods at a very rapid rate.

Aside from the factors already referred to as regulating the abundance and destructiveness of agricultural insects, various poisons are in very general use for the control of such pests. Under present conditions these are the most direct and probably the most efficient means that can be employed for the protection of many crops, although with other crops there are apparently insuperable difficulties to the satisfactory use of such insecticides. One of these relates to insects which feed internally, boring in stems and living in fruits or other places where they cannot be reached by the spraying or dusting of poisons. Even in the case of species like the Mexican bean beetle which feed externally on the underside of leaves, the application of poisons in this position is not easily accomplished.

At the time the Colorado potato beetle began its invasion of the eastern United States agriculturists were in despair, for it appeared that the cultivation of this important crop would have to be abandoned almost entirely over large sections of our country. However, as a result of the discovery that Paris Green dusted or sprayed upon the foliage would destroy the beetle grubs without seriously injuring the plants, the potato crop was harvested in spite of the beetle, and spraying for potato bugs has become a commonplace pastime for those who attempt the culture of potatoes. The substitution of other, less soluble arsenical compounds such as arsenate of lead has rendered spraying a more effective and safer procedure, and careful studies of the life history and habits of specific insects have greatly extended the field of usefulness of the arsenical insecticides. This is well illustrated by studies made on the codling moth by Melander. This insect is a very serious pest of the apple, within the fruit of which its developmental stages are passed. It is usually controlled by spraying the young fruit with an arsenical, but the advantage gained varies within very wide limits depending upon the exact time at which the spray is applied, the method of application, and the type of nozzle used (Fig. 11). Slight modifications in the form of calyx cup of the young apple, due apparently to different climatic conditions, have in turn a profound influence upon the efficacy of the spray, and in some regions several sprayings must be substituted for the single spraying found to be effective at other places.

Thus, in spite of their simplicity of action, arsenical sprays can be prescribed with confidence only after a careful and painstaking diagnosis has been made.

The arsenical insecticides are usually referred to as

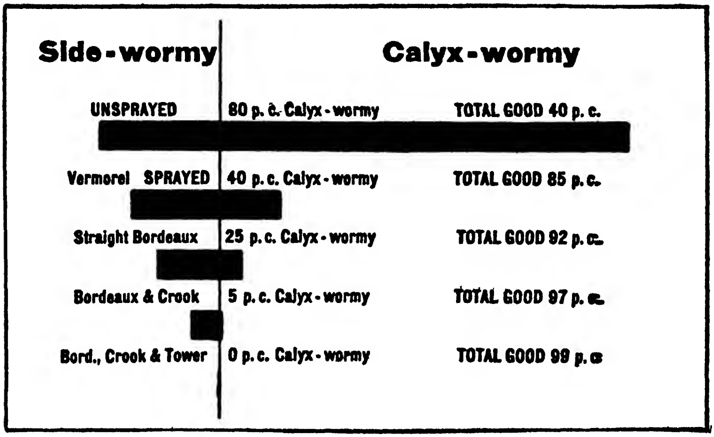

FIG. 11. Chart illustrating the effects of spraying with lead arsenate by different methods for the control of the codling moth (*Carpocapsa pomonella*), a widespread and serious enemy of the apple. In this case unsprayed trees yielded only 40 per cent of good fruit, while of the wormy fruit 80 per cent became wormy from larvae entering the fruit at the calyx cup. When sprayed with a Vermorel nozzle giving a mist spray, 85 per cent of the fruit was good, while of the wormy fruit 40 per cent became wormy from larvae entering at the calyx cup. When sprayed with a Bordeaux nozzle giving a forcible, penetrating spray, 92 per cent of the fruit was good, while of the wormy fruit 25 per cent became wormy from larvae entering at the calyx cup. When sprayed with a Bordeaux nozzle set at the proper angle by means of a crook, 97 per cent of the fruit was good, while of the wormy fruit 5 per cent became wormy from larvae entering at the calyx cup. Finally, when the latter spraying was done from a movable tower, 99 per cent of good fruit was obtained and no apples became wormy from larvae entering at the calyx cup. (After Melander.)

stomach poisons because their toxic action is accomplished through the medium of the alimentary tract. As we have seen, they are readily ingested by chewing insects when applied to the plants upon which such insects are feeding. Many of our most destructive insects do not feed by chewing, however, but subsist upon juices which they extract from their food plant by means of a piercing, sucking beak which is thrust into the tissues of the plant. Such haustellate insects manifestly will not take into the mouth any arsenical poison present upon the surface of the plant, and no successful means have been devised for introducing poisonous materials into the sap, with which they might be taken into the body of the insect.

For the destruction of such insects other materials known as contact insecticides are in general use. These consist of various substances, such as several alkaloids obtained from plants, including nicotine, pyrethrine, and rotenone. Also certain oil emulsions and a calcium sulphide preparation known as lime-sulphur wash are used for this purpose. These insecticides kill through contact, by actual poisoning, suffocation, or otherwise. They are often used in combination with the arsenicals and with a fungicide, such as the copper compound known as Bordeaux mixture. Thus when several insects of different types and fungous diseases are to be dealt with upon the same plants, specific combinations may be prescribed. Some of the methods of treatment available for application to various fruits are shown in the accompanying diagram (Fig. 12).

Fumigation with poisonous gases or the vapors of highly volatile liquids are also frequently employed.

These can be used only in confined spaces however. Most efficient for this purpose is hydrocyanic acid gas, but on account of its deadly nature this is not entirely safe for use even in competent and experienced hands.

Although it has not as yet been thoroughly tested,

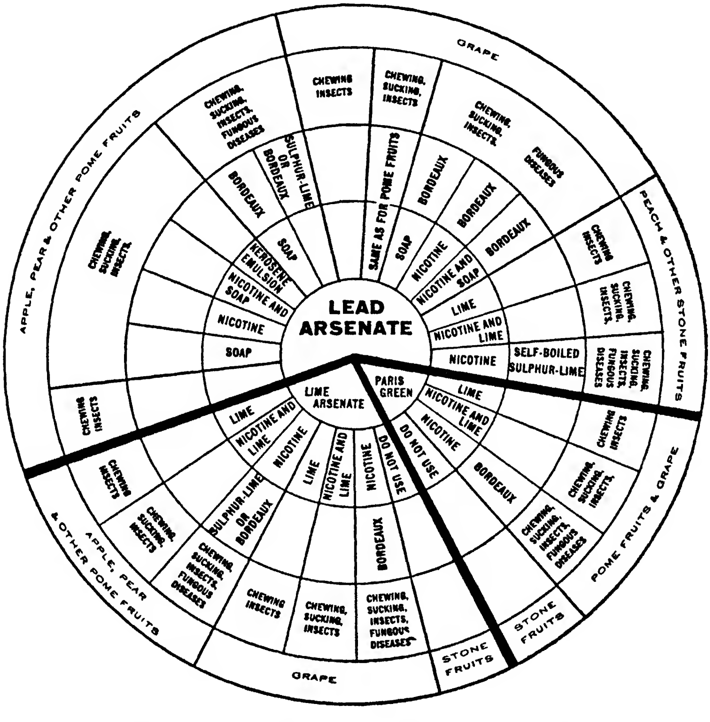

Fig. 12. Diagram illustrating the various combinations in which several arsenical insecticides may be combined with contact insecticides and fungicides for the protection of certain orchard fruits from insects and fungous diseases. The sections between the heavy black lines represent the combinations suitable with three different arsenicals, while the smaller sectors represent suitable treatment for several types of injury to the particular plants that are indicated about the periphery of the diagram. (Slightly modified from Quaintance.)

it appears that DDT may supersede both the arsenicals and contact insecticides for certain purposes because it is equally efficient in many cases for both chewing and sucking insects. Another new insecticide developed during the war by the British is benzene hexachloride. This shows great promise, and experiments undertaken in this country tend to show it to be especially useful as a poison for the Mexican cotton-boll weevil and other cotton pests, the weevil being especially refractory to the arsenical insecticides.

After foods are harvested they are commonly stored for considerable periods before being finally utilized, especially in the case of staple crops such as cereals, beans, etc. During this time they are by no means free from insect injury; in fact, their deterioration is undoubtedly hastened more by insect activity than by any other agency. The insects concerned are a most cosmopolitan lot, gathered from all quarters of the globe, for their world-wide dissemination has been most readily accomplished in the extensive shipments of such products. The Orient is represented by several Chinese bean weevils which affect the stored seeds of leguminous plants, Southern Europe by the Mediterranean flour moth, Mexico by the Mexican grain beetle, and so on, while the majority of the more common pests are so widely scattered that it is almost impossible to ascertain their original home.

Owing to the nonliving character of the material in which these insects live, it is possible to control them easily by means of simple physical or chemical means, such as heating to a temperature that will destroy insect life, or fumigation by some insecticide such as carbon bisulphide, carbon tetrachloride, or hydrocyanic acid gas, after which they may be marketed in sealed containers. Most efficient is the use of heat. Raising the temperature to 50° centigrade (122° Fahrenheit) for a short period is sufficient and this does not affect the flavor of most edible products.

In spite of the ease with which these insects can be controlled, they entail an immense economic loss which is probably in the neighborhood of $20,000,000 annually in the United States. Their origin as enemies of stored products which are maintained under purely unnatural conditions may at first sight seem a trifle obscure, but they all undoubtedly represent species originally enjoying very limited opportunities for multiplication, and subject to great vicissitudes. Like agricultural pests they now flourish with the barriers removed.

CHAPTER III

FOREST INSECTS

The necessity for the conservation of forests and the rational utilization of their products has long been recognized by all who have given attention to such matters. Changes in private and public policy have come slowly, however, and until recently but little attempt has been made to manage forests with regard to both their present and future values. As a consequence forestry has lagged far behind agriculture, and "forest conservation," although it has now become a by-word with the American public, has but a brief history in our own country. Despite the great value and vast importance of forest products, it is easy to find a reason for the more rapid application of scientific ideas to agriculture, for there the results of improved methods manifest themselves within a single season. On the other hand, timber trees are of slow growth, and, unlike agricultural crops, they have existed in enormous quantities ready for man's use without any effort on his part to further their growth. So long as primeval forests were available in sufficient amount and in convenient locations, little care was taken to provide for a future supply of lumber. In fact it was tacitly assumed that nature would provide a continuous supply of trees, and she was left to her own devices to replace what human agency had ruthlessly removed.

Under the conditions now prevailing she has consistently failed to replace forests that have been cut over. This has come about on account of fire and other disturbing elements resulting from human activity, and also from certain innate and immutable biological characteristics of growth and reproduction among the species of trees that make up the forest. Thus to one section of the world after another has come the realization that forestry must be put on a permanent basis if forest products, like agricultural crops, continue to be necessary for human existence.

There appears to be no promise of a future which will lessen our demands upon the forests, and there is every probability that forest products will be called upon in rapidly increasing measure. For example, the development of new uses or the rapid expansion of those already extant which require pulpwood has reached gigantic proportions, especially in our own country. This pulp comes almost entirely from various woods, although in the near future it is probable that considerable quantities of paper pulps may be made from sugar cane. After the sugary sap has been expressed, the dry residue, or bagasse, can be processed into coarser grades of paper. Unfortunately, such a procedure may not save as much wood as might be expected, since in many localities a part of this bagasse now serves as fuel to boil down the sap into crystallizable sugar syrup. Where oil is available, however, it may replace vegetable fuels. Some of these cellulose products are valuable, like the fabric made of chemically modified cellulose, and they lessen our needs for other plant fibers, especially cotton and flax. Others, like paper, are a mixed blessing, particularly the newsprint which goes into the ephemeral pulp magazines and newspapers. The most alarming increase comes from the gargantuan appetites of the present daily papers and popular weeklies, and it is doubtful that any curb on such wastage will soon be forthcoming. Not only does this entail great material loss, but it has also developed a large class of nonproductive individuals who administer the advertising materials with which the public is bombarded on behalf of manufacturers and merchants of every description. One bright side to the picture is the realization by a select few that the future of our forests cannot be completely neglected in the face of an obviously imminent starvation of our printing presses.

The problems entailed in maintaining forests in a productive state and those to be dealt with in rehabilitating depleted forests, or in fostering the development of new ones, are numerous and intricate, but manifestly they have much in common with those encountered by the agriculturist. One of the most striking differences is the slowness with which the lumber crop matures in comparison with the rapid, commonly annual attainment of maturity by agricultural crops. This element of time at once exerts a profound influence on the commercial aspect of the matter, since the returns on the money invested in forests and spent in their maintenance are so delayed that they dwindle in amount when compared with those which may be obtained from investments of other kinds. Added to this is a psychological aspect due to the deep-seated human aversion for rewards in the too-distant future. These matters could be dwelt upon at great length, but they are far from the present discussion, except that they explain in great measure the past and present relations between the human race and the forests. One point which must be borne in mind is that the element of time bears also a very important biological relation to the welfare of forests. This is least noticeable in many primeval forests of mixed character, but becomes increasingly significant in those of pure growth and those which are reproducing themselves after depletion through extensive cutting, while it is of prime importance under the conditions prevailing where extensive reforestation is undertaken.

Still another difference between the propagation of agricultural crops and forest trees depends upon the fact that the latter have not been improved through selection and hybridization. Thus our food plants yield greatly enhanced returns, while the forest trees do not. It is only now that serious attempts are being made to develop more productive strains of our common, valuable forest trees.

We have pointed out in connection with the insect enemies of agricultural crops the general relationship which exists between these plants and insects. In the case of forest insects, it will soon be seen how greatly the long developmental period of trees affects the character of the depredations of insects that live at their expense. Another difference which influences damage by insects depends upon the development of woody tissue, which is practically absent in all of the agricultural crop plants, and which serves as food for quite a considerable variety of insects. On the other hand, the large fleshy roots so characteristic of many food plants are not developed in trees, which are consequently not injured by insects of the type that are so destructive to vegetables like the carrot, radish, etc. With the horticultural trees, like the apple and peach, forest trees have more types of insect enemies in common, but with the exception of nut trees, various palms, such as the coconut, oil-nut, and date, and a few others, especially in the tropics, the fruits of forest trees are of little consequence so long as sufficient seed is produced to allow for reproduction. In exceptional cases, certain insects actually do prevent the development of seeds to such a degree as to menace seriously the reproduction of certain species of coniferous trees, but ordinarily their influence upon seed production is not of any great importance.

Aside from the fundamental differences in material composition between the individual tree and the herbaceous agricultural plant, and not to consider for the moment the slow development of the tree, we find another very striking difference in the environments encountered by insects which feed upon the two types of plants.

In the previous chapter on agricultural insects, attention was called to the way in which associations of very diverse plants have been replaced by large masses of crop plants belonging to single species. This change has upset entirely the balance which existed under natural conditions between the plants and their insect enemies. Many forests are comparable to the miscellaneous associations of plants which have given place to cultivated fields; in fact, much of the present agricultural land was once covered by forests. On the other hand many forests, for example those consisting of coniferous trees, are frequently composed of single species growing to the practical exclusion of all others over very extensive areas. When such is the case, the situation is very similar to that presented by agricultural plants. It is, however, fundamentally different in at least one respect: these trees are growing under natural conditions, and with their slow growth could never have reached their present age if they were regularly subject to damage comparable to that inflicted upon agricultural plants growing continuously in pure sand. These coniferous forests present peculiar conditions in relation to insect damage which are of great importance at the present time, and they afford interesting material for speculation as to the damage which may be caused by insects in the future to any pure forests of other kinds of trees that may be planted for specific purposes. Extensive plantings now being made for the production of pulpwood will present a situation of this kind and undoubtedly serious entomological problems will present themselves.

A characteristic of the insect damage to coniferous forests is the great fluctuation which it exhibits both in extent and severity from year to year. The appearance in great abundance of many of the insect enemies of conifers often shows a striking similarity to the epidemics of certain human diseases, although the reason for their later disappearance is undoubtedly due to very different causes. One common insect of Europe is of especial interest since it is a close relative of the gipsy moth, already introduced into and widely established within the United States. This is the nun moth, feeding in the larval stages upon the foliage of various conifers. It was once imported into our own country, but fortunately never became permanently established. When the caterpillars are abundant, they may completely defoliate trees over wide areas and cause them to die in large numbers, since coniferous trees very frequently fail to survive complete defoliation. The more important and extensive "epidemics" of the nun moth experienced in recent times occurred in 1795, 1839, and 1890, or approximately fifty years apart. Since this is about the period required for the individual trees to attain a mature size, the appearance of the insects shows a very interesting parallel to the more or less regular appearance from year to year of many insects destructive to annual agricultural plants. In the case of trees of this sort, it is evident that a more frequent occurrence of such outbreaks would seriously menace the continued existence of the host-tree species. The earlier outbreak cited above was suddenly terminated during the third summer as the result of the appearance of a fatal infectious disease of the caterpillars, and such diseases, as well as parasitic insects, in combination with a scarcity of foods, are undoubtedly responsible for the curbing of many invasions of this kind.

In both Europe and North America the larch tree is affected by the leaf-eating, caterpillar-like larva of the larch sawfly, an insect common on both continents. Like many other forest insects, this species has in a number of instances appeared suddenly in great abundance in localities where it had previously been hardly noticed for many years. Since the middle of the last century there have been about half a dozen outbreaks of this kind, culminating in a very widespread one in 1903–1907 which involved a considerable part of the area in the northeastern part of America where the larch is native, and caused the death of a large proportion of the mature larches in this region.

During the decade of 1910–1920 certain parts of eastern Canada and a considerable portion of the state of Maine suffered from an invasion of the spruce budworm (*Tortrix fumiferana*), an insect which defoliates the balsam fir and spruce. This insect moved like the incoming tide and extended its destructive range from year to year. The spruce woods of northern Maine, furnishing much of the pulpwood from which some of our better-class papers are produced, suffered severely for several years. During this period certain areas in succession lost a goodly part of their tree population of spruce and balsam fir, after which the insects suddenly disappeared. If we can judge by the past history of this species, it may quite possibly again reappear in destructive abundance within a few years, since previous outbreaks occurred in 1806 and again in 1878. As a result of its ravages, however, there is grave danger that these forests may be replaced by more rapidly growing and less valuable hardwood trees, which would not under natural conditions again give way to spruce and fir for perhaps two or three hundred years. In the history of the world this is a mere incident, but it is a very severe blow to one of our important present-day industries.

In the northwestern states and western Canada there is a small, pale, yellowish-white butterfly, *Neophasia menapia,* quite similar to the common European cabbage butterfly now so abundant in the United States. It feeds during its larval stages upon the foliage of several kinds of western conifers, and over the short period during which it has been observed has several times suddenly appeared in incredible numbers in rather definitely circumscribed areas. At such times extensive portions of the forests are defoliated, and the trees succumb as a result of the injury.

This insect and others that produce the general defoliation of coniferous trees may not always cause the immediate death of the trees, but in cases where the weakened trees might otherwise recover, they open the way for depredations on the part of another group of destructive insects known as the bark beetles. The latter are small, brownish or blackish, hard-bodied insects, represented by numerous species that live at the expense of trees of almost every description. Some of the larger ones, belonging to the genus Dendroctonus, attack perfectly robust, healthy trees, but the majority live in weakened, moribund, or dead trees. Those of the first type commonly appear in the form of invasions or epidemics, of which many have been noticed in our own country from time to time. The others find great opportunities for multiplication following sporadic outbreaks of other insects like those mentioned above, and may complete the ruin of considerable areas of forests that might eventually have recovered from the effects of partial, or even complete defoliation.

Fortunately the bark beetles that kill healthy trees are few in number, but they are rather widespread in our own country, and our coniferous forests have suffered greatly from them in numerous instances. Destruction in these cases also has usually been due to sudden outbreaks of limited duration. Thus at several times during the last century spruces in the northeastern states have been killed over rather definite areas by the spruce-bark beetle (*Dendroctonus piceaperda*). With this, as with other bark beetles, the parent beetles excavate galleries in the inner bark or cambium, along which they deposit their eggs. When these eggs hatch, the larvae burrow off to the sides, where they dig out lateral tunnels and feed upon the cambium layer until they attain full growth, after which the emerging beetles bore their way through the outer bark and leave the tree. Extensive injury to the cambium interferes with the metabolism of the tree and kills it after the manner of the girdler's axe.

More spectacular than the work of the spruce-bark beetle has been that of the Black Hills beetle (*Dendroctonus ponderosae*). Following its sudden appearance in large numbers in the Black Hills National Forest of South Dakota during the season of 1897, its ravages assumed the proportions of an epidemic there, and Hopkins has estimated that trees of the western yellow pine containing nearly a billion feet of timber were killed before the epidemic subsided several years later.

The control of the Dendroctonus bark beetles is by no means easy and is made more difficult by the fact that outbreaks often start in spots where lumbering operations cannot readily be undertaken. Infested trees when felled may be freed from the developing beetle larvae by peeling off the bark or by scorching the logs by fire. Floating them in water will also destroy the insects by suffocation or drowning. Such methods are commonly applied when feasible in order to prevent the infestation of other trees by the emerging beetles. As the beetle grubs do not burrow into the wood, they do no damage to the logs for lumber. Even the heat of the sun when the logs lie in the open will often kill a part of the breed. Heat of 50° centigrade (122° Fahrenheit) will destroy all insect life, and temperatures frequently rise to this point under the direct rays of the sun.

As mentioned on a previous page, mixed forests present a problem to the entomologist somewhat different from that just discussed in connection with the unmixed, or pure, growths of coniferous forests. Our mixed forests are composed mainly of deciduous, or broadleaved, trees, and these ordinarily contain an assortment of tree species belonging to at least several of the natural families of plants, combined with much shrubby and herbaceous growth. They at once exhibit a great diversity of plants and support a correspondingly large and varied insect fauna. A considerable proportion of these insects are species dependent upon plants other than trees; some live upon the rotting wood or bark of fallen trees, others upon fungi, many are predatory or parasitic upon the foregoing, till only the small number remaining are actually destructive forest pests. Each of these in turn, is almost entirely restricted to one or several related trees as food plants, so that the interrelationship of trees and insects becomes a very complicated one. It would seem that such an environment should tend to equalize from year to year the damage done by insects to specific kinds of trees and to inhibit the development of extensive outbreaks. Such a conclusion appears to be borne out by experience except in a few cases, and there the explanation must be sought along other lines.

It might appear from such a brief comparison of insect damage to pure coniferous forests (that is, those which practically inhibit the development of undergrowth on the forest floor) with mixed forests of deciduous trees that we may have overlooked some fundamental principle regulating insect damage to trees of the two types. That such is not the case is shown by the less noticeable and more restricted outbreaks of certain insect species that occur in deciduous forests where one species of tree may greatly predominate, or in cases of insects that readily attack an extensive series of trees. That the excessive importance of forest insects in our own country may also be due in part to the great amount of waste, uncared-for woodland suggests another factor which may perhaps modify these conclusions.

The striped maple caterpillar (*Anisota rubicunda*) is an example of an insect whose outbreaks occur in deciduous forests where one species of tree predominates. This is a defoliating species, of rather general distribution in the cooler portions of eastern North America. It is naturally always more abundant where maples are numerous, but occasionally appears in localized outbreaks of quite definite duration. An example of an insect species which readily attacks an extensive series of deciduous trees is the European gipsy moth

(*Porthetria dispar*), now prevalent in a part of New England and the Pennsylvania mountains, where it was introduced accidentally through the agency of man.

The gipsy moth lives as a caterpillar on the foliage of a large number of deciduous trees, and, when pressed for food, will devour with evident relish many shrubs. Even the foliage of pines and other conifers will serve as food for the caterpillars after they have become partly grown. Although certain trees such as the oaks are its favorite food, it is a truly polyphagous insect, and a forest of deciduous trees contains few species which it will not readily attack. It finds commonly, therefore, conditions very similar to those encountered by the enemies of coniferous trees. Consequently we find that its history in Europe, as far back as it has been recorded with accuracy, includes a series of sudden outbreaks. Thus in Europe in 1731, 1761, 1794, 1837, 1871, and 1909 certain localities were visited by hordes of these caterpillars which defoliated everything in the vicinity. It is very remarkable to note the great regularity with which these outbreaks have occurred (respectively 30, 33, 31, 34, and 38 years apart), particularly when it is remembered that they have in no way been coincident geographically. It must be remembered, of course, that at many intermediate dates there have been subsidiary outbreaks of lesser severity and more restricted range, but the periodicity of this insect and that of the nun moth, mentioned on a previous page, are undoubtedly manifestations of some principle which influences the destructiveness of many forest insects.

In connection with agricultural insects we have already called attention to the importance of entomophagous parasites, and the regulatory effect exercised by these is fully as great in the case of forest insects. In fact, some of our most accurate knowledge of the economic value of parasitic insects has been gained through a study of the parasites of the gipsy moth, which was made on an elaborate scale by the Federal Bureau of Entomology in its well-directed efforts toward preventing the spread and curbing the destructive activities of the gipsy moth in New England. Since this insect bids fair to become one of the worst forest insects over a considerable portion of North America, it may be worthwhile to review its status in regard to natural control by parasites in both Europe and America. It was first introduced into the United States about 1868 in a little town near Boston, where it did not become sufficiently abundant to attract attention for nearly twenty years. Since then it has spread very slowly but persistently in spite of the various repressive measures undertaken to prevent its multiplication and dissemination. At the present time it is the most abundant caterpillar feeding upon trees over a large part of its range, and has caused unbelievable havoc in the woodlands of eastern Massachusetts and contiguous territory.

The slow rate of spread of the gipsy moth is in striking contrast to that of the European cabbage butterfly, which has been cited on another page, and, aside from the vigorous repressive measures undertaken to delay its dispersion, is due to the inability of the adult female moths to fly. On this account, aside from accidental transportation, the species must depend upon the larvae for migration, since when newly hatched from the egg these are commonly blown to considerable distances by the wind. Nevertheless, a closely related European moth, the brown-tail moth (*Nygmia phaeorrhoea*), first detected in 1897 at almost the same place as the gipsy moth, had after twenty years encompassed but little more territory. It was at that time distributed over a narrow coastal strip scarcely over one hundred miles in width extending from Cape Cod northward through Maine into Canada. The cause of the slow spread of the brown-tail moth is not easily pointed out, for this species flies readily and finds its favorite food plants widely distributed. Since 1917 it has practically disappeared and can no longer be regarded as a pest, due apparently in great part to the heavy toll exacted by a prevalent fungous disease of the caterpillars. Lest we be too cheered by this happy turn of events, another European caterpillar, that of the satin moth (*Stilpnotia salicis*), has recently appeared in New England. The slow movement of these pests (Fig. 13) is gratifying from an economic standpoint, but is of only temporary significance, at least in the case of the gipsy moth, which appears likely to extend its range by imperceptible steps and to assume nation-wide importance.

The eggs of the gipsy moth are laid in clusters of several hundred attached to the bark of trees, logs, boards, wagons, freight cars, and all sorts of objects on which they may readily be transported to great distances. It is really surprising, therefore, that this pest has not already been widely disseminated throughout the United States. An infestation imported separately from Europe was discovered in New Jersey in 1920, and the

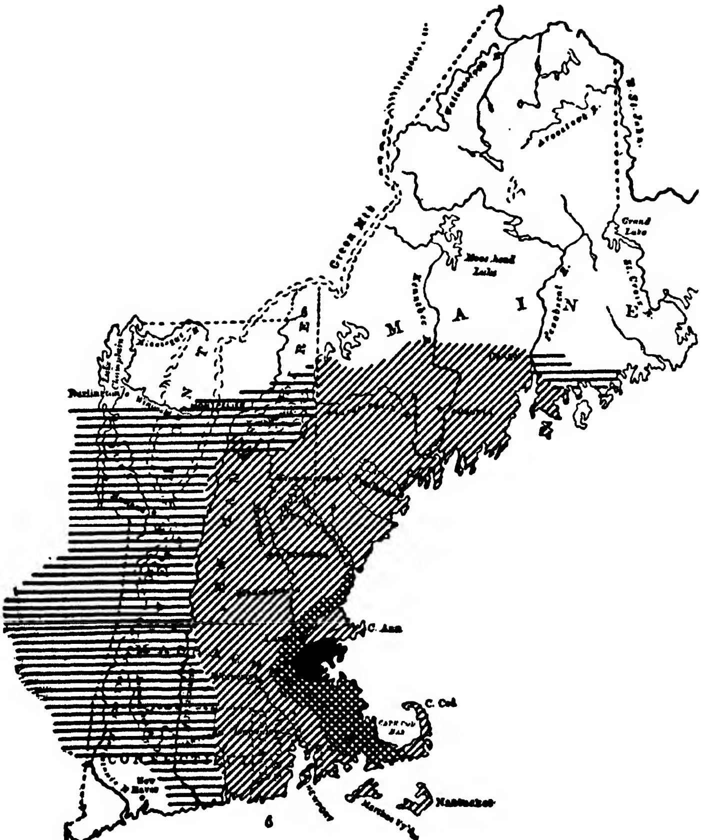

FIG. 13. Map of the New England states showing the spread of the gipsy moth (*Porthetria dispar*). In 1900, twenty years after its introduction near Boston, it had spread over the area marked in black. The cross-hatched lines indicate its distribution in 1905, the slanting lines its range in 1918, and the horizontal lines its extension at the present time.

history of this introduction is extremely interesting for it shows that such insects can be exterminated even though already firmly established. The New Jersey in-

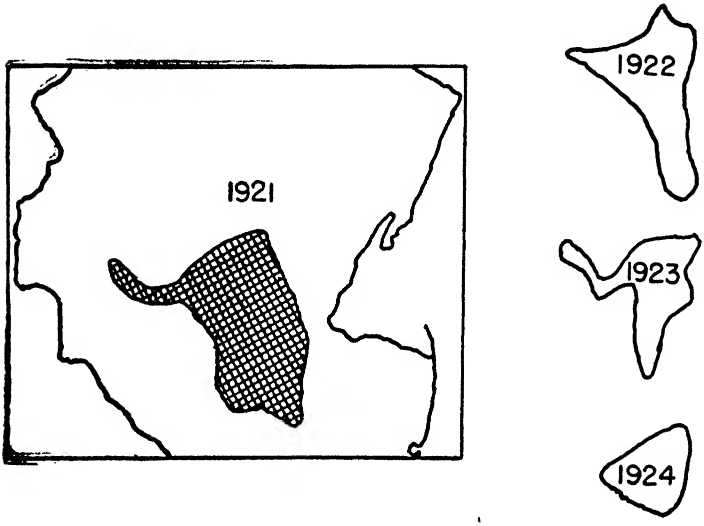

FIG. 14. Progress of the work to exterminate the gipsy moth from New Jersey. In 1920 the infested area included four hundred square miles. After a year's work in 1921, the abundance of the insect was greatly reduced, but the area of infestation (shown by the shaded area) was not appreciably reduced. In 1922, 1923, and 1924 rapid progress was made, and by the end of the decade no gipsy moths remained.

festation embraced an area of approximately four hundred square miles when discovered, and that year over eight hundred colonies were found, including all together more than three million egg-masses, which represented an expectation of about a billion caterpillars to hatch the next season. By the application of all available methods of destruction over the course of ten years the infested area was rapidly reduced in size and finally completely freed from the pest (Fig. 14). A similar, more extensive area in the mountainous region of Pennsylvania represents a more difficult problem, and it would appear that even in these days of glorified public spending the New Jersey experiment cannot be repeated here.

In Europe the gipsy moth has a number of insect parasites which serve to reduce its numbers greatly below those present in the infested American districts, although, as we have already seen, severe outbreaks in Europe are by no means unknown. In Japan the species is still less destructive, presumably on account of more efficient control by parasites. Since parasites capable of attacking the moth were practically absent in the American fauna, an extensive attempt has been made to colonize the Eurasian parasites on this continent. After this work had been well under way for about ten years, and after numerous technical difficulties had been overcome, a series of the parasites was successfully imported and liberated. Some of these proved to be of great value, and they have an important advantage over arsenical sprays and other methods of control in that they maintain themselves when once established without requiring repeated human effort with a lavish expenditure of money from year to year.

A large predatory European beetle (*Calosoma sycophanta*) which feeds upon the caterpillars has also been liberated in America, and has multiplied with astonishing rapidity.

Efforts have also been made to foster certain diseases of the gipsy moth caterpillars. Most important of these is one caused by a virus, but this spreads so rapidly and widely without artificial aid that efforts to propagate it are quite superfluous. Known as the wilt disease, this malady results from the growth of the virus in the nuclei of the cells in the fat body and other organs of affected caterpillars. These nuclei become hypertrophied and filled with microscopic polyhedral particles, then suddenly the whole caterpillar turns into a liquid mass or "wilts." In places where the trees have been defoliated the wilt disease commonly appears in midsummer, resulting in a very high mortality. Apparently identical diseases affect caterpillars of many kinds, but their etiology is difficult to elucidate and little is specifically known about them.

This method of control is particularly adaptable to forest insects, since the principle of annual rotation as applied to agricultural crops is impossible in the case of trees, and although long term rotation is possible, it does not bear the same relation in insect abundance. Spraying with arsenicals also is unprofitable, and not at all practicable except under exceptional circumstances. It appears, therefore, that control of forest insects cannot be undertaken along as many lines as that of agricultural insects, and from this point of view at least, forest insects present much the more difficult problem. Recent experiments with DDT for the control of the gipsy moth hold out a promise that this material may be adapted for use in dealing with many forest pests. Numerous difficulties remain to be overcome, however.

The relation of parasites to the abundance of the gipsy moth in America cannot, of course, be regarded as entirely similar to that existing in Europe, where the moth is native, and an inquiry into the parasitic control of this moth in its native home, or of any of our native insects, will reveal much more accurately the nature of the regulatory effect of parasites in the case of most of our forest insects. One common native insect enemy of deciduous trees closely related to the gipsy moth is the white-marked tussock moth (*Hemerocampa leucostigma*). This species is especially destructive to shade trees in cities. The caterpillars, which are familiar to nearly everyone, are beautiful objects, adorned with pencils of black and scarlet hairs, and with dense tufts of buff-colored hairs on the back. They are periodically abundant in most of our eastern cities, usually increasing in numbers for several years, and then rather suddenly almost disappearing, gradually to regain their previous abundance.

Some years ago Howard showed that the preparatory stages of the tussock moth are subject to attack by at least twenty-one primary parasites belonging to several different families of insects. These in turn fall prey to fourteen hyperparasites, which attack the primary ones and thus tend to reduce the numbers of the latter, although they do not prevent the destruction of the parasitized caterpillars in any case. There are two or three broods of the tussock moth each season, and, as has been noticed in the case of other insects having more than one brood each year, the first is less heavily parasitized than the second or later ones. This is probably due to a greater mortality during hibernation among the parasites than among the hosts, so that the host species usually shows a lesser degree of parasitism early in the season, but due to a greater prolificacy and rapidity of multiplication the parasites gain the upper hand later in the season, only to lose most of their advantage again during the hibernating months. When the host has been especially abundant one year, however, and thus permitted an unusual increase among its parasites, it may be very highly parasitized early the next season. Such a condition was noticed with the tussock moth by Howard in Washington in 1895 and 1896. During the season of 1895 this pest had shown an enormous increase and threatened the destruction of shade trees throughout the city. The third, or autumn, brood was very heavily parasitized, and on examining the pupae of the first brood during 1896 it was found that from 624 cocoons collected only 12 moths emerged, while from those remaining (excluding a few which had died of disease) no less than 916 specimens of parasitic insects emerged, indicating a mortality of over 98 per cent. This explains very satisfactorily the great fluctuation in numbers noticed with this species, as also with many other pests which gradually become more and more abundant from season to season for a number of years, and then suddenly suffer a setback, are greatly decimated, and become relatively unimportant for a number of years until they can regain their lost ground. When again very abundant, their parasites enjoy unusual opportunities for multiplication, and there is another abrupt decrease in the numbers of the host species.

Another species of moth, the American tent caterpillar (*Malacosoma americanum*), shows similar fluctuations. This is one of our very abundant apple pests in the eastern states, although its original and preferred food plant is the wild chokecherry. The caterpillars appear very early in the spring living in colonies, each representing the individuals hatched from a single egg-mass laid on a twig the previous season. They spin an ugly communal web in the crotch of a branch which is well-known and detested by all orchardists. These "nests" increase in numbers from year to year until it seems that they will envelop the entire countryside; then there is a sudden decrease one year and some ten or twelve seasons are required to regain maximum abundance. These cycles are due to a "build-up" of parasites and disease.

The condition just described is similar in a way to the outbreaks of other forest insects discussed earlier in the present chapter, but although the depredations terminate suddenly in both cases, their appearance is gradual in one instance, and quite without warning in the other. Possibly entomologists have only failed to read the signs aright, but it seems more likely that most extensive and unexpected invasions are due to other causes.

One interesting case of an insect enemy of deciduous trees, which closely parallels the condition seen with agricultural insects, is that of the locust borer (*Cyllene robiniae*), an enemy of the yellow locust (*Robinia pseudacacia*). The larvae of the locust borer feed within the sapwood of living trees, where they tunnel in the trunk and branches. This tree is native over a very restricted range along the Appalachian Mountains from Pennsylvania to northern Georgia, but has been planted over wide areas throughout the eastern states on account of its rapid growth and valuable timber, particularly suitable for railroad ties. The locust borer has spread with its host tree, and the thickly planted groves of locusts have offered such opportunities for the multiplication of the insect that the propagation of these trees has been abandoned in many localities where they might otherwise have been grown very successfully and profitably.

On the other hand, certain species of trees are much less generally susceptible to injury by insects. This is, of course, particularly noticeable in the case of introduced kinds that have been brought in without their natural enemies and have not proved attractive to the members of our native insect fauna. Notable among these are certain exotic shade trees such as the ginkgo and the ailanthus, or tree of heaven. The former is entirely unrelated to any of our native trees and the latter, now well-known as the "tree that grew in Brooklyn," has such foully malodorous foliage that few self-respecting pests will touch it. Another introduced shade tree, the beautiful Asiatic cork tree (Phellodendron) with delightfully aromatic foliage and berries, seems also to be immune to insect damage. Even some of our native trees like the sweet gum (Liquidambar) and certain oaks fare much better than others like the poplars, willows, and ash. Nevertheless, such generalized statements cannot be relied upon as infallible. For example, the introduction of the gipsy moth in New England has meant wholesale injury to the oaks of that region, whereas the rating of the ash has risen high since it is quite free from injury by the gipsy caterpillars.

The age of individual trees may exercise a considerable influence upon the amount of damage caused by insects. It may be stated, with few reservations, that where old or well-matured trees occur among very healthy and vigorous young specimens, the former are almost always more liable to attack. Thus from an entomological standpoint the felling and removal of the older and more mature trees in a forest that contains individuals of mixed ages is a very wise and satisfactory practice. Even though the younger trees are less readily killed by insects, their growth may be temporarily checked, and a part of the increment to the forest by rapid growth may be lost. However, if the fully matured trees had borne the brunt of the attack they would quite possibly have succumbed altogether, and have served in addition as breeding places for a much larger brood of insects to attack the remaining trees the next season. The relation which this bears to proper forest management is at once evident, for the utilization of mature trees or those which have ceased to grow at a satisfactory rate tends to eliminate the ones which should be removed solely upon entomological grounds. In this way the application of methods devised with little or no reference to insects is a procedure which the entomologist can heartily recommend.

Aside from the general preference exhibited by insects for the older trees in a forest, there are some species which select distinctly vigorous trees, saplings, or even seedlings, and these are not amenable to even partial control by the ordinary cultural methods. One of these, the white-pine weevil (*Pissodes strobi*), attacks saplings or small trees, and owing to its habit of killing the leaders or terminal shoots produces a deformation of the otherwise straight trunk of the white pine. A number of the weevil eggs are placed by the parent beetle within the tender bark near the tip of the tree, and the resulting colony of larvae work their way downwards beneath the bark. They usually pass the first lateral shoots before becoming fully grown, and destroy the part through which they have burrowed. Consequently one of the lower side branches must assume the place of the leader, and when it does the axis of the tree is displaced to one side. Commonly the same tree may be attacked several times in succession, and its value to the lumberman greatly lessened. When white pine is growing in dense stand the trunks of the trees that have been attacked by the weevil are less severely deformed. Isolated trees, on the other hand, have their trunks so badly bent and angled that logs suitable for sawing into boards cannot be cut from them. Such "pasture-pines" form picturesque objects to adorn the landscape, and fortunately they are not coveted by lumbermen.

In New England much attention has recently been given to the propagation of white pine, owing to the lessened supply of this valuable wood and to the fact that it appears to be the species most suitable to replace much of the hardwood timber that is being decimated by the gipsy moth and other insects. Suddenly in 1938 this region was visited by a tropical hurricane of great intensity which uprooted a very considerable part of the mature and semimature white pines over a wide path through Connecticut, Massachusetts, and further to the northward. A second visitation that occurred only six years later, in 1944, has made it very evident that this region is by no means immune to such destructive windstorms. As the pines suffered more severely than other species of native trees, the advisability of planting them extensively in New England is now highly questionable.

The white pine, both as seedlings in natural reproduction and in areas where small nursery-grown trees have been set out for reforestation, is often severely injured and extensively killed by a small beetle, *Hylobius pales*, the adults of which eat the succulent bark from the tiny trees. The preparatory stages of the Hylobius are passed in the stumps of the cutover areas, where their feeding causes no harm, but the voracious adults kill a large proportion of the seedling trees in the vicinity of their breeding places, and are thus a very important factor affecting the growth of the incipient white pine forest.

The saplings of certain deciduous trees also have insect pests which select them in preference to their older companions in the forests. The aspen and other poplars are frequently killed in considerable numbers by a wood-boring beetle of the genus Saperda. A single Saperda larva develops within the stem, producing a gall-like swelling which usually spells death for the young tree.

Thus far we have considered the forest, or the individual trees, as living plants whose successful growth, or even life, may be endangered by the presence of destructive insects. From a purely economic standpoint, however, the value of a forest is measured by the quantity and quality of timber which it produces, and it is perfectly true that the lumber in mature trees killed by caterpillars or bark beetles is not appreciably decreased in commercial value. From an esthetic standpoint there is a vast difference between a growing or a lifeless shade tree, but a forest tree killed by such insects as do not affect the wood is, *per se*, at the time of its death as valuable for timber as one felled for that particular purpose. There are two factors which modify such conditions. In the first place, such trees as are accessible and marketable are not necessarily those that are affected by insects, and the real loss depends upon what immediate use can be made of the timber. Following severe epidemics or invasions of insect pests, it is usually impossible to make prompt use of the killed trees and they begin to decrease rapidly in value. A case in point is the killing of spruce and fir by the spruce bud-worm, referred to on a previous page. The location of the areas affected was such that the utilization of the dead trees before they became worthless was utterly impossible due to the elaborate preparations required for logging on an extensive scale. This is, unfortunately, almost always true. Secondly, the deterioration of the timber in killed trees is due in great measure to the activities of many insects which will not attack living trees, but which follow in the track of various primary destructive agencies and reduce or utterly ruin the value of the trees as timber. There are many species of insects of this type present in comparatively small numbers in all forests, where they find a limited food supply in the scattered trees that have recently succumbed to old age, overcrowding, lightning, windstorms, etc. As these causes of death remain tolerably constant from one year to another, there is ordinarily no great variation in the insect population, which unites with saprophytic fungi in hastening the disintegration of the dead or moribund trees.

Any sudden destruction of trees furnishes extraordinary opportunities for an increase of these insects, and they consequently appear in a secondary wave following the outbreaks of such primary enemies as the Dendroctonus bark beetles mentioned on a previous page, or in the wake of severe windstorms, brush fires, and the like. For example, the pine forests of the Gulf states are periodically swept by violent windstorms embodying the unspent energy of West Indian hurricanes that have strayed to our coast. In such an event many trees are laid flat over extensive areas. A common, large, longicorn beetle known as the pine sawyer (Monochamus), which is widely distributed in this region, finds these trees excellent material, and its work soon becomes apparent. The beetles deposit their eggs in little pits which they excavate in the bark, and their large, succulent larvae tunnel the wood with their food burrows until it is unfit for most purposes. Outbreaks of this kind can, of course, be foreseen much more readily than some of the other type which we have referred to previously, but the damage they cause is no less severe and the application of remedial measures is frequently very difficult. Such an outbreak of Monochamus was foreseen in the New England area devastated by the 1938 hurricane. It failed to materialize, however, for the sudden superabundance of logs suitable for the development of these beetles was so great that there were not sufficient beetles to make much impression on the food supply. Since the young larvae can develop only in freshly-dead bark, the logs that lay over the first season were not later attacked, and consequently many perfectly sound logs were cut and sawed during the second winter following the hurricane. Many other logs that had been floated in ponds were, of course, also saved from injury, since the larvae cannot develop in water-soaked logs.

The distinction between those insects that affect the wood or bark of living trees and those occurring in trees recently dead is not to be closely drawn, and when much dead or dying timber is present in a forest it may furnish such favorable opportunities for the development of some species that the whole forest becomes endangered; for when thus produced in large numbers, many wood-boring or bark-beetles that live normally in dead wood may migrate to living trees and injure or destroy them. Such dead or decaying timber in a forest is thus a menace to the living tree population, through the part which it takes in the multiplication of insects that may on occasion affect living trees. Fire-scorched trees may in the same way be attacked by bark beetles and succumb where uninjured trees would not have suffered, and vice versa, insect-killed trees, especially in the case of pure coniferous forests, may constitute a great fire menace due to the more combustible nature of the lifeless trees after the bark beetles or other primary enemies have left them. There appears to be good evidence that some of the destructive forest fires which have occurred in the great coniferous forests of the western United States have been furthered by insects in this way.

An especially interesting example of a series of insect enemies that may follow one another in a tree as it passes from robust health into a gradual decline that ends in death is presented by several insects that affect the elm in New England. Since the history of the insects concerned is so well known and the sequence of events so clearly marked, I cannot refrain from considering the matter in some detail.

In the late thirties of the last century there appeared in America near the city of Baltimore a small European beetle known as the elm-leaf beetle (*Galerucella luteola*), which feeds upon the foliage of various elms. The adult beetles are especially attracted to the American elm. They deposit their eggs upon the leaves, which serve as food for the larvae. Two or three successive broods develop in a single season and greatly weaken the elms affected. The elm-leaf beetle has gradually spread till it is now present generally throughout the more temperate sections of eastern North America.

Many years later, in 1890, there was noticed on Long Island another European insect of very different appearance and habits, the leopard moth (*Zeuzera pyrina*). This insect is a large moth which in the larval stages feeds in the branches and trunks of a great variety of trees and shrubs. The parent moth deposits great numbers of eggs in the crevices of the bark, and the larvae on hatching migrate to the tips of the branches, where they enter small twigs. In these they construct small, circular burrows until they have increased too much in size to remain within the twigs. They then leave them to enter more commodious small branches, and may thus move into larger quarters several times before completing their growth. This requires two or three seasons, and the large caterpillars often partially girdle large branches or the trunks of small trees by tunneling transversely through the superficial sapwood and inner living bark. The leopard moth slowly spread along the Atlantic seaboard after its establishment on Long Island, and has proved itself to be practically omnivorous. One entomologist found it attacking over 150 different kinds of shrubs and trees. Although commonly found in many healthy and rapidly growing trees, it seems to be particularly attracted to elms that are not in prime condition. As a consequence it has found trees weakened by the elm-leaf beetle greatly to its liking and has followed the beetle very generally, reducing the vitality of the elms to a still lower ebb. At the present time the leopard moth occurs in America in only a very limited region from New Jersey to Massachusetts, but it is undoubtedly destined to cross the entire continent in the future.

Some years later a third European insect enemy of the elm was noticed in this country. This was a small bark beetle (*Eccoptogaster multistriata*) which made its appearance in the vicinity of Boston about 1906. Its habits are similar to those of the Dendroctonus beetles so destructive to coniferous trees, but the elm-bark beetle attacks only sickly trees or the dying branches of more prosperous ones. After the manner of many other bark beetles, large numbers of individuals commonly center their activities upon selected trees, riddling the inner bark with their burrows. Trees weakened by the leopard moth are very susceptible to their attacks and succumb rapidly. Where the beetles are not checked by preventive measures they may then destroy more healthy trees, especially small ones, which cannot withstand the onslaughts made by swarms of bark beetles. The elm-bark beetle has not yet spread far beyond the point of its introduction, but, like the leopard moth, will unquestionably extend its range by slow steps until it occurs generally throughout the United States.

From the preceding account it can be readily seen how the elm-leaf beetle, the leopard moth, and the elm-bark beetle naturally follow one another, and how they affect the conditions of the elms growing where they are prevalent. At the present time the only part of the country where all three insects occur is along our north-eastern seaboard, but there the havoc they have wrought is painfully evident. In Cambridge, Boston, and many surrounding towns that once boasted of many magnificent elms only pitiful remnants remain.

There is still another chapter to the story of the poor, sadly afflicted elms. A very malignant disease of elms in Europe is the Dutch elm disease, due to a parasitic fungus (*Ceratostomella ulmi*). The mycelium of this fungus grows beneath the bark of the trees, killing the branches and finally the entire tree. It is native to Europe, but was imported into our own country only a few years ago. First noticed near New York City, it spread out rapidly, particularly into neighboring parts of Connecticut. Although it may be disseminated in other ways, almost the sole method of infection is by spores carried on the bodies of the elm-bark beetle. When these beetles emerge through the bark of an infected tree they are contaminated by the spores of the fungus, and when they excavate their burrows in other trees, these are inoculated with the disease. Control of the Dutch elm disease is difficult and eradication practically impossible, so that it appears very probable that elms over a much wider area will soon be menaced by this newly-arrived alien enemy. Already it is spreading northward into New England and as far west as Ohio, Indiana and Iowa.

A condition of this sort is, of course, an extraordinary instance, for all three insects are introduced species freed from many of the handicaps that hamper their multiplication in their native land, but it illustrates most beautifully in an exaggerated form what is constantly taking place in our forests. Agricultural crops do not lay themselves open to attack by insects in this way since they are replaced by a new generation each succeeding year, and consequently their relations to insects are, in this respect at least, less complex.

Lastly, there is a type of injury by forest insects which closely parallels that mentioned in connection with agricultural products in storage. Stored lumber, and even that which has been fashioned into tools or furniture, is frequently damaged by insects which are capable of developing in extremely dry wood. These are, in the main, certain beetles characteristic of arid or desert regions that find a close approach to their natural environment in stored forest products. Their originally very limited distribution has been greatly extended, and they are becoming more or less cosmopolitan in range, establishing themselves as opportunity offers in places far from their native homes.

CHAPTER IV

HOUSEHOLD INSECTS

As a highly socialized animal, man has lived in communities since before the dawn of historic times. His relations with his fellows have continued to grow more complex, but the association of families into more or less permanent households is of such long and continuous standing that it has offered an opportunity for many insects to take up their abode with him. They have found an increasingly attractive environment as human communities have enlarged and become more thickly populated. Even the more modern residential abominations such as apartment houses, hotels, prefabricated dwellings, and house-trailers have failed to drive them back into their native haunts.

To the biologist this association is by no means strange, for it finds parallels among other social animals like the ants and termites. These gregarious insects almost invariably harbor in their nests various nonsocial insects, known as myrmecophiles and termitophiles, or simply as "guests." These latter insects are highly modified species showing peculiar adaptations for life with their social insect hosts. Some of the guest species are welcome, in that they are accepted by the ants or termites as legitimate members of the family. Others are recognized as nuisances, thieves, or worse, and live a seemingly precarious existence quite comparable to that of the rats, mice, or larger pests which make our own life miserable. The household insects associated with man are a very commonplace lot compared to the myrmecophiles and termitophiles, a condition due no doubt to the keener senses of the ants and termites in comparison with those of the human species, as well as to the comparatively smaller size of all insects in relation to man. It must be remembered also that our own household insect fauna dates back only a few thousand years, while the ants and termites perfected their social organizations at least during Tertiary times, probably more than fifty million years ago. Like the less highly adapted myrmecophiles, the tiny denizens of the human household live as tolerated or persecuted guests, for hardly any would be considered welcome additions by the ordinary person, no matter how fond he might be of dogs, cats, canaries, or other household pets.

Probably the most widespread and persistent insect visitor in houses is the housefly, named *Musca domestica* by Linnaeus in recognition of its then well-known habits. The housefly is probably a native of India, whence it has followed man to the most remote regions of the world. It invariably occurs where human communities become established, but it is so wedded to human society that it is never to be found elsewhere. Originally a native of the tropics, it can successfully overwinter in cold regions under the conditions brought about by civilization, for it finds places of sufficient warmth to enable it to withstand the rigorous winters of very cold climates. In cool regions it is never abundant in the spring, but due to its rapid development becomes increasingly numerous as the season progresses, again to disappear rapidly in the autumn. On account of its importance to public health, the habits of the housefly have already been considered elsewhere.

Many of us are familiar with the old saying that houseflies bite before a storm. Although responsible for many things, the housefly cannot bite, but the stable fly (*Stomoxys calcitrans*), a related fly of similar size and color with a sharp beak, is frequently mistaken for it. The stable fly also originated in the old world, whence it has spread almost as extensively as the housefly. It is a blood-sucking species, confining itself mainly to the larger domestic animals, which it torments during the later months of the summer season. It does not enter houses so commonly as the housefly, nor does it very frequently bite human beings. It bites more commonly in damp, sticky weather, and has thus given rise to the adage of the biting housefly.

Several of the larger, noisy, metallic green or blue flies that invade houses are species which live in the larval stages upon decaying animal material. They can hardly be classed as typical household insects. Our common species occur also in Europe, but are probably native to both continents.

Another very interesting fly which almost invariably appears on windows in the early spring of our temperate regions is the cluster-fly (*Pollenia rudis*). It is somewhat larger than the housefly and of lazy, awkward flight. These flies often occur in large clusters within window casings, entering for hibernation, and later seeking to escape through the glazed windows on the approach of spring. The cluster-fly lives in the larval stages as an internal parasite in earthworms.

A very abundant and annoying, tiny fly makes its appearance regularly in the latter part of the summer in most households, and frequently persists far into the winter. These little flies (Drosophila) live as larvae in decaying fruit, with which they may easily be introduced. Our common forms appear to have been brought here in fruits from the tropics, but their larvae will develop readily in the decaying portions of most fruits or even the less strongly acid types of pickles. The flies are very small and appear to come from nowhere almost instantaneously when overripe fruit is exposed. They are attracted to alcohol in any form, and it is the alcoholic fermentation of the fruits which attracts them. So overpowering are their inebriate tendencies that they will flock to an open flask of Kentucky corn whiskey, or even to wine or strong vinegar. Never having had experience with the more powerful condiments to which we ourselves have grown immune, under such circumstances they suffer prompt death by drowning. From a biological standpoint they are extremely interesting, for some of our most important recent discoveries concerning the mechanism of heredity have come from experimental studies of these tiny creatures.

Mosquitoes are very important from the standpoint of disease and have been referred to in considerable detail in a previous chapter. A few species may be regarded as truly domestic or household insects. Thus the house mosquito, *Culex pipiens*, native to Europe but now widespread in the temperate northern regions of both hemispheres, almost always breeds in close proximity to dwellings. The larvae occur abundantly in rain barrels, cisterns, and similar receptacles, and the adults enter houses with unusual persistence. In tropical countries the same is true of the yellow-fever mosquito (*Aëdes aegypti*) and the Filaria mosquito (*Culex quinquefasciatus*), both of which are truly domestic forms. Many other kinds of mosquitoes, especially the malarial forms, readily venture indoors, but this habit is much more pronounced and constant in the case of the ones first mentioned.

Several species of cockroaches or roaches have become closely associated with man and are now widely distributed throughout the world. These insects are particularly interesting in this respect because they belong to a group of insects of very primitive character which has existed with little change over long geological periods. One would not, therefore, expect to find the numerous present-day cockroaches very adaptive or versatile in their behavior. Nevertheless, several species have cast their lot with man since his advent, and have followed him in his wanderings. One of these, the small, so-called German roach (*Blatella germanica*) is especially widespread and abundant in the cooler parts of the Northern Hemisphere. In spite of its name, its association with mankind probably antedates the race to which it has been referred. From its probable home in the Far East it has spread westward, and reached America only at a very recent date. It was first noticed by the residents of New York City at the time the Croton aqueduct was put into operation, and was called by them the Croton bug on the belief that it had come with the water supply. This was a natural supposition, for these warmth-loving insects congregate in proximity to hot-water pipes or in warm or humid kitchens. The

Croton bug is the smallest of the domestic cockroaches and is even more agile than its larger relatives. Like them it is a very general feeder, consuming all sorts of animal matter, cereal products, paste, glue, bread, etc. All of our domestic roaches show their tropical origin in their inability to withstand cold, and their occurrence in cooler climates is restricted to heated dwellings.

Three of our larger roaches, *Blatta orientalis,* the oriental cockroach, *Periplaneta australasiae,* the Australian cockroach, and *Periplaneta americana,* the American cockroach are thought to have originated in the Orient, in Australia, and in the American tropics respectively, but have been widely distributed for so long that their provenience cannot be stated with any great assurance. All are much larger than the Croton bug, especially the Australian and American species, and they do not occur in such abundance in cooler regions. They find especially salubrious conditions on shipboard, particularly in the tropics, where they are almost always numerous in spite of attempts to eradicate them. Such being the case, it is easy to see how they have found migration easy. Abundant in almost every shop and house in cities of the tropics, in cooler climates they appear most commonly in places that are kept warm and moist. As they are especially fond of starchy and saccharine materials, bakeries, breweries, and sugar refineries frequently harbor them in large numbers, where they are a great nuisance. The repulsive cockroach odor and flavor which are often imparted to food soon become familiar to those who live or travel in tropical countries, and may sometimes be detected in sugar from northern refineries as well.

Not so far removed zoologically from the cockroaches, but of very different habits, is the familiar and cheerful cricket. These insects enter houses more commonly in the autumn and are far more regular visitors in the country than in cities. Their shrill chirping is an accomplishment of the male sex only. It is produced, like most noises made by insects, by rubbing together parts of the body with a rapid motion. In the case of the cricket each fore wing has a finely grained, rasping surface; when the two are opposed, a succession of jerky motions made by the cricket evokes the shrill notes, of far more penetrating quality than might be expected from such a small creature. Crickets remain torpid in cool weather but their activities readily respond to warmth, so that the appellation of the Cricket on the Hearth is quite appropriate.

The erratic, darting flight of several tiny species of moths that periodically appear in dwellings is always a signal of alarm to the housekeeper, since these clothes moths are well-known to every one both as winged insects and as the cause of moth-eaten garments. Quite contrary to most moths, these forms feed in the larval state not upon foilage or vegetable material, but upon wool, fur, feathers, and material of animal origin. Their eggs are deposited very generally upon articles of clothing made from such materials, and the tiny larvae may construct cases for themselves or ill-defined burrows lined with loose silk which they spin about them. There are several species, all rather closely similar, and probably of Eurasian origin. They are now widespread and closely associated with man. Undoubtedly under natural conditions the clothes moths were not abundant and lived a rather precarious existence, but they were well known to the ancients, whose crude garments suffered as do the highly tailored and garnished clothes of the present day. A few scattered instances are known of rather closely similar small moths whose larvae feed on the fur of living animals, such as sloths, and about the base of the horns of certain African ungulates. We may perhaps trace the habits of our clothes moths to some similar origin.

The larvae of several small beetles cause damage similar to that due to the clothes moths. They belong to a family of beetles known as the Dermestidae which feed very generally upon dry animal matter of various kinds. The entomologist can speak with great feeling upon the subject of these pests, for they show a great fondness for his collections of pinned insects, upon which they feed with great readiness. In households, carpets, rugs, and heavy furs frequently suffer. Two of the smaller species belong to the genus Anthrenus, and are minute beetles of mottled color. The larvae are succulent, bristly grubs extremely resistant to dryness and otherwise very tenacious of life. Their origin and habits are somewhat veiled in mystery; at least one of our species is of European origin, and the other is probably a native American insect. Their depredations have been particularly noted in the households of only certain of our cities, and, as the adult beetles are often abundant upon flowers far from dwellings, the larvae undoubtedly breed generally in the open. The beetles commonly appear on window panes in the spring in company with the somewhat larger brown *Attagenus piceus*, a related widespread insect of similar habits.

One of our most generalized and primitive wingless insects, known as Lepisma, is a common household insect. It is a long, tapering, scaly insect with three slender, thread-like appendages at the tip of the body, rather suggestive of a fish on account of its form and glistening coat and hence commonly called the "silverfish." The silverfish feeds upon glue, paste, or starch and will gnaw into wallpaper, starched clothing, or other objects containing such materials. It studiously avoids the light and is rarely seen till some object is moved, when it will dart toward shelter in a most agile fashion. At the present time these insects are widespread in Europe and North America, but when or how they became companions of man remains rather doubtful.

Certain powder-post beetles, referred to previously as destructive to stored wood products, occasionally make their presence in houses known in a very spectacular fashion through the collapse of a chair or other article of furniture in which they may have been present for a long time. Feeding in thoroughly dried wood, successive generations of these insects will completely riddle the interior of wooden articles, avoiding the surface layer, and thus giving no evidence of their activities until the material literally crumbles into dust when it becomes too weak to support the burdens imposed upon it. The so-called "death watch" is a related insect, whose deliberate and audible gastronomic process is responsible for the intermittent "ticks" upon which so much superstition has been based.

Some of the very destructive household insects are those that actually eat away the wood of which the house itself is built. Most important of these are various termites, of which there are many species in the tropics and a few whose range extends well into the colder temperate regions. In our own country they are abundant in the South, and one species, *Reticulitermes flavipes,* is common as far north as southern New England and the Great Lakes region.

Termites eat wood entirely and under natural conditions live in stumps, dead trees, and logs. They are social insects, usually nesting in the soil or in nests of their own construction above ground. Quite naturally they find a fine source of food in houses built of wood when the timbers are in contact with the soil. Under such conditions they burrow into the wood until it is honeycombed with small anastomosing cavities. Like the powder-post beetles, the termites do not break through the outer surface, so that they and the mischief they have done remain hidden till something gives way or collapses without warning. Consequently, extensive damage has frequently occurred before the culprits are detected.

Quite similar damage is caused to timbers, porch pillars, etc. by some of our large carpenter ants of the genus Camponotus. Unlike the pale, soft-bodied worker caste of the termites, the carpenter ants are dark-colored, active creatures that run about in the open during all hours of the day and night. Their burrows are larger than those of the termites and they do not use the excavated wood for food. This is chewed off in the form of fine sawdust and carried out next to the entrance of the nest, where it accumulates and gives mute evidence that internal trouble is brewing.

A few insects and spiders are attracted to houses, not by the human inhabitants, but by other domestic insects. These are much misunderstood creatures whose presence is usually incorrectly interpreted. Spiders are highly predatory, and although their webs may be unsightly, they serve greatly to reduce the numbers of flies. Other jumping spiders, which do not spin webs, are also adept at catching flies and exhibit no habits that could render them other than pleasant companions.

Although all spiders subdue their prey with poison secreted in their fangs or chelicerae, the bite of all but some of the large tropical tarantulas is only slightly painful, and they do not bite unless picked up and held in the hand. Among our common species there is one exception, however. This is the black widow (Latrodectus), a rather small spider with a shining, globular abdomen marked with a pale reddish spot. The venom of this small creature is far more virulent, in comparison with its bulk, than that of the poisonous serpents. It is a neurotropic poison causing widespread muscle spasm in the abdomen and other parts of the body, and in rare cases death has resulted from a bite inflicted by the black widow. They occur very rarely in houses, more frequently in outhouses, but fortunately they seldom bite. It has been recently found that administration of the drug prostigmine provides a highly satisfactory treatment.

Perhaps the most maligned visitors to our summer cottages are certain large hornets, which construct the intricate and wonderfully fashioned paper nests so familiar to most of us in our early youth as objects of awe and hatred. These hornets feed their young with flies which they capture for the purpose, and their errands frequently bring them to our dwellings, into which they occasionally enter. Contrary to much human tradition they do not ordinarily make use of their powerful stings unless grossly annoyed and their peaceful mission should never be doubted. Like all social insects they defend their nests and brood with great vigor and are no respecters of persons when their home is threatened. The hornets, belonging to the genus Vespa, are largely replaced in our southern states by other paper wasps known as Polistes. The larvae of Polistes are fed by the adults upon caterpillars of various kinds which are sought and captured by the wasps, to be chewed up and distributed to their brood.

Although the sting of these wasps is painful, only in the rarest of cases does it result in more than local irritation. However, occasionally a person may be sensitized by a previous sting and develop an allergy to the specific poison. A later sting then produces a true anaphylactic reaction of a very acute type, which must be promptly treated with epinephrine to reduce the edema and avoid serious consequences. Such cases are fortunately rare and quite naturally many physicians are not aware of their existence.

Many insects which overwinter in the adult condition find that they can avoid the rigors of the hibernating season by seeking shelter in houses. The majority of these are beetles. A variety of these creatures appear upon window panes in their search for a means of egress in the spring, and continuous observation will readily reveal the fact that some kinds are quite regular visitors.

Through his slow and tedious emergence from savagery, and undoubtedly from the much more remote stages of his evolutionary development, man has retained a small number of epizoic or external body parasites belonging to several groups of insects. The number of such insects affecting the human species appears to be generally less than the number of those affecting other mammals, and this may perhaps be due to the more cleanly personal habits which he has been able to acquire. If we carry the matter further back, however, to the stage of our as yet undetermined forebears, we find that the monkeys and anthropoid apes are also comparatively free from bodily insect parasites. It is possible, therefore, that we may have our much despised anthropoid ancestors to thank for this, at least. It is known that monkeys actively catch and destroy fleas and other parasites, but—if the whole tale must be told—they are eaten to insure their destruction.

Several of the groups of insects which include human parasites have already been mentioned as carriers of certain diseases. From this account it will be remembered that it is rather difficult to draw the line closely between true human parasites and other blood-sucking species that only rarely attack man. There are all sorts of intergrades between species like the stable fly or the common green-head fly of our seashore resorts, to whom human blood serves for only an occasional meal, and the body louse, which passes all stages of its existence on the body, upon which it is entirely dependent for food. Thus the females of certain mosquitoes suck human blood almost exclusively but are free-living creatures, and during their preparatory stages are aquatic. The human flea (*Pulex irritans*) is generally restricted to man as a host during its adult life, but its preparatory stages occur in accumulations of dry organic matter of other kinds. While this is the only flea peculiar to the human species, our domesticated dog and cat have fleas peculiar to themselves which have been widely distributed with these animals, and are common household pests in most parts of the world. Indeed, the fleas most annoying to persons in the United States are usually of the kinds regularly present on dogs, cats, or even rats, rather than the human flea, although the latter is a pest in certain parts of California.

Most closely dependent upon man are a couple of species of Cimex known as bedbugs. Although wingless like the flea and dependent upon human blood for food, during its preparatory stages, as well as in the full-grown condition, the bedbug is free-living. Strange to say, this insect does not appear to be responsible for the transmission of any specific disease. It has been under suspicion at various times but so far has not been definitely proved to be a disease-carrier.

No reference to household insects could be complete without some mention of the numerous species that gain entrance to dwellings through the medium of food and remain there in materials kept for future use. Some of these have already been referred to in a previous chapter as enemies of stored food products. As the household pantry is only a miniature storage place for varied food products, spices, miscellaneous drugs, and sundry other materials of plant and animal origin, its insect fauna is restricted only by the substances on hand and the rapidity with which those infested by insects are removed.

Certain ants are very annoying visitors to pantries, into which they wander from their nearby nests to feed upon and carry home the saccharine substances of which they are very fond. These ants are usually very small species and are especially abundant in warmer countries. They are extremely persistent in their search for food and are not easily discouraged. Occasionally the large carpenter ants mentioned on a previous page will seek out pantries in search of food, particularly at night. They are especially fond of fruits and jam.

Dry cereals of all kinds are particularly susceptible to injury by insects, and it is difficult to keep even small supplies free from such pests. Several species of small moths live as caterpillars in flour, meal, rolled oats, and natural breakfast foods, although they do not appear to be able to subsist upon some of the patent varieties. During the process of feeding they spin loose strands of silk which web the material together. If once admitted to receptacles containing suitable food, they pass through successive generations until the contents are completely destroyed. A great variety of beetles have similar habits, some preferring coarse materials, others the finer flours, or rice, etc.

Animal foods such as hams, dried meats, and cheese are frequently damaged by the larvae of certain beetles and flies which normally occur in carrion, skins, and similar substances. One of these, the cheese-skipper, is the larva of a small fly, *Piophila casei*, quite thoroughly domesticated as an inhabitant of cheese. Its name is derived from the power of the larva to skip or jump by bending and then suddenly straightening the body. If these larvae are accidentally swallowed they are able to withstand the action of the digestive fluids and may cause very distressing symptoms. The larvae of quite a number of other insects, mainly flies of various kinds, are also capable of remaining alive or even able to develop in the digestive tract, and others develop regularly beneath the skin of animals. Species known to affect man beneath the skin are very rare and restricted to the tropics, but two common species affect cattle in this way in Europe and North America and are the cause of considerable loss. Affections of this sort are known by the general name of myiasis. Human cases are fortunately of uncommon occurrence.

One of the most versatile of the pantry insects is the so-called "drugstore beetle" (*Sitodrepa panicea*), formerly of common occurrence in apothecary shops, where it fed upon the stores of spices, aromatic roots, red pepper, and ill-smelling or strongly flavored plant materials. The fondness shown by the grubs of this beetle for ginger and cayenne pepper is quite remarkable, for such substances would seem to be rather pungent for a regular diet. Even dry tobacco forms the favorite food of the related cigarette beetle (*Lasioderma serricorne*), the larvae of which sometimes riddle cigars with their food burrows. As these burrows rarely perforate the wrapper of the cigar, their presence is unnoticed until one of them is engulfed by the burning zone of tobacco. As the beetle grub explodes with a miniature puff of steam, the aroma of fine Havana is suddenly defiled by the odor of scorched fat, a substance with which the grub is well upholstered.

Even libraries, especially in warm, humid climates, are not immune to insect damage. A select *cotérie lit-*

téraire of insects displays its fondness for books by devouring them from cover to cover, including the bindings. They display little preference, other than to avoid heavily coated papers and to pick by choice musty old volumes. "Bookworms" include termites, the larvae of certain beetles, cockroaches, silverfish, and a few other lesser pests variously attracted by the paper pulp, paste, and glue incorporated into the books. Their special preference for antique volumes or first editions is probably due to previous invasion by molds which enhance their food value.

This is only a very small part of the varied series of insect guests which we house and nourish, and which add to the complexity of modern life. However annoying they may be, we must admire them for the persistence with which they force themselves upon us.

CHAPTER V

THE OUTLOOK FOR THE FUTURE

From even a most cursory examination of the activities of insects as they directly affect the human species it is very evident that insects are, as a group, highly injurious to man, although their influence in this direction is slightly tempered by a small number of species that are directly beneficial.

This is, however, a very unfortunate way in which to regard the matter, although it is a viewpoint that has been impressed upon the minds of many of us in early childhood. Starting with the assumption that all animals were created with reference to their usefulness to man, the old-fashioned pedagogue tried to fathom the depths of the divine mind and to ascertain in what way many obviously noxious insects might fit into this scheme. Less orthodox, but also unfortunate from the standpoint of biological understanding, is the still-too-common attempt to regard all living things as either useful or injurious to man.

Nevertheless it would seem that for reasons of expediency the entomologist must regard quite a considerable number of insects as falling into one or the other of these mutually exclusive categories, regardless of any consideration of the interdependence among different species, which he cannot formulate in exact terms. Following this a little further, it is clear that our practical dealings with insects are necessarily confined almost entirely to the eradication or reduction of the many species that are detrimental. These include primarily the great variety that spread diseases of man or of domesticated animals, those annoying to ourselves or to domestic animals, those destructive to agricultural crops and to useful wild plants, those detrimental to forests, and those injurious to stored products.

It is also clear from the foregoing chapters that scarcely any two insects may be dealt with most satisfactorily in exactly the same way. This difficulty imposes upon the entomologist the task of discovering in as great detail as possible the exact life history and economic relations of a vast series of insects, in order that energy may not be lost in the misapplication of control measures. The last few years have seen great advancements in our knowledge of this field, which have already borne fruit in the rapidly increasing efficiency of practical work. We can be sure that the near future will see rapid progress along these lines.

The now widespread custom of spraying plants for the destruction of insects has been made far more efficient through careful attention to the physical and chemical properties of the sprayed materials and their physiological effects upon specific insects. In the same way, fumigation with poisonous gases has been made more dependable. Various more or less fundamentally new methods of combating various insects are also continually coming into general use, usually through some ingenious application of physical or chemical knowledge to specific insects whose habits or physiological requirements at some stage of their life cycle lay them open to attack. Thus mosquito larvae may be eliminated by oiling the surface of the water in which they are developing, and housefly larvae may be prevented from completing their growth in manure by storing it in specially constructed pits. In the same way the chinch bug, cotton-boll weevil, alfalfa weevil, certain grasshoppers, cutworms, and a great variety of other pests are commonly controlled in rather unique fashions. In fact, the most efficient means of combating many insects are not at all conventional, even to the entomologist.

Collaboration between chemists and entomologists during the last few years, coincident with the recently concluded World War II, has resulted in discoveries of far-reaching importance relating to insecticides. Foremost among these is the introduction of DDT and several less widely known synthetic substances whose toxicity to insects far exceeds that of the insecticides previously in use. Although DDT is now in general use, we do not yet know very clearly just how far its future usefulness may extend, nor what its limitations may prove to be. Undoubtedly still more satisfactory substances will be produced, and we may look forward to revolutionary changes in our methods of controlling insect pests.

The same period has also seen the introduction of entirely new kinds of repellants to replace the former moth balls, camphor, naphthaline, and dichloricide, and ill-smelling cosmetics compounded of tar, citronella, and the like to frighten away mosquitoes. So far, these recently discovered repellants have been employed mainly against mosquitoes, black flies, mites, ticks, and other bodily parasites, especially those implicated in the transmission of diseases, but it is evident that we may expect their field of usefulness to be extended to many other types of insect pests.

The biological method of reducing the numbers of injurious insects offers at the present time one of the most promising fields in which to speculate concerning the future development of entomological practice. Much has already been said of the principles and details concerned in the introduction and furthering of diseases and of predatory and parasitic enemies in the induced natural control of insect pests. This method was devised as a direct result of an understanding of the biological environment of insects, and has been applied with the greatest success to the control of imported pests. With certain modifications it has also proved of use in dealing with native insects. Its possibilities have by no means been fully explored, although it is continually receiving more attention. There is no doubt that this work will continue to advance, in our attempts to modify permanently the conditions that are met by insect species imported into new regions.

The use of vegetarian insects to reduce the abundance of noxious weeds is another practical application of entomology which holds considerable promise. A weed has been defined as a successful plant, and the majority of them, like our most successful insect pests, are introduced plants which have become naturalized in the absence of the natural enemies and diseases which beset them in their native habitat. The application of the biological method to the control of weeds and other undesirable plants is exactly the reverse of that just described in dealing with insect pests. Insects destructive to the particular plants must be introduced, colonized, and allowed to feed and multiply at the expense of the weeds which it is desired to eliminate.

Great success has attended the application of this method in some cases, notably in destroying the American prickly pear cactus in Australia, where it had taken possession of vast areas of agricultural land. Great danger attends the use of this method unless the food habits of the insects concerned are fully known without the shadow of a doubt and it is certain that they cannot be potential enemies of crop, garden, or other desirable plants.

The rapid and continual influx of new insect pests into countries like our own that enjoy extensive commercial intercourse with other parts of the globe will undoubtedly continue in the future, and the specific problems of the entomologist will become more international in their nature.

Practically all of the barriers to the dispersal of small animals, like insects, that existed when living things reached their present state on the earth have either been removed or made less certain in their action. Mountain ranges and deserts have been bridged by highways, over which a continuous stream of humanity and materials is passing, bringing with it everything that can make the comfortable journey. Oceans, the most effective natural barriers, are crossed in all directions with cargoes containing many things not listed on the purser's books. Finally, airplane travel has made long journeys a mere overnight jaunt, not to mention the almost unlimited opportunities for unscheduled landings in a great variety of environments. In short, there is endless opportunity for small living things to migrate to all quarters of the globe. Even tropical insects find in the human communities of cooler lands opportunities to live under climatic conditions which they could not otherwise withstand.

Such migrations of insect life have, of course, been in progress for many years, and their economic significance has long been realized. Gradually, in various parts of the world, legislative measures have been enacted aiming at a restriction of the opportunities for noxious insects, weeds, and for animal and plant diseases to gain entrance to new regions. These are naturally modeled after the quarantine measures taken to prevent the spread of human diseases. They have been effective in great measure in preventing the rapid spread of insects, although, in the nature of the case, they could never be absolute without abolishing all commerce. In proportion to the actual efficiency of the quarantine service and the difficulty of inspection, which naturally vary within very wide limits, the spread of insects has been impeded. In many cases the importation of certain plants and products has been prohibited. This has been done because the most general method of spread for agricultural, horticultural, and forest insects is upon the host plant, and one of the more probable dangers is thus removed insofar as it is possible to exclude the specific materials. Whether the wholesale exclusion of food plants or their adequate inspection is to be preferred from a practical point appears to be rather a question of opinion. So far as the ultimate result is concerned it matters little, for the immigration of undesirable insects will take place only with greater difficulty and at a slower rate as human ingenuity is pitted against a seemingly hopeless problem.

There is, however, a bright side to this picture. Several instances have been mentioned earlier in this volume of introduced pests that have actually been exterminated after becoming well established. Although the expenditure of money and labor required for undertakings of this kind may seem exhorbitant, there can be no question that the elimination of the gipsy moth from New Jersey, of the Mediterranean fruit fly from Florida, and of *Anopheles gambiae* from Brazil were all well worth the cost. Moreover, these accomplishments have amply disproved the generally accepted view that such attempts are doomed to failure.

What surprises the entomologist more than the introduction of so many insect pests into our own country is the fact that more have not established themselves. It is evident that many insects do not become naturalized so easily as might be expected, and that when once well established some of them spread very slowly. This is evidenced by the long time required by the gipsy moth to become abundant at the point of its introduction in New England and the subsequently deliberate extension of its range, even before adequate control measures were inaugurated. Quite probably it now occurs in many isolated places far outside its recognized range, but the spread of this species and of the brown-tail moth has been extremely slow in comparison with other imported species like the cabbage butterfly and the Colorado potato beetle. Such differences are partially, but not entirely, explained by the naturally migratory habits of certain species, and they may be dependent also upon the ease and rapidity with which some species become established in isolated localities.

So far as the interchange of insect pests between Europe and America is concerned, the New World has decidedly played the losing game. Whether this has a biological basis is doubtful, for undoubtedly the more thrifty and painstaking European peoples have scrutinized more carefully the things which have been received into their domain. On the other hand it is quite possible that the fauna of the palearctic region may impose a more severe struggle for existence upon newcomers from our region than occurs in the inverse direction. At any rate, America seems so far to have received more undesirable insects from abroad than has Europe.

The most promising outlook which the entomologist can enjoy arises from the decreasing prevalence of several of the more important insect-borne diseases. Through his efforts, coupled with those of medical investigators and sanitarians, really wonderful progress has been made in the reduction and restriction of malaria, yellow fever, plague, and typhus fever. The future will undoubtedly see still greater activity along this line. One must not suppose, however, that the medical entomologist need not expect to receive setbacks at any time, or to have new problems thrust before him. Certain disease-bearing insects may be expected to extend their range in the same way that other insects are migrating. On account of their close association with man, many of the insect carriers of human diseases are already very widespread, but many unpleasant surprises are doubtless now hidden in little-known parts of the world, whence they may spread without warning.

The actual extermination of disease-bearing insects is, of course, quite as difficult as that of other kinds. Where such species carry diseases peculiar to man, however, the elimination of human cases quickly results in the disappearance of the disease. Thus the yellow-fever mosquito, although still abundant in the coastal districts of the American tropics and even in our own southeastern states, becomes wholly innocuous after the human population is freed from the virus.

To a very considerable extent we can discount various dire predictions that a lusty crop of tropical diseases may become prevalent in our own country after the war. Such pessimistic views are in great part born of the superstition that the tropics are rampant with a plethora of dangerous wild beasts, reptiles, and insects, together with a continuous round of horrible diseases incomparably worse than those which beset the civilizations of temperate climates. This belief dies hard, but its death should be hastened by those of the younger generation who have seen much of the world during their service in the armed forces.

Man's ability to control animate Nature (aside from himself) has been immeasurably increased during the past half century and appears just at present to be sharply on the up-grade.

INDEX

INDEX

DATE OF ISSUE

This book must be returned within 3, 7, 14 days of its issue. A fine of ONE ANNA per day will be charged if the book is overdue.