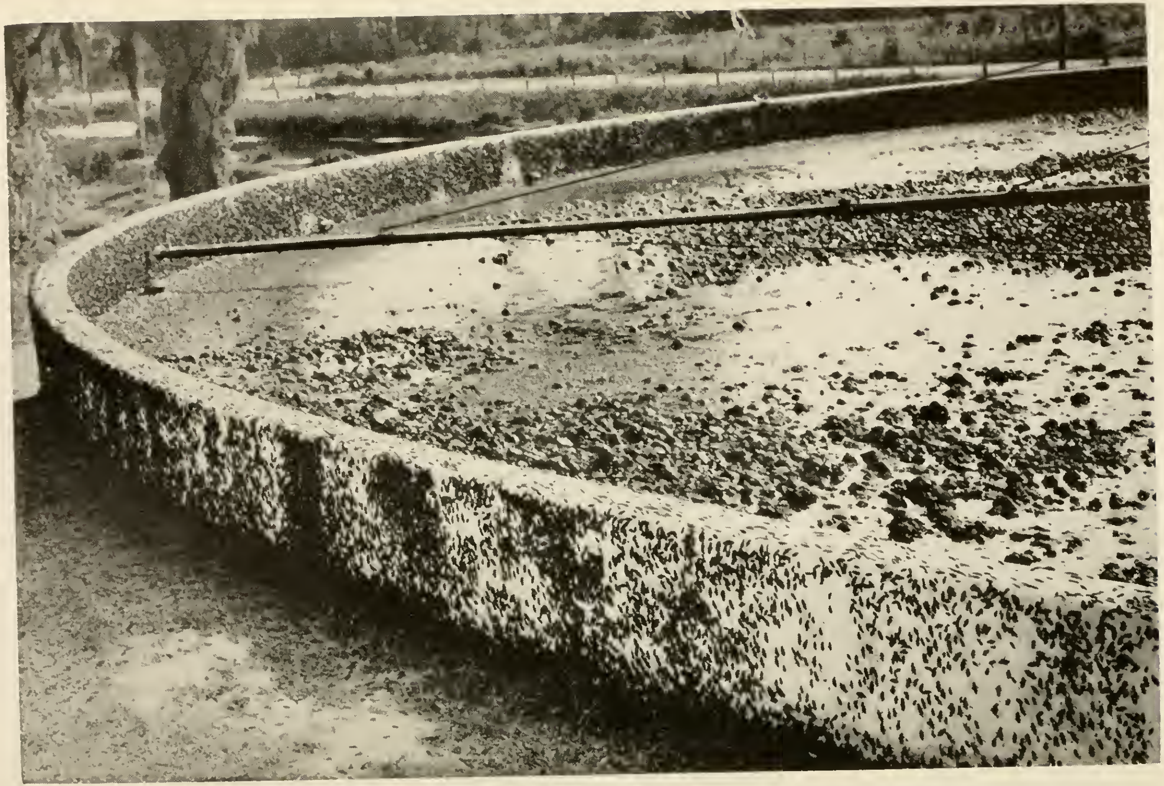

Cockroaches migrating out of a trickling filter at the University of Florida sewage treatment plant during the process of flooding. (See p. 12 for details. Courtesy of Division of Public Relations, University of Florida, Gainesville.)

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THE MEDICAL AND VETERINARY IMPORTANCE OF COCKROACHES

(With Seven Plates)

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FOREWORD

It is rare indeed that a reviewer finds that a publication completely changes his orientation to the matter discussed. In all honesty that was the end result of reading this detailed, comprehensive, and fascinating review of the relationships, both probable and possible, of cockroaches and disease.

Although the cockroach has long been the target of intensive control efforts in both the civilian and the military communities, my personal grudge against the insect has been based more on suspicion than fact. I would surmise that most physicians, like myself, have been influenced by the lack of emphasis on the disease transmission potential of the cockroach in most medical curricula. This review has corrected that deficiency. It has replaced a complacent acceptance of the insect as an unpleasant nuisance in areas of poor sanitation with a firm belief that greater attention must be placed on increased attempts to demonstrate, both in the laboratory and in the field, possible relationships between the prevalence of cockroaches and the incidences of certain diseases. Perhaps these insects have received less attention in this country than they have deserved. One could say the same for typhoid fever, smallpox, yellow fever, dengue, and malaria. The pronounced and sustained increase in the level of sanitation in the United States over the past one hundred years has relegated many diseases and disease vectors to a very low level of attention. It is only appropriate that the general medical population in this country should turn greatest attention toward problems of current domestic importance. On the other hand, the Medical Officer and related medical scientists of the Armed Forces must of necessity consider such problems in the light of conditions existing today in areas in which they may be required to serve. With complete candor I recommend this review to all who, in uniform or out, practice the art and skill of disease prevention the world over.

Lt. Col. Herbert L. Ley, Jr., MC
Research and Development Division, Office of The Surgeon General
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THE MEDICAL AND VETERINARY IMPORTANCE OF COCKROACHES[1]

By

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(With Seven Plates)

> As concerns the field of insect microbiology, we seem to have got ahead of ourselves in many respects. There has been very little effort to group our forces, so to speak, and for the most part the available knowledge and information is not properly known, organized, or appreciated.
>
> Steinhaus (1946).

I. INTRODUCTION

Since World War II there has been a resurgence of interest in the infectious agents transmitted by cockroaches, in the pathogens that survive experimental introduction into cockroaches, and in the dispersal of cockroaches from sewers. We realize that it is rarely practicable for investigators to scan all the pertinent literature or to bolster reports of experimental research with detailed accounts of related observations. Yet a thorough knowledge of all relevant material will always be needed in planning and evaluating future investigations. No previous publication has adequately summarized the background literature relating cockroaches and disease; in fact, some of the earlier literature and some contemporary foreign publications seem to have escaped notice. For these reasons, it has seemed desirable to survey the known relations of cockroaches to disease and to make the integrated results of the survey available for general use.

Because there is a voluminous literature on the transmission of disease agents by cockroaches, one might expect to find this subject well covered in current textbooks and reference books. Such is not the case. We surveyed about a dozen prominent books in the fields of

[1] Part of the cost of publication of this paper was borne by the Office of the Surgeon General and the Quartermaster Research and Engineering Center, Department of the Army.

medical entomology, parasitology, and preventive medicine to determine the extent to which this subject was covered. All the authors agreed that cockroaches are sanitarily undesirable because they are potential health hazards. Yet, generally, the subject was handled briefly and was based on only a few references.

Pierce (1921) devoted a chapter to disease agents transmitted by cockroaches, in which he summarized about a dozen papers published between 1900 and 1916. Riley and Johannsen (1938) indicated that cockroaches have long been under suspicion as carriers of disease organisms; they discussed the problem in about two pages with a dozen references. Neveu-Lemaire (1938) covered the subject in about three pages with a few incomplete references (only authors' names were cited). Rosenau (1940) summed up his half-page discussion of five references: "Roaches must therefore be regarded as a sanitary menace." Dunham (1940) flatly stated, "Roaches do not transmit any disease to man." Nevertheless, he admitted in the next sentence that they might mechanically contaminate food with pathogenic organisms. Herms (1939) devoted three and a half pages to cockroaches as carriers of infectious agents but stated no definite conclusions (six references and original data). Chandler (1949) cited cockroaches at least eight times, as prominent transmitters of disease agents. Matheson (1950) devoted a half page to cockroaches and human disease but concluded, ". . . nothing has been established of the importance of roaches in disease dissemination." Busvine (1951), in a half page, discussed the hygienic importance of cockroaches and concluded that ". . . the cockroach is less likely to carry infection than the common housefly, because, though its habits are equally unpleasant, its mobility is less." Martini (1952) devoted about three pages to cockroaches but very little to their relation to disease. Faust (1955) cited cockroaches as intermediate hosts of human helminths and mechanical vectors of several pathogenic organisms. The one current text most likely to counteract this almost universal lack of emphasis is "Insect Microbiology" by E. A. Steinhaus. Although he did not discuss cockroaches and disease as an entity, Steinhaus (1946) cited numerous instances of biologic relationships between cockroaches and micro-organisms.

In addition to the textbook authors cited above, several of the authors of experimental reports have concluded that cockroaches are vectors of disease agents; these are cited in section XV.

This review is a documented summary of the tangled relations between cockroaches and the organisms that cause disease in man and other animals. It directs attention to the impressive body of literature that incriminates cockroaches as actual or potential vectors of disease agents. Undoubtedly we have overlooked some of the literature; we have eliminated some reports that were too fragmentary to form a basis for conclusions. But we have attempted to cite the significant publications.

We hope that the information assembled herein will provide epidemiologists, sanitarians, and medical entomologists with both basic knowledge and a keener appreciation of the potentialities of common cockroaches as transmitters of the agents of disease.

To make the review easier to read, we have grouped the annotated lists of pathogenic organisms, naturally or experimentally associated with cockroaches, in appendices. The appendices contain the meat of our argument; they should not be overlooked.

> One of my native patients in S. Rhodesia always slept in the open, as he preferred to give up his hut to the cockroaches! He placed food there for them and slept outside undisturbed.
>
> MOISER (1947).

II. THE VECTOR COCKROACHES: THEIR HABITS, HABITATS, AND DISPERSAL

There are more than 3,500 known species of cockroaches (Rehn, J. W. H., 1951). J. A. G. Rehn (1945) estimated that less than 1 percent of the known species are domiciliary pests. However, we should point out that most species of cockroaches have never been implicated in the transmission of disease agents. The pest cockroaches, which are all more or less closely associated with man, are the only ones of proven medical or veterinary importance. The vast majority of cockroaches are presumed to be medically harmless; but it is well to keep in mind that, should any of these change their habits and become followers of man, they too may become as potentially dangerous as the known domiciliary species.

The following cockroaches have been incriminated, naturally or experimentally, in the transmission of pathogenic agents or have been claimed to bite man. The cited common names were taken from Rehn (1945) or Sailer (1955).

Scientific Name	Common Name
1. *Blaberus atropos* (Stoll)	....
2. *Blaberus craniifer* Burmeister	....
3. *Blaberus discoidalis* Serville	....
4. *Blaberus fuscus* Brunner	....
5. *Blatta orientalis* Linnaeus	Oriental cockroach

Scientific Name	Common Name
6. *Blattella germanica* (Linnaeus)	German cockroach
7. *Eurycotis floridana* (Walker)	....
8. *Leucophaea maderae* (Fabricius)	Madeira roach
9. *Nauphoeta cinerea* (Olivier)	Cinereous cockroach
10. *Neostylopyga rhombifolia* (Stoll)	Harlequin cockroach
11. *Periplaneta americana* (Linnaeus)	American cockroach
12. *Periplaneta australasiae* (Fabricius)	Australian cockroach
13. *Periplaneta brunnea* Burmeister	....
14. *Periplaneta ignota* Shaw	....
15. *Polyphaga saussurei* (Dohrn)	....
16. *Pycnoscelus surinamensis* (Linnaeus)	Surinam roach
17. *Shelfordella tartara* (Saussure)	....
18. *Supella supellectilium* (Serville)	Brown-banded roach

The habits of common, cosmopolitan species such as the American, oriental, German, and brown-banded cockroaches are so well known that we shall not expound them here, except to emphasize their relation to the dissemination of infectious agents. General information on the habits of cockroaches can be found in any current entomological textbook, in Mallis (1954), in Gould and Deay (1940), and in U.S.D.A. leaflet No. 144 (1950). Rehn (1945) gives an excellent account of the mechanism and extent of the world-wide dispersal of 11 domiciliary cockroaches, "man's uninvited fellow travelers."

Very little biological information has been recorded for most of the species listed above or for unlisted domiciliary species that are much less well known and which have not yet been implicated in transmission of disease agents. With the exception of *Blaberus atropos* and *Blaberus fuscus,* whose habits are unknown to us, the species listed are all domiciliary to some degree; evidence for this statement is given below.

Blaberus craniifer. This species is a household pest in Cuba (Deschapelles, 1939).

Blaberus discoidalis. This species is found in Ecuador in eating places as well as in patios and gardens (Campos, 1926). In Puerto Rico it may be found with *Leucophaea maderae* in fruit debris in stores (Wolcott, 1950) or in homes where, however, it is never abundant (Seín, 1923). Occasionally this species is introduced with tropical plants and it may become temporarily established in greenhouses in the United States (Hebard, 1917).

Eurycotis floridana. This species has been recorded from Georgia, Florida, and Mississippi, where it is found outdoors in sheltered areas such as stumps, under signs, and bark of dead trees (Hebard, 1917). Occasionally it enters houses (Creighton, 1954; Roth and Willis, 1954).

Leucophaea maderae. This is a widely distributed tropical and subtropical species (Rehn and Hebard, 1927). It frequents habitations, warehouses, and other structures, and at times is a very abundant and serious pest (Rehn, 1945). It is apparently of African origin (Rehn, 1937). Heer (1864) found that in Funchal, Madeira, this species is found mainly in houses, primarily in kitchens. During the day the insects group together in dark places and at night roam throughout the house and feed on material of plant origin. Wolcott (1950) considered *L. maderae* to be semidomesticated in Puerto Rico, where it is found most often in fruit stores and markets. Seín (1923) stated that it is not often found in homes but abounds in small inns and other places where fruit, particularly bananas, and vegetables are kept. This species has been reported as a household pest in the Windward Islands (Marshall, 1878) and the Philippines (Uichanco, 1953) ; it is definitely a domiciliary species in tropical regions where it is established, although it is capable of living apart from man in a purely wild state (Gurney, 1953). In New York City an infestation of this species was reported to be localized in apartment buildings occupied by migrant families from Puerto Rico; it is highly probable that the species was introduced from Puerto Rico (Gurney, 1953).

Nauphoeta cinerea. This is considered to be at least a semidomestic species. Rehn (1937) stated his impression that the species originated in East Africa and has spread throughout much of the Tropics along trade routes. He considered it to be a domiciliary species and stated that it occurs in the huts of the Shilluk natives in the Sudan (Rehn, 1945). It is found in feed rooms of poultry plants in Hawaii (Illingworth, 1942) and in grain stores and fowl-feeding pens in Australia where adults have also been found in dwellings (Pope, 1953). Mackerras and Mackerras (1948) captured this species in hospital wards in Australia (see p. 67). *N. cinerea* has become established in feed mills around Tampa, Fla. (Gresham, 1952; Ratcliffe, 1952; Gurney, 1953).

Neostylopyga rhombifolia. Hebard (1917) stated that this species is probably domiciliary with habits similar to those of *Periplaneta americana.* According to Rehn (1945), it is a domiciliary species of Indo-Malayan origin that has spread to Africa and the New World (Mexico, Venezuela, Argentina) through the inadvertent agency of man. It has been reported as a household pest in the Philippines (Uichanco, 1953).

Periplaneta australasiae. This circumtropical species (Hebard, 1917) is a household pest in the Philippines (Uichanco, 1953). Pope (1953) stated that in Brisbane, Australia, it is commoner in dwellings than *P. americana.* In Puerto Rico its habits are similar to those of

P. americana and *P. brunnea* (Seín, 1923). *P. australasiae* is generally domiciliary, but it also occurs in various outdoor hiding places in the West Indies (Rehn and Hebard, 1927) ; its habits are similar in Florida (Hebard, 1917). It is very abundant in tropical Africa and tropical America under domiciliary conditions (Rehn, 1945). In Ecuador it is one of the commonest cockroaches in kitchens and pantries of houses (Campos, 1926).

Periplaneta brunnea. This species is a circumtropical domiciliary pest that in this country is established in Florida, Georgia, and Texas (Hebard, 1917). "It is widely distributed in the American tropics and also those of the Old World, often occurring with *americana.*" (J. A. G. Rehn *in* Mallis, 1954.) According to Seín (1923), the habits of this species are identical to those of *P. americana* in Puerto Rico.

Periplaneta ignota. In Brisbane, Australia, this species is occasionally found in dwellings (Pope, 1953).

Polyphaga saussurei. This species appears to be one of the commonest domiciliary cockroaches in south-central Asia (Bei-Bienko, 1950). It apparently feeds on human feces, because human cestode eggs have been found in its intestine (Zmeev, 1936).

Pycnoscelus surinamensis. This is a circumtropical species whose range extends into subtropical regions (Rehn, 1945). In the United States it is established in parts of Florida, Louisiana, and Texas, and occasionally becomes established farther north in greenhouses or other structures that are heated during the winter months (Hebard, 1917). In Tanganyika it is sometimes found in enormous numbers in huts, infesting baskets of stored millet, African beer, or the remains of a meal (Smith, 1955). Uichanco (1953) cited it as a household pest in the Philippines. *P. surinamensis* is less likely to occur withindoors than under stones, boards, and other loose trash (Rehn, 1945). This species also burrows into the soil.

Shelfordella tartara. This common species of Central Asia is often found in houses having clay floors; it may be of epidemiological importance because of its domiciliary habit (Bei-Bienko, 1950).

In temperate climates domiciliary cockroaches tend to establish themselves in heated buildings, but during summer months they may breed prolifically out-of-doors. In tropical and subtropical climates breeding may occur outdoors or in unheated structures the year around. Cockroaches generally congregate in dark, sheltered areas that afford them suitable microclimates and easy access to food. Presumably it is the search for these amenities that results in the dispersal of cockroaches into new areas.

Being omnivorous, cockroaches eat practically every food used by man and his animals, as well as biological waste products such as garbage and sewage. Cockroaches are found wherever man stores or prepares food for himself or for his domestic, experimental, and exhibition animals. So from market to kitchen, laboratory, or zoo, cockroaches have ample opportunity to contaminate food that is not adequately protected. This contamination may be feces and vomitus, dead cockroaches, or disease organisms. Except for parasites for which cockroaches are intermediate hosts, the disease organisms are transmitted mechanically in the insect's feces, in its vomitus, and on its legs and body.

People living in civilized, highly sanitized areas rarely are aware of the truly tremendous cockroach infestations that may exist under poor hygienic conditions. Gal'kov (1926) cited conditions in mine-workers' living quarters in the Nizhne-Tagil district of the Ural region: "The cockroaches and bedbug population of the barracks was terrifying. Every crack in the doors and beams of the walls and ceilings, in the floor, the boards of the cots, benches, and tables were positively crammed with them. In the corners near the stove, the cockroaches covered the walls in a dense carpet." Lamborn (1940) emphasized similar conditions in Africa. Moiser (1947) reported that more than 2,500 cockroaches were trapped in one night in a wide-mouthed bottle, baited with cooked meal, that had been placed in an African native's hut.

Wolcott (1950) cited an infestation of *Leucophaea maderae* in a small fruit store in Puerto Rico where the owner cleaned out over a bushel of these cockroaches. Seín (1923) stated that in their hiding places, "hills" of Madeira cockroaches can be seen composed of individuals clinging to one another.

DeLong (1948) described the types of heavy cockroach infestations that may be encountered in supermarkets (i.e., grocery department stores). He had seen 100-pound bags of onions and potatoes in which the number of German cockroaches surpassed the number of vegetables. Hundreds of German cockroaches were found in balances and cash registers; behind the sloping mirrors used in back of the produce racks, German cockroaches ". . . may be massed several inches deep on the back of the mirror for the full length of the fluorescent tube." DeLong reported that the oriental cockroach is also common and numerous in supermarkets, where it hides during the day in cracks in the foundations, inside walls, under furniture, or behind cartons. At night this species is conspicuous on the floor where it feeds on available food. The American cockroach occasionally becomes a pest in supermarkets, but is of minor importance when compared with the other two species.

Mallis (1954) described conditions in a four-room apartment in Austin, Tex., in 1947. The cockroach population was estimated to be 50,000 to 100,000, mostly *Blattella germanica*. These insects were killed with an insecticidal spray, but within six months it was estimated that 15,000 to 25,000 German cockroaches had again established themselves in the apartment. Mallis (1954) also reported finding approximately 280,000 cockroaches in 177 apartments examined in four cities in Texas in 1947. Over 99 percent of these were German cockroaches.

Current literature on insect control indicates that, in spite of modern insecticides, cockroaches are a continuing problem in food-handling establishments: dairies (Adams, 1947; Gerlach, 1947; Gould, 1946); bakeries (Vincent, 1949); food and meat packing plants (Burke, 1944; Parker, 1948; Somers, 1951); mess halls and restaurants (Carpenter, 1944; U.S.P.H.S., 1952). Even food plants with an adequate sanitation program report new invasions of cockroaches from time to time (Clark, 1954).

Although there are specific differences in their behavior, many cockroaches show relatively little discrimination in their choice of food and habitat. This does not imply that all species are found in exactly similar locations, but only that all domesticated species may be found in both clean and dirty habitats, the latter being those in which disease organisms may be acquired. For example, cockroaches indiscriminately eat both the food and the feces of man and domestic and other animals. By feeding first on infected feces and later on food, cockroaches may readily effect the transfer of enteric parasites from animal to animal by the fecal-oral route.

Although Jennings and King (1913) reported that cockroaches will not readily feed on fecal material, other observers have found otherwise. Barber (1914) stated that in his experiments, *Periplaneta americana* ate human feces readily. Porter (1930) stated that fecal matter is highly attractive to cockroaches. Human feces were apparently the sole food of *P. americana* in mines in western Bengal (Chandler, 1926). Jung and Shaffer (1952) found experimentally that *P. americana* ingested about 0.1 gram of human feces at a single feeding. A photograph showing *Periplaneta americana* apparently feeding on human feces in a sewer manhole is shown in plate 4. These examples could be multiplied, but there is no doubt that cockroaches will eat feces on occasion and become carriers of pathogenic viruses, bacteria, and protozoa (see appendices). In fact, in nature it is only by coming in contact with or by eating feces that the insect can acquire intestinal parasites.

Mallis (1954) reported that a dairy in San Antonio, Tex., found its bottled milk contaminated with coliform bacilli. The contamination was traced to the bottle caps, and it was only after the bottle caps were stored where cockroaches could not enter that the contamination disappeared.

Cockroaches become contaminated with feces in sewers, latrines, privies, animal cages, chicken houses, etc. Monkeys, other zoo or laboratory animals, birds, and possibly man, may become infected by eating captured cockroaches. More probably, however, man would be infected by disease organisms carried onto his food or his person by cockroaches that have fed on or crawled over feces or some other source of infection.

Jettmar (1935) concluded from observations in Manchuria and Transbaikalia (Buriat Mongol Republic) that cockroaches were well suited to carry infectious material. He saw great numbers of *Blattella germanica* feeding on secretions flowing from the nostrils and mouths of corpses of persons that had died of lung diseases. These secretions were recognized as containing masses of infectious bacteria in almost pure culture.

Morrell (1911) cited sputum, pus, and decaying refuse as supplementary foods of cockroaches. In his experiments, he fed German cockroaches tuberculous sputum which they "devoured voraciously."

Antonelli (1930), while investigating two outbreaks of typhoid fever in Italy, found that *Blatta orientalis* frequented sewers and open latrines and migrated into the houses. Dow (1955) trapped *Blattella germanica* (or possibly *B. vaga* [R. P. Dow, p. c.[2]]), *Periplaneta americana,* and *Periplaneta brunnea* in outdoor privies in Texas in 1948. Paired traps were placed in both house and privy in the same yard. Greater numbers of *P. americana* were found in the privies than in the houses, but the opposite was true for the other species. *P. americana* was found in great numbers in latrines in Iran (Bei-Bienko, 1950). Cockroaches greatly favor latrine pits in Venezuela, also (Tejera, 1926). In Malaya the favorite breeding places for cockroaches are improperly sealed septic tanks and covered drains (Anonymous, 1939). Large populations of cockroaches are also found in septic tanks and cesspools in Java (Jan H. Vanderbie, p. c.). Bonnet (1948) stated that in Hawaii, *Periplaneta americana* and *P. australasiae* are frequently found in restaurants and homes, but can always

[2] p. c. = personal communication.

be collected just inside the tops of cesspools and sewer manholes. In Queensland, Australia, *P. australasiae* is usually found in homes, while *P. americana* is more prevalent in sewers and manholes (Pope, 1953).

In southwestern Georgia, *Blattella germanica* outnumbered all other species of cockroaches inside homes, but *Periplaneta americana* was most prevalent (99 percent) in sewer manholes (Haines and Palmer, 1955). Population pressure, it was concluded, may be a factor inducing movement from sewerage systems into homes. Haines and Palmer found that *Periplaneta fuliginosa* (Serville) was the most common cockroach in and around privies, but during the summer months the numbers of *P. americana* trapped in privies approached those of *P. fuliginosa*. What their data also show, but which these workers did not comment on, was that *P. fuliginosa* was, next to *B. germanica*, the most common cockroach inside homes. So far as we know, *P. fuliginosa* has not been examined for pathogens, yet its habit of frequenting both privies and homes suggests that such an investigation would be desirable. *Periplaneta brunnea* apparently was also trapped in significant numbers in both privies and homes during the warmer months of the year.

Gould and Deay (1940) stated that *Blatta orientalis* frequently migrates into homes through sewerage and drain pipes, but they cited no specific observations. Fair (*in* Rosenau, 1940) stated that for sanitary reasons the plumbing should be tight to prevent egress of cockroaches and other vermin that may find their way into the drainage system.

Eads et al. (1954) experimentally tested the ability of *Periplaneta americana* to pass through two common types of plumbing traps. American cockroaches were placed in a cage attached to one end of a P-type trap having the usual water baffle, similar to those used under sinks and wash basins (see photograph in Anonymous, 1953). Another cage was placed over the other end of the trap. In the first test, 1 of 16 cockroaches passed the barrier within 6 days. In a second test, 3 of 16 cockroaches passed the barrier within a few days. In another test, 49 cockroaches were caged at the lower end of a drum-type trap, of the kind used under bathtubs, that contained water as a deterrent. Within a week, 4 cockroaches had passed through the trap. This same information is given by Von Zuben (1955).

Gary (1950) noted that in Houma, La., the sewage lift stations had always been heavily infested with cockroaches; when the walls of the wet well were sprayed with insecticide, the men were almost driven out by the fleeing cockroaches. Gary instituted odor and cockroach control in the city's sewers by dosing the sewage at the heads of the lateral sewers with orthodichlorobenzene. The first day that the treatment was applied, the influent sewage carried a mass of dead cockroaches. Workmen also reported that when the dosing stations were put into operation, cockroaches were quickly driven out of cracks in the manholes. From the photograph accompanying Gary's article (see pl. 2), the cockroach was apparently *Periplaneta americana* or another species of *Periplaneta.*

In a recent personal communication, Dr. Theodore Olson has described a very heavy infestation of *Periplaneta americana* (pl. 3) which was found in the sewer system approximately 90 feet from the surface of the ground, under the University of Minnesota campus; this sewer receives wastes from a group of hospital buildings. Dr. Olson wrote us as follows: "When I first entered the area, roaches scurried away in all directions and in their haste many lost their grip on the ceiling. As a result we were unpleasantly pelted by a shower of scrambling half-flying insects picked up by the gust of air which was produced when we opened the steel doors between the tunnel and the sewer. By the time we returned to take these pictures not all of the roaches had yet returned to the area and the photo shows only a part of the total aggregation. The warmth from the heating tunnel undoubtedly attracted the insects to this area where humidity was right and food and water could be obtained readily. To us it is an interesting example of the heavy roach population which may develop even in the northern tier of states." An examination of plate 3 shows clearly that these insects were well established in the sewer; nymphs, recently molted individuals, adult males and females, and females forming oöthecae are visible.

Although most reports have implicated the American cockroach in sewer infestations, heavy infestations of the oriental cockroach have also been found in sewers in Bedford, Ind. (Anonymous, 1957): "People reported roaches invading homes and apartments from outlets in bathtubs, sinks and lavatories. Basements were heavily infested with 'water bugs' coming up through drains. Pest control operators were finding yards, walks and porches teeming with Oriental roaches at night." Heavy cockroach infestations were found in most sewer manholes. Inspections two weeks and a month after the manholes had been sprayed with 4-percent chlordane revealed a successful decrease in oriental cockroaches in premises.

Lohmeyer (1953) reported an extremely heavy infestation of cockroaches (identified as *Periplaneta americana* by Dr. L. A. Hetrick [p. c.]) in the standard-rate trickling filter of the sewage treatment plant at the University of Florida. This filter had been in operation for five years but had never been flooded during that time to control filter flies. The filter was finally flooded because cockroaches had been seen collecting on the outside walls at night. When the flooding water was within 4 inches of the top, the filter medium was covered with a mass of cockroaches so thick that the rocks were completely hidden (see frontispiece, pl. 1). When the insects were killed by insecticide, those removed occupied a minimum volume of over 2½ cubic yards; several times that quantity died in the adjacent woods. Contamination of cockroaches in trickling filters can probably be assumed. Fair (*in* Rosenau, 1940) stated that trickling filters remove 90 to 95 percent of the sewage bacteria. Obviously, more pathogenic bacteria are present in the influent sewage than are present in the effluent. Silverman and Griffiths (1955) state that the percolating filter is not a serious obstacle to the passage of helminth ova in sewage, and they cite experiments by others to prove this point. Hence, helminth eggs could also be a source of contamination to cockroaches residing within the filter bed.

Nelson (1952) reported that cockroaches were the most prevalent filth-carrying insects of San Tomé, Venezuela. They were present in practically every building under natural conditions of no control, and they were numerous in sewer lines as well: "Literally millions of roaches, crickets, and centipedes—not to mention rats—live in sewer lines and invade homes through connecting lines or overland. . . . Cockroaches overran the kitchen and dining hall; they hid under and in sugar bowls; they were sometimes found in soup and in food. The first treatment of the messhalls and other kitchen installations yielded an approximate half barrel of dead bodies, and it was impossible to walk across a floor without crushing hundreds of bodies."

Schoof and Siverly (1954) surveyed 22 sewer manholes in Phoenix, Ariz., for a 7-week period and found a weekly average of 92 to 143 specimens of *Periplaneta americana* per manhole. Jackson and Maier (1955) surveyed sewer manholes in the same city and found 300 to 400 *P. americana* in certain manholes.

Eads et al. (1954) reported that about 40 percent of 762 sewer manholes in Tyler, Tex., were found to be infested with *P. americana*. Four other species of cockroaches were also captured in the manholes: *Periplaneta fuliginosa* in 3 manholes, *Blatta orientalis* in 10 manholes, *Parcoblatta bolliana* (Saussure and Zehntner) in 1 manhole and *Parcoblatta pensylvanica* (DeGeer) in 1 manhole. Dr. R. B. Eads (p. c.) stated that *P. fuliginosa* has become a very common domiciliary cockroach over much of the State.

Of 67 sewer manholes examined in Austin, Tex., over 77 percent contained light to heavy infestations of *Periplaneta americana* (Eads et al., 1954). In Galveston, Houston, and Corpus Christi, Tex., Eads et al. (1954) found the American cockroach present in over 50 percent of the manholes inspected. They reported that similar conditions were found in other Texas cities.

Domestic cockroaches may live and breed in close association with their food, or they may move out of sheltered areas under cover of darkness and migrate to obtain food and water. Natural migrations of cockroaches have been observed only a few times. Probably migrations are common, but as they undoubtedly occur at night or other periods of low illumination, they have seldom been observed. Recent experimental studies, reported below, have been made in an attempt to determine the extent of cockroach dispersal from sewers. This field holds much promise and it is hoped that further studies will be made.

Dorsett (*in* Howard, 1895), on a dark, drizzly day, observed thousands of *Blattella germanica* issue from the rear of an old restaurant in Washington, D. C., and march directly across a muddy street to the building opposite. Several men with brooms were unable to stop the advance. Howard believed that this was a true migration brought about by overpopulation, as there was no evidence of insecticide being used in the restaurant.

Walden (1922) reported a heavy infestation of *Blattella germanica* in a dump in New Haven, Conn. At one edge of the dump this species was found in numbers under loose bark and in cavities in trees. Several specimens of *Periplaneta americana* were also found in the trees. The cockroaches were active at night and swarmed on nearby houses and street trees as far as a city block from the dump. Felt (1926, 1928) reported a similar occurrence in a city in the Hudson Valley, in which *B. germanica* multiplied in a dump to such an extent that it became a veritable nuisance to the neighborhood. Hansens (1949, 1950) stated that a dump in New Jersey was sprayed with fuel oil and set on fire in an attempt to control German cockroaches: "This treatment resulted in flights up to four blocks from the dump even though these insects do not usually fly. There are a number of other instances where fire has resulted in otherwise harmless and unnoticed cricket and roach infestations becoming municipal problems in a few hours." Many years ago in Austin, Minn., Dr. Theodore Olson (p. c.) witnessed a mass migration of *B. germanica* from a city dump to a relatively new sewage treatment plant approximately one-quarter of a mile away. "The insects completely overran the plant even penetrating the electrical conduit system. Later when certain electrical junction boxes were opened they were literally packed with dead roaches. The migration occurred just prior to the first snowfall, and shortly after the city council decided to discontinue the use of an open dump."

Gould and Deay (1940) reported that specimens of *Periplaneta americana* have been observed migrating from restaurants and city dumps on several occasions. In one instance these cockroaches migrated during the summer from store buildings three blocks away and established themselves in decaying trees from which they entered homes. Alfieri (1920) reported an extraordinary abundance of this species in depots and warehouses in Egypt from which both nymphs and adults migrated into habitations, especially during the night. Stenburg (1947) reported that inside treatment of houses with insecticide only partially reduced infestations of American cockroaches. But after an outside application of spray to incinerators, garbage disposals, garages, and outside lavatories, no further migrations into the treated buildings occurred. The Unionport section of the Bronx (New York City) has been "invaded" by hordes of flying cockroaches (Anonymous, 1952). According to Dr. Ralph Heal (p. c.), these cockroaches were *Periplaneta americana* which swarm out of the sewers each year and appear in the streets and basements of adjacent buildings.

Lederer (1952) for several years observed the *Periplaneta americana* that inhabited the zoo at Frankfurt am Main. The insects congregated in groups of 20 to 300 individuals in heated spaces. After dark they traveled extensively through the aquarium building in search of food, returning to their resting places by daybreak. During warm weather, the cockroaches spread to all parts of the building, but when cooler weather arrived they withdrew into heated areas. During warm, sunny days, individuals or small groups left the aquarium building and migrated to nearby animal houses which they colonized. Dispersion from aquarium to animal houses apparently occurred only with an increase in the cockroach population and in warm weather. However, dispersal within the aquarium building could occur with a limited population. On these migrations between buildings, *P. americana* occasionally flew distances up to 30 meters in fairly straight courses or in flat arcs about ½ meter to 1½ meters above ground.

Beebe (1951) observed a daytime migration of at least 30 individuals of *Blaberus giganteus* (Linnaeus) through the pass at Rancho Grande, Venezuela, at an elevation of 1,100 meters. The insects were flying in a compact group at 10 o'clock in full sunlight.

Kudo (1926) observed that at the University of Illinois, from March to November, *Blatta orientalis* crawled out of crevices at the bases of buildings in the evening and were found in large numbers on walls and lawns. Weinman et al. (*in* Shuyler, 1956) stated that this species is frequently found outdoors around homes during the summer months and can become exceptionally numerous in garbage and trash dumps. Spear et al. (*in* Shuyler, 1956) stated that in warm climates or during warm weather, the oriental cockroach may live outside buildings and feed inside the buildings. Shuyler (1956) reported a marked increase in the frequency of occurrence and duration of infestations outdoors in the temperate north-central area. He also stated that the yards of whole blocks of homes have been described as "alive" with oriental cockroaches on warm summer nights. Shuyler (1956) also observed that the German cockroach occurs, sometimes in large numbers, outside buildings.

Experimental studies of the dispersal of marked cockroaches have barely scratched the surface of this field. Porter (1930) released 10 marked *Blattella germanica* at Johannesburg, South Africa. Four were recaptured between 34 and 48 hours after release and at distances 105 to 360 feet from the release point. The remaining 6 insects were not seen again. According to Stenburg (1947), the sphere of activity of *B. germanica* in houses is quite limited; the insects seemed to move only short distances from their resting places and apparently always returned to approximately the same place.

Schoof and Siverly (1954) released 6,500 radioactive *Periplaneta americana* in four sewer manholes in Phoenix, Ariz., in October 1952. Marked cockroaches were recovered at three of the release sites for 8½ weeks. One marked specimen was trapped at a yard site 60 feet from a release point. There was no evidence that the cockroaches migrated either within the sewer system or into homes.

On the other hand, Jackson and Maier (1955), in a similar study in Phoenix in July 1953, obtained positive evidence of cockroach migration from sewers. When 1,200 radioactive *Periplaneta americana* were superimposed on a native manhole population of 300, 71 tagged individuals were recaptured during the next 15 days. One was caught in a kitchen 80 feet from the manhole. Five others were caught in yard traps at distances of 15 to 95 feet from the release site. In addition, 65 tagged cockroaches were captured in the sewer system adjacent to the release site at distances up to 350 feet from the release manhole. In another experiment, 500 cockroaches native to a manhole were made radioactive. Four tagged individuals were recaptured in 15 days of trapping, one in a yard trap 33 feet from the release point and three in a manhole 170 feet downstream. Similar results were reported earlier by these workers (Jackson and Maier, 1953, 1954).

Eads et al. (1954) observed the dispersal of marked *Periplaneta americana* from sewers in Tyler, Tex. Prior to the experiment, they had observed as many as 11 cockroaches per hour leave a manhole at night (pl. 5). In May 1953, 1,000 cockroaches were painted and returned to the manhole from which they were originally obtained. The first recovery of a marked cockroach was from an apartment house 6 days after the release. Within a 3-week period, 15 marked cockroaches were recovered from the same apartment house. So many other marked cockroaches were seen by the residents that they demanded that the manhole be sprayed to eliminate the insects. About 2 months after the release, one marked cockroach was taken in a grocery one block from the release site. After a second release of 1,000 marked cockroaches in another manhole, 5 were collected in a home adjacent to the release site. Four marked specimens were killed in a home 3 days after a third release of 1,000 painted cockroaches. A week after a fourth release, one marked insect was captured in a home.

It has been conclusively demonstrated that cockroaches do migrate from sewers into homes. Probably the extent of migration is much greater than recovery of marked insects would indicate. The marking technique is admittedly an insensitive method for measuring insect dispersal because so few marked insects are ever recovered. The problem is further complicated by the probable migration of unmarked cockroaches from the sewers between manholes. In the cited experiments, large numbers of unmarked cockroaches were trapped with the few marked individuals. If a means could be devised for marking all cockroaches within a sewer system, the extent of migration into adjacent dwellings would undoubtedly be much more readily apparent.

III. VIRUSES

Recent laboratory studies have shown conclusively that cockroaches may acquire, maintain, and excrete various viruses. Results of these experiments are described in Appendix A. Four unspecified strains of poliomyelitis virus have been found occurring naturally in wild-caught cockroaches. Four identified strains of poliomyelitis virus have been successfully inoculated into cockroaches with subsequent recovery of virus. In addition, cockroaches have also been experimentally infected with Coxsackie virus, mouse encephalomyelitis virus, and yellow-fever virus.

Natural transmission of viral diseases by cockroaches has not yet been proved, but the published data show that cockroaches are certainly potential vectors of viruses. The experimental transmission of poliomyelitis virus from *naturally infected* cockroaches to susceptible hosts has been a particularly significant finding (Syverton et al., 1952). These workers isolated four strains of poliomyelitis virus from four lots of cockroaches captured in two States on the premises of paralytic poliomyelitis patients. The cockroaches were the common domiciliary species: *Blattella germanica, Supella supellectilium,* and *Periplaneta americana.* This is apparently the first time cockroaches have been found contaminated with a virus in nature.

Insect vectors apparently are only accessory to the general mode of spread of poliomyelitis, which is still unknown (Howe *in* Rivers, 1948, 1952). The virus has frequently been recovered from house flies and filth flies during epidemics, but epidemics have built up and run their course during fly-control programs (Howe *in* Rivers, 1952). Epidemics continue into cold weather beyond the fly season, and people in clean suburbs with well-screened homes suffer to the same degree as those in slums (Howe *in* Rivers, 1948). Paffenbarger and Watt (1953) reported that fly-control measures which reduced the incidence of dysentery did not reduce the number of cases of poliomyelitis or affect the duration of an epidemic in Texas. They concluded that the major role in the spread of the epidemic was person-to-person contact between paralytic cases and susceptible hosts, directly or through an intermediary. Sabin (1951) concluded that the most important route in poliomyelitis infection is the spread from person to person by the fecal-oral route and that contaminated food or drink, whether by humans or flies, is an important mode of entry. Theoretically, transmittal of poliomyelitis virus by contaminated cockroaches could fit into all of these situations, perhaps better than house flies.

Cockroaches, being less obvious and less feared than flies, rarely are subjected to widespread eradication as have been flies. Cockroaches are no respecters of homes and may be brought into the cleanest with groceries, in cases of beer, or may enter by migration. Cockroaches, unlike flies, breed indoors the year around, a fact that makes them potential vectors in winter when flies are dormant. Obviously, much more work remains to be done before the role of cockroaches as possible vectors of poliomyelitis can be ascertained. Yet the finding of poliomyelitis virus in three species of wild-caught cockroaches (as opposed to laboratory-inoculated) suggests that a more concerted effort should be made to control cockroaches, as well as to determine their relation to this disease.

The Coxsackie virus may retain its virulence in the American cockroach for 15 days after being ingested (Fischer and Syverton, 1951a). The "C" viruses have been recovered in feces and from sewage in cities where Coxsackie infections had occurred, which suggests that cockroaches might be vectors as they have ample opportunity to acquire the virus in sewers.

Although Findlay and MacCallum (1939) reported that yellow-fever virus retained its activity when injected into the abdomen of *Blattella germanica,* they did not suggest that cockroaches necessarily play any part in the epidemiology of yellow fever. However, they point out that monkeys supplement their diets with insects and suggest that it would be of considerable interest to determine the natural animal foods of monkeys in yellow-fever areas. It would also be of interest to determine whether these monkeys could be infected with yellow fever by eating cockroaches that had been injected with the virus; this experiment apparently was not run.

We have found several records (e.g., see section on helminths, pp. 27, 95, 105) of monkeys feeding on cockroaches, but only the following reference indicates how cockroaches might acquire the yellow-fever virus in nature. Whitfield (1940) stated ". . . cockroaches are omnivorous, and no considerable employment of the imagination is necessary to see a possible connection between dead mosquitoes, excreta from other sick monkeys, and general detritus, etc., infected with the virus; scavenging cockroaches, and monkeys catching the cockroaches. The possibilities of such a cycle of infection are not confined to the laboratory, and it is reasonable to suppose that infection *via* the alimentary canal may possibly be a contributory cause of jungle or rural yellow fever."

Yellow fever is basically an infection of the hemapoietic system; during the first 3 days of fever, the virus is readily available to certain blood-sucking mosquitoes in which it must multiply for about 12 days before the mosquito can transmit it by bite. (Theiler *in* Rivers, 1948; Herms, 1939). Cockroaches have been known to bite man (see pp. 30-32), yet we do not know definitely whether they imbibe blood. Cockroaches have been known to gnaw on the extremities of dead and dying humans (Drury, 1782), but the virus has only once been isolated from a man dead of yellow fever (Theiler *in* Rivers, 1948). Cockroaches are known to feed on dejecta, but it has been conclusively shown that dejecta from yellow-fever patients are not factors in the epidemiology of yellow fever (Herms, 1939). There remains, of course, the unanswered question, can cockroaches be infected with yellow fever perorally? There would seem to be no other way in which they could become infected in nature. Findlay and MacCallum injected the virus into their cockroaches parenterally.

IV. BACTERIA

The evidence that implicates cockroaches in the transmission of bacterial disease agents is largely circumstantial. Yet much of the evidence is so persuasive that we find it impossible to accept cockroaches as only minor annoyances of little medical importance. Although papers that demonstrated natural and artificial contamination of cockroaches with bacteria began to appear in the last century (e.g., Cao, 1898), more papers on this subject have been published since 1940 than in all the years before. This gathering momentum can hardly be fortuitous.

The information relating cockroaches to transmission of pathogenic bacteria (Appendix B) includes isolation of bacteria from wild-caught cockroaches and experimental inoculation of cockroaches with bacteria in the laboratory. Both categories implicate cockroaches as potential vectors of infectious agents. The first class is particularly significant because it includes organisms that the cockroaches acquired naturally through their own activities. Certain bacteria that have been transmitted to cockroaches experimentally may be of lesser importance because under natural conditions these bacteria may be less accessible to the insects.

About 45 species of bacteria that are not pathogenic to vertebrates have been found in cockroaches. These are not discussed.

More species of pathogenic bacteria have been found associated with cockroaches than all other kinds of disease organisms together. Cockroaches have been found naturally contaminated with about 40 species of pathogenic bacteria; many of these have also been transmitted to cockroaches experimentally. In addition, over 20 other species of bacteria have been introduced into cockroaches experimentally. At least three species of bacteria did not survive in cockroaches; this latter figure does not include negative results with bacteria that were positive in other experiments.

The diseases caused by pathogenic bacteria that have been found occurring naturally in or on cockroaches include various generalized and specific infections, dysenteries, gastroenteritis, summer diarrhea, enteric fever, food poisoning, typhoid fever, plague, gas gangrene, leprosy, and nocardiosis.

Additional diseases caused by bacteria that have been transmitted to cockroaches experimentally include Asiatic cholera, cerebrospinal fever, pneumonia, diphtheria, undulant fever, glanders, chicken cholera, anthrax, black leg, tetanus, rat leprosy, and tuberculosis.

One of the most convincing examples of the transmission of a bacterial disease agent by cockroaches is the report by Graffar and

Mertens (1950) describing the role of *Blattella germanica* in the transmission of *Salmonella typhimurium.* These workers observed the following facts during an epidemic of food poisoning in the nursery at the Clinique Pédiatrique de l'Hôpital Universitaire de Bruxelles: 1. Persistence of an epidemic of intestinal infection of *Salmonella typhimurium* in spite of quick isolation of the patients, the absence of healthy carriers, and the suppression of infecting contact, direct or indirect, between the babies, with the exception of indirect contact through cockroaches. 2. Finding that cockroaches ran over the covers, clothing, and bodies of the babies at night. 3. Capture of a cockroach carrying numerous bacteria of the species *S. typhimurium,* in the vicinity of the babies. 4. Immediate check of the epidemic when the nursery was disinfected with DDT.

This epidemic prevailed for nearly 2 months in a nursery containing permanently 16 to 20 infants. Of the 50 children that passed through the nursery, 16 were contaminated with *S. typhimurium.* During most of the epidemic, cockroaches had not been suspected because they were not seen during the day. When the nursery was about to be closed, a night nurse called attention to the cockroaches. Thirty *Blattella germanica,* one of which was contaminated, were captured before the nursery was disinfected. It is highly significant that from the day the nursery was sprayed with DDT no more living cockroaches were seen, and no more cases of evident or hidden infections of *S. typhimurium* were detected.

Concerning salmonellosis, Watt (*in* Maxcy, 1951) stated that the case against arthropods as transmitters is circumstantial and the lack of direct evidence in itself indicates that insects probably play a minor part in the spread of human salmonellosis. However, the findings to date indicate that intensive control measures are warranted in any area where both cockroaches and *Salmonella* infections are prevalent and that strong efforts should be made to control these insects in hospitals and public eating places (Mackerras and Pope, 1948; Graffar and Mertens, 1950; Janssen and Wedberg, 1952).

In recent years, cockroaches as well as other insects have come under suspicion as possible vectors of the bacillus of Hansen's disease. Doull (*in* Maxcy, 1951) stated that the evidence for insect vectors in the transmission of leprosy is based on analogy and is largely presumptive. Simons (1952) strongly inclined to the view that the cockroach and the bedbug should be suspected, because leprosy is the pauper's disease and the vector should be an insect that is important in the lives of unhygienically living people.

Clinical evidence for the transmission of leprosy is conclusive

(Smith et al., 1948). Leprosy is not highly contagious and is probably acquired by infecting superficial abrasions of the skin (Freund and Middlebrook *in* Dubos, 1948). Although transmission is presumed to be from person to person, indirect transmission has not been disproved; in fact, Smith et al. (1948) cite three examples of indirect transmission of leprosy, one in which leprosy developed after an injection of leprous blood, and two cases in which leprosy began in tattooed areas about three years after the tattooing.

Moiser (1944, 1945, 1946, 1946a, 1947) observed that cockroaches in southern Africa bite savagely at night, leaving scars which in patients (Moiser, 1946a) at least, have repeatedly been found to contain Hansen's bacillus. This observation was anticipated by Lamborn (1940) who stated that cockroaches may on occasion feed directly on the leper. These findings, together with the data from field and laboratory studies of the relationship of several species of cockroaches with *Mycobacterium leprae,* warrant serious consideration (see pp. 75-77). Wilson (1946) points up the problem succinctly in his evaluation of Moiser's study: ". . . if the work of several observers, operating in widely separated districts, should establish the fact that micro-organisms resembling Hansen's bacillus are commonly found in cockroaches associated with human leprosy, and are not found in cockroaches generally, then the evidence of the association of leprosy with cockroaches would be strong enough to demand further investigation, and even to justify the instigation of preventive measures."

In 1954 Dubois reviewed the role of invertebrates in the transmission of leprosy. He cited only Arizumi and Moiser for evidence of cockroach transmission, although Macfie, Tejera, Lamborn, and Radna had all published supplementary observations prior to 1950. Dubois's main objections to accepting cockroaches as vectors are (1) that the exact nature of the acid-fast bacilli found in the cockroaches is not known (except by morphological appearance), and (2) the fact that cockroaches bite humans seems to be poorly established. These objections are sufficiently valid to deserve comment.

Man is highly resistant to experimental infection, and no other animal is susceptible to infection with human leprosy (Smith et al., 1948). Hence, it has not been possible to prove that the acid-fast organisms found in cockroaches are identical to *M. leprae.* Yet the isolation of bacilli that are morphologically similar to *M. leprae* from insects that have fed on leprous material is highly suggestive, especially when similar organisms are not found in control cockroaches (Lamborn, 1940). Moiser (1946) suggested that leprosy may be primary in the cockroach and secondary in man, and that the bacteria multiply in the cockroach.

Dubois (1954) cited the opinions of three individuals who stated that cockroaches do not bite man. One, an entomologist, was quoted as writing, "I have never heard nor read a statement to the effect that species of Blattidae bite human beings and if I did, would not believe anything so ridiculous." The biting of humans by cockroaches is discussed on pages 30 to 32. The biting habit is not characteristic of cockroaches, however, and is probably restricted to primitive areas with poor sanitation and heavy cockroach infestations.

Infection through cockroach bites alone need not be an essential mechanism in the transmission of leprosy. Moiser (1946, 1946a) contended that the bites or the feces of infected cockroaches are the real source of infection in leprosy. Wilson (1946) expounded this idea in suggesting a mode of infection analogous to the transmission of *Pasteurella pestis* by fleas: contaminated cockroach feces may be rubbed or scratched into the skin. Under primitive conditions, such contamination may be commonplace.

If cockroaches are entirely mechanical vectors of leprosy, they could conceivably transport *M. leprae* on their legs from leprous individuals to existing lesions in the skin of sleeping humans without either biting man or excreting the organism in the feces. There are many references to cockroaches climbing over the bodies and faces of sleeping children and adults, summarized on pages 28 to 30, in addition to the references on biting.

The Leprosy Research Department, School of Tropical Medicine, Calcutta (1948), has investigated the relationship of cockroaches to transmission of leprosy. The examination of cockroaches (species not identified) captured in a leprosy hospital and in other areas disclosed the presence of acid-fast bacilli in the gut contents of over 50 percent of 398 insects. These bacilli were morphologically unlike the leprosy bacillus and were not more numerous in cockroaches collected in the hospital than in those collected elsewhere. Cultures of acid-fast bacilli were prepared from the gut contents of six cockroaches. These workers, therefore, concluded that the acid-fast bacilli in captured cockroaches were not the leprosy bacillus. However, when leprous material was fed to a number of cockroaches showing no acid-fast bacilli in their feces on three consecutive days, acid-fast bacilli were found in the cockroach feces in decreasing number for two weeks thereafter. There was no indication that the ingested bacilli multiplied in the gut of the cockroaches. On this basis, these workers concluded that their work did not support Moiser's hypothesis that cockroaches may play an important role in the transmission of leprosy. Yet, in their conclusions, they ignore their successful experiments in contaminating cockroaches with leprous material which presumably was recovered as acid-fast bacilli for a period of two weeks following ingestion.

The possible transmission of leprosy bacilli by insects has not yet been exhaustively investigated, but until the epidemiology of leprosy is determined, cockroach control should certainly be encouraged in areas where leprosy is endemic.

Herms and Nelson (1913) found more *Micrococcus pyogenes* var. *albus* on the single pair of hind legs of the German cockroach than on the remaining two pairs of legs combined. They attempted to explain this heavy infestation as a result of the manner in which the cockroach uses its legs in walking; they stated, "The tibia and tarsi are in contact with the surface on which the insect walks, being parallel with the body. Very often the insect stands on the hind pair of legs, with the remaining legs barely touching the surface." Actually, during the normal walking process, the tibiae of the cockroach rarely touch the substrate and contact with the surface is made with the euplantulae, arolia, or claws, depending on whether the substratum is smooth or rough (Roth and Willis, 1952). Perhaps the difference in the size of the legs may be a factor in the greater number of micro-organisms found on the hind legs; the hind legs being larger than the others could harbor more bacteria. Jettmar (1935) found that, after *Blatta orientalis* had walked on a culture of hemolytic streptococcus, the cockroach transferred more of the pathogens mechanically from the hind end of its body than from its feet. This observation may be related to those of Herms. The cockroach cleans its abdomen with its hind legs, using them like a scraper or brush (Turner, 1913; Wille, 1920), and in this way could pick up more bacteria on its hind legs than on the others.

Cockroaches are naturally immune to many of the bacteria that are pathogenic to man. Most of the micro-organisms listed in Appendix B have no effect on the insects. In some instances, the numbers of micro-organisms decreased in the cockroaches and could not be recovered from the feces. McBurney and Davis (1930) concluded that *Salmonella typhosa* is either killed in the intestines of *Blatta orientalis* by some unknown agent, or its ability to ferment and to agglutinate is destroyed. On the other hand, Morischita and Tsuchimochi (1926) tested the sterilizing power of the intestinal contents of *Periplaneta americana*, as represented by a solution of feces. *S. typhosa* did not die even after 3 hours in this solution. Possibly this was too short an exposure. Wedberg et al. (1949) failed to recover *S. typhosa* from *Blaberus craniifer,* even though billions of the bacteria were fed repeatedly to these insects. Similar results were obtained by Janssen and Wedberg (1952) with *Blattella germanica* which failed to produce a single positive stool 24 hours after feeding on billions of *S. typhosa;* only 2 of 45 stools were found to be positive, and these were passed within the first 18 hours after the insects had fed on the pathogens. Jung and Shaffer (1952) concluded that, although *P. americana* appears to have some mechanism for eliminating many hundreds of ingested *Salmonella,* it may harbor certain strains for at least a week if it eats feces containing at least several thousand of these microorganisms.

Not all *Salmonella* decreased rapidly in the cockroach, however. Various species listed in Appendix B survived in the guts or feces of cockroaches for periods of 18 to 42 days, and on the pronotum 78 days (Olson and Rueger, 1950). Fecal pellets have remained infective for more than 4 years (Olson, p. c.; see p. 66).

The results of experiments with the vibrios of Asiatic cholera have been variable possibly because of differences in techniques of feeding the pathogens to the test insects (Akkerman, 1933). Some workers have reported a relatively rapid decrease in the number of microorganisms excreted (Toda, 1923). In *Periplaneta americana* most of the vibrios died in the foregut and Akkerman (1933) suggested that the degree of acidity that prevails in the gut may be harmful to the pathogens and have something to do with their depletion. Morischita and Tsuchimochi (1926) tested the sterilizing properties of a solution of feces from *P. americana.* The pH of the solution was about 6.7; it did not kill *Vibrio comma* within 3 hours. Jettmar (1935) claimed to have extracted a bacteriophage active against *V. comma* from the intestinal tract of *Blattella germanica.*

Periplaneta americana and *Leucophaea maderae* are relatively little susceptible to plague bacilli inoculated directly into the body cavity of these insects (Barber, 1912). Plague bacilli rapidly died or lost their virulence in the intestine of *Blattella germanica* (Jettmar, 1927).

Macfie (1922) failed to recover *Neisseria gonorrhoeae* Trevisan (cause of gonorrhea) from the feces of *P. americana* after the insects had fed on the pathogen. *Brucella abortus* (cause of undulant fever in man) does not remain alive in the intestinal tract of the American cockroach for more than 24 hours (Ruhland and Huddleson, 1941). Other negative results in feeding experiments are listed in Appendix B. The reader is referred to Steinhaus (1946, 1949) for a general discussion of immunity in insects.

The anthrax bacillus can multiply in the intestine of *Blatta orientalis* (Cao, 1898). Küster (1903) reported data suggestive of multiplication of anthrax bacilli in the gut of *B. orientalis*. There was an inverse relation between the number of days the anthrax bacillus remained in the cockroach's gut and the infection time in hours after injection into mice: 6 days/104 hours, 12 days/41 hours, 15 days/36 hours, and 16 days/24 hours. This is based on the assumption that an increase in the number of micro-organisms shortens the infection time. Cao (1898, 1906) found that certain bacteria (e.g., "Bacillo similcarbonchio" and "Bacillo proteisimile") isolated from the oriental cockroach were pathogenic for guinea pigs. Continued passage through the cockroaches and variation in diet increased the virulence of these and other originally nonpathogenic bacteria. Ekzempliarskaia (*in* Pavlovskii, 1948) also found that the virulence (to guinea pigs) of *Mycobacterium avium* and *Mycobacterium piscium* increased after the bacteria passed through the intestine of *Blatta orientalis*. Moiser (1946, 1946a) stated that *Mycobacterium leprae* is found in such numbers in cockroaches that have fed on leprous nodules as to suggest multiplication in the body of the insect.

V. FUNGI

Two fungi, *Aspergillus fumigatus* and *Aspergillus niger,* which are sometimes found associated with pathological conditions, have been found naturally in cockroaches. *Geotrichum candidum* was successfully inoculated into a cockroach, but *Histoplasma capsulatum* was not recovered in feces after feeding experiments. An annotated list of these organisms is given in Appendix C. These observations apparently cover the field. Yet a very large number of fungi are associated with insects (Steinhaus, 1946); for this reason, the dearth of information about pathogenic fungi that may possibly be associated with cockroaches is particularly surprising. This might be a fertile field for further study.

About 40 species (mostly Laboulbeniales) of nonpathogenic fungi and about 6 yeasts have been found on or in cockroaches. These are not discussed.

VI. PROTOZOA

Only four protozoa pathogenic to man have been reported to be associated naturally or experimentally with cockroaches (Appendix D), in contrast to many nonpathogenic forms. The pathogenicity of three of these, *Balantidium coli, Entamoeba histolytica,* and *Giardia intestinalis,* is unquestioned, but that of the fourth, *Trichomonas hominis,* is doubtful.

About 90 species of nonpathogenic protozoa have been found in cockroaches. Approximately half of these are found in the wood-feeding cockroaches, *Cryptocercus* and *Panesthia*. Although interesting, the nonpathogenic forms are beyond the scope of this review.

> It becomes more and more evident that eating roaches is a very bad habit for animals that habitually indulge in it.
>
> CHANDLER (1949).

VII. HELMINTHS

Cockroaches are known to harbor a fairly large number of helminths, some of which may occur as primary parasites of man and other vertebrates (Appendix E).

Next to the bacteria, the helminths form the largest group of pathogenic organisms transmitted by cockroaches. The eggs of seven species of helminths have been found naturally in cockroaches; eggs of five other species were passed unharmed through the guts of cockroaches and appeared in their feces. Cockroaches have been found to serve naturally as the intermediate hosts of 12 species of helminths and as the experimental intermediate hosts of 11 other species. Four doubtful records are listed and discussed. Attempts to infect cockroaches experimentally with three cestodes and five nematodes were completely negative. About 45 species of helminths that are primary parasites of cokroaches and not pathogenic to vertebrates are known. These are not discussed.

Some cockroaches have been found to serve as excellent experimental hosts in studies on the life histories of various parasitic worms (Hall, 1929). It is this ability to support the development of certain species of helminths, especially spirurids and acanthocephalids in nature, that makes cockroaches potentially dangerous. The development of species of *Gongylonema,* primary parasites of sheep, cattle, and horses, as accidental parasites in cockroaches is an example of cockroaches serving as hosts for worms that cannot depend on such hosts for transmission in nature (Hall, 1929).

The finding of *Protospirura columbiana* in rats killed in the National Zoological Park in Washington, D. C., but not in rats caught in other parts of the city suggested to Cram (1926) that the normal host of this spirurid may be a rodent other than the rat present in the park. Cram suggested that rats and cockroaches, commonly present in zoological gardens, may play a part in the dissemination of parasites not native to a country but brought into zoos with exhibition animals.

This belief of Cram's was vindicated by Brumpt and Urbain (1938, 1938a), who found that the acanthocephalids *Prosthenorchis elegans* and *Prosthenorchis spirula,* which in nature are found in monkeys, lemurs, and coati, were able to adapt easily to new hosts found in zoological parks. These worms developed there in the German cockroach which, though probably not a host in the forests where the normal primary hosts are found, was capable of maintaining and spreading infection in zoos.

The rat parasite *Gongylonema neoplasticum* occurs naturally in at least four species of cockroaches which serve as intermediate hosts. The work of Fibiger with *G. neoplasticum* in relation to rat cancer is of interest because for it he was awarded a Nobel prize in 1926. However, this work provoked a controversy of acclaim and criticism that has continued up to the present time. Fibiger (1913, 1913a) believed he had found a correlation between the presence of *G. neoplasticum* and the occurrence of stomach tumors in rats. The arguments about the importance of parasites in the production of cancer (see Anonymous, 1913; Sambon, 1924, 1926a; Simpson, 1924; Yokogawa, 1924, 1925a; Goyanes, 1926; Leiper, 1926; Oberling, 1944) have been resolved only recently. Hitchcock and Bell (1952), using *Gongylonema neoplasticum,* in carefully controlled experiments failed to produce acceptable malignant lesions in rats. They showed further that lack of vitamin A in the diet heightens the deleterious effect of the parasites; rats that were maintained on a diet deficient in vitamin A developed pathologic changes similar to those described by Fibiger. Hitchcock and Bell concluded that *G. neoplasticum* acts as a biologic, chronic irritant and produces only minimal effects on the forestomach epithelium in the absence of concurrent nutritional deficiency.

Sondak (1935) found cockroaches, captured in places where food was prepared in Leningrad, carrying normal eggs of *Enterobius vermicularis* and *Trichuris trichiura;* as a result, he concluded that the most radical measures must be undertaken to destroy cockroaches in places where food is prepared and served. He cited a 1930 report by Filipchenko and Dansker on conditions contributing to infection of communal eating places and children's institutions by eggs of parasitic worms of man. They had found eggs of *Taenia* sp., *Ascaris lumbricoides,* and *T. trichiura* on dining tables, chairs, benches, and even on dishes. Although admitting that fouling of these objects can be due to insufficient cleansing of the hands, Sondak pointed out that cockroaches, crawling through a dirty environment, can also be a mechanism for carrying eggs of these parasites.

Tropical hygienists must be strongly recommended to pay attention to the connection between cockroaches and eventual inexplicable cases of illness.

Akkerman (1933).

VIII. ALLERGY

Cockroaches have long been known to crawl over sleeping persons. As early as 1699, Lehmann (*in* Hennicke, 1761) reported cockroaches feeding on milk that had flowed around the neck of a newborn child. Vinson (*in* Hasselt, 1865) stated that it was not at all rare on Reunion (=Bourbon) Island for cockroaches to crawl over the faces of sleeping people, attracted there by the taste or odor of food or drink on the mouth or lips. Moseley (1892) observed that a large cockroach on board H.M.S. *Challenger* would sip moisture from his face and lips while he was dozing. In Brazil, H. H. Smith (*in* Marlatt, 1902) and his wife sometimes had to brush cockroaches from their faces at night. Rau (1940) noticed that, while he was sleeping in his laboratory, *Periplaneta americana* would crawl on his face and imbibe moisture from his nostrils. More recently, cockroaches have been seen in hospitals crawling on the faces of sleeping babies (Frings, 1948; Graffar and Mertens, 1950). In a personal communication about his original observation, Frings wrote as follows: "As to the matter of cockroaches crawling on infants—I saw this myself. . . . The incubators had a beautiful population of roaches which the pest control man I was accompanying was not allowed to go after. It was while watching the playful antics of these *Blattella germanica* that I noticed some of them walking around on the infant and actually feeding on a little bit of caked milk at the corners of its mouth." In addition to these observations, the numerous records, in the next section, of cockroaches biting man also imply that the insects crawl over sleeping persons.

The possibility of bodily contact with cockroaches is thus well established, particularly in tropical areas and even in temperate climates where control measures are not adequate. Small wonder, then, that certain skin diseases have been attributed to contact with cockroaches. Vinson (*in* Hasselt, 1865) noted that among the residents on Reunion there appeared a special blistery rash on the face about the mouth. This agreed with the condition known as herpes simplex (=labialis [Scott *in* Rivers, 1948]), but Vinson believed that the dermatitis should be called herpes blattae. He stated that, unlike herpes simplex, herpes blattae could be easily prevented by rinsing or washing the face before sleeping. He attributed the blister-raising properties to the cuticular grease or to a discharge from the mouths of the cockroaches.

Simons (1952) indicated that certain linear dermatoses in the Tropics are caused by secretions left on the skin by crawling insects and that cockroach dermatitis is one of these. An edema of the eyelids is also attributed to the cockroach. Simons (1952) also noted that in the Tropics, both East and West, a type of urticaria or edema is frequently attributed to the bite of the cockroach.

A recent personal communication from Mary F. Lerner, M.D., of Brooklyn, N. Y., is of interest. Dr. Lerner treated a patient who had severe generalized hives. The clinical history of this case follows: "In September, 1943, . . . I had occasion to move some cartons which had been there for over a year. An army of cockroaches appeared and I started to stamp on them. Two days later I started to itch all over and was covered with hives. Bathing in bicarbonate only exacerbated the condition. The doctor gave me adrenalin and that helped for four hours. No other medications seemed to help. This lasted four days. Then, when I started to get dressed it started all over again. When I removed my shoes and peds (which were the sames ones I had worn) the itch disappeared. The doctor told me to discard these shoes and peds and I never had a recurrence." Dr. Lerner stated that the hives and itching were controlled by the administration of adrenalin every four hours and a mixture of ephedrine and sedation repeatedly; the situation was not controlled until it was realized that putting on the shoes and peds, which the patient had worn while crushing the cockroaches, caused a recurrence of the hives and itching.

Certain species of cockroaches produce secretions which are stored in quantity in specialized glands and which may be irritating to man. For example, the adults of *Eurycotis floridana,* when disturbed, eject an aldehyde, 2-hexenal. This secretion is irritating to sensitive areas of the skin of some individuals (Roth et al., 1956). Recently, William and Anne Bunting of Yorkshire, England, experienced poisoning while cleaning out a culture container in which they kept *Eurycotis decipiens* (Kirby) from Trinidad. He (p. c.) wrote, "We both suffered from vertigo, running eyes, nausea; we were unable to face any food that day, and our tongues were yellow for twenty-four hours." He also observed that this cockroach is capable of ejecting the secretion a distance up to 3 feet.

Pavlovskii and Shtein (1931), in studying the effects of the bite of *Blatta orientalis* on human skin, noticed a degeneration of epithelial cells, necrosis, and inflammation which they attributed to a toxic effect of the insect's saliva. An emulsion of the salivary glands produced the same symptoms as the bite of the cockroach when rubbed into skin damaged with a sterile needle.

> A Kenya doctor was asked whether cockroaches bite. His reply was "Of course they bite! I can demonstrate half-a-dozen bites in my outpatients any morning."
>
> MOISER (1947).

IX. COCKROACH BITES

Whether cockroaches naturally bite man has been the subject of some controversy (see Dubois, 1954, and our discussion of leprosy, pp. 20-23). In areas where cockroaches are well controlled or where cockroach populations are not large, cockroach bites may be rare phenomena. In primitive areas that lack adequate insect control, and especially in tropical areas that support large cockroach populations, particularly in sleeping quarters, biting has been well documented.

Ligon (*in* Sloane, 1725) and Jeffereys (1760), describing conditions in the West Indies, stated that cockroaches entered beds and bit the sleepers. Catesby (1754) mentioned cockroaches scratching the faces of men and biting the greasy fingers of sleeping children. A similar occurrence was noted by de Azevedo Marques (1925); he also reported that in Brazil cockroaches gnaw on the fine flakes that collect on the skin covering the heads of sleeping people, on the substance that collects in the corners of the eyes, and on the feet. Drury (1782, 1837) stated that in the West Indies *Blaberus discoidalis* (=*giganteus* of Drury [Rehn and Hebard, 1927]) attacked people who were not sleeping under bed nets, that the sick and dying had their extremities attacked, and that the ends of the toes and fingers of the dead were frequently stripped of flesh. Hartnack (1939) reported that persons have been thought to be victims of crimes until it was found out, by accident, that skin defects had been caused by cockroaches feeding on the corpses. He also stated that the oriental cockroach may eat dead rats down to the skeleton.

Durie (1870) reported an instance of cockroaches nibbling off all of a toenail down to the quick. Nicols (1870) mentioned that sailors frequently complained of having their toenails and fingernails and the hard parts of the soles of their feet and hands nibbled by cockroaches. He also recounted a personal experience: "On returning from a shooting excursion in salt swamps in tropical Australia, with my feet blistered and sodden, I was put to sleep in a room swarming with cockroaches (the small species). The night was intensely hot, and my feet were exposed. I had slept soundly for some hours, when an intolerable itching and irritation about my feet awoke me. I felt these objectionable insects running over and gnawing at my feet. On striking a light, I found they had attacked the skin and entirely eaten it away from a large blister, leaving a raw place as large as a shilling. I slept again, and in the morning found they had completed the work, and established a painful sore. The whole of the hard skin of the heel was also eaten down to the pink flesh. The nails were not attacked. I have now, at a distance of four years' time, bluish scars on the skin." Kingsley (1870) confirmed Nicols's account, citing a similar experience of a friend who was "marked for life" by cockroaches on board a ship from Jamaica.

Webster (1834) also stated that cockroaches will attack the toenails of persons in their sleep. Smith (*in* Marlatt, 1902) observed that in Brazil the toenails were bitten off by cockroaches, and that in the house where he was staying cockroaches had bitten off the eyelashes of about a dozen children. Kellogg (1908) reported that ships came to San Francisco from voyages around the Horn with the sailors wearing gloves to protect their fingernails from being gnawed off by the hordes of cockroaches that infested the ships. Gates (1912) stated, "All of us who have been more than a short time in the naval service have had our troubles with roaches . . . and it is solemnly affirmed [that] even the toe nails of the personnel of the navy have long suffered from their ravages." Heiser (1936) mentioned that on board ship in the Orient, cockroaches gnawed off the passengers' corns. Bronson (1943) recounted the experience of a friend who was cook on a small West Indies schooner. This man awakened from a nap with his face sweating terribly. On looking into his mirror, he found that the cockroaches had eaten the galley grease from his face, taking off a layer of skin as well. Each night the cockroaches gnawed the calluses on the bare feet of the sleeping crew.

Gal'kov (1926), in workers' quarters at platinum mines in the Urals, saw a nursling child whose face, hands, and belly were covered with tiny wounds caused by cockroach bites. In another barracks a child's corpse which had lain exposed overnight had its face eaten away by cockroaches. According to the inhabitants of the barracks, cockroaches very often attacked sleeping persons, especially the women, biting the skin of their ears, face, and other places where the epidermis is thin. Moiser (1945, 1946) reported that cockroaches bite African natives savagely at night. Although he mentioned that

Blattella germanica and *Oxyhaloa buprestoides* (=*murrayi*) are common in Southern Rhodesia, Moiser did not specifically implicate these species as biting man. Moiser (1947) also reported that although he had never seen a cockroach in the act of biting, the African natives were well aware that cockroaches bite. Zimmerman (1948) reported that cockroaches gnawed on his feet while he slept on a copra schooner traveling in Fijian waters.

Rageau and Cohic (1956) stated that in heavy infestations, *Blattella* and *Periplaneta* would attack man (particularly nursing infants), nibbling the skin, especially at the ears, and gnawing at scabs, thus enlarging wounds. They observed exceptional cases of such attacks by *Periplaneta australasiae* and *P. americana* at Nouméa (New Caledonia) and received information from J. Guiart who reported a similar attack by *Blattella germanica* at Espiritu Santo (New Hebrides).

Lederer (1952) observed that *Periplaneta americana* fed readily on open wounds of animals in the zoo at Frankfurt am Main, Germany, but he did not imply that the wounds were cockroach bites.

According to Pospelow (1904; *in* Pavlovskii and Shtein, 1931), the bite of *Blatta orientalis* produces characteristic triangular patterns, particularly at the neck, chest, elbows, and feet, which are covered by dried blood crusts. Pavlovskii and Shtein (1931) experimentally determined the effect of the bite of *B. orientalis* on human skin. The insects were induced to bite skin moistened with sugar solution. The bite resulted in a slight pain and itching; 24 hours later, the bitten areas were covered with scabs. In these spots, the skin was destroyed almost to the corium. Damage to the epidermis was attributed to mechanical effects of the bite.

The positive act of cockroaches biting humans has been reported at least 18 times; there are undoubtedly other similar reports that we have not seen. Admittedly, many of the accounts lack the authenticity of direct personal observation, but even so, this body of evidence cannot be ignored. Most of the reports seem to be independent observations as there were no attempts to document the statements. Moiser (1947) even stated that he had found no references, other than his own, to the fact that cockroaches bite man. He also pointed out that African natives habitually live, cook, eat, store food, and sleep in huts that are heavily infested with cockroaches. We conclude that under such primitive, unsanitary living conditions, food-seeking cockroaches may incidentally bite man. (See also Sells, 1837, p. 132.)

X. ACCIDENTAL INVASION OF MAN

Kalm (1772), on his travels in North America, was told a first-hand account by a man whose ear had been entered by a cockroach while he was asleep. The experience was described as being extremely painful. The cockroach backed out of the ear canal after the man threw water into his ear. Baldwin (1906) described a similar occurrence in which a "kitchen" cockroach, a little over an inch long, had wedged itself tightly into the external auditory meatus. The patient complained of a "tremendous buzzing" in her head. The meatus was considerably reddened by the scratching cockroach. Stiles and Hassall (1928) reported two other cases of invasion of the ear. In the first case (attributed to Mader [1897]), a male patient who slept in a kitchen complained of ringing in his ear and headache. A dead *Blatta orientalis* was removed from the ear, in which it had been lodged for several days. In the other case, the invasion was attributed to *Blattella germanica.*

Sheard (1922) reported that while he was on shipboard in the Mediterranean his nasal passage was entered by a cockroach. He had experienced a slight fullness in the left nostril for about a day. After blowing his nose forcibly several times, he obtained sudden and complete relief by ejecting a full-grown cockroach from his nostril. The insect was quite dead and was enmeshed in a film of clear, tenacious mucus. Presumably the cockroach had crawled into the nostril while Sheard was asleep, possibly two or more days earlier.

Stiles (1918) received specimens of several nymphs and an oötheca of *Blattella germanica* purported to have come from an abscess of the jaw. A patient under observation in a hospital, with a large swelling under the angle of his left jaw, expectorated a bloody sputum. The oötheca and the cockroaches were apparently present in the sputum. However, it is extremely doubtful that the egg case was placed in the abscess by the female cockroach, or that the egg case and nymphs migrated through the abscess into the patient's mouth. A female cockroach may have dropped an egg case on the patient just before the eggs hatched or as they were hatching; the egg case and nymphs may even have been in the receptacle for the sputum before the patient spit.

Hennicke (1761) reported an invasion of a 1-year-old child, through the mouth, by cockroaches similar to *Blatta orientalis.* The infant coughed up one insect that was still alive and excreted another after being treated with a prescribed medicine.

Johnson (1899) reported that a nursling of 6 months, who showed symptoms of a toxic condition apparently of intestinal origin, had been invaded by cockroaches. About 2 hours after the child had taken a prescribed purgative by mouth, the father reported that the patient had passed 6 "cockroaches" and that the stools were of an extremely disagreeable odor. The floor of the room was overrun with cockroaches, and Johnson suggested that the insects had been attracted to the child's mouth by the sirupy cough mixture she had been taking.

> Cockroaches thrive in British Columbia. . . . On this trip I had them served to me in three different styles, alive in strawberries, a la carte with fried fish and baked in biscuit.
>
> CAUDELL (1904).

XI. COCKROACHES AS HUMAN FOOD

Inasmuch as cockroaches may harbor organisms pathogenic to man, it is significant that in some areas of the world these insects are eaten as food. The following summary includes only reports of cockroaches that were apparently consumed as food rather than as medicine; the medicinal uses of cockroaches are discussed in the next section.

According to Miall and Denny (1886), salted cockroaches were said to have an agreeable flavor which was apparent in certain popular sauces. This information was probably taken from Webster (1834) who noticed that ". . . common salt and water saturated with the juices of the cockroach had all the odour and some of the flavour and qualities of soy. . ." Dagen (*in* Melville-Davison, 1911) claimed that "shelled" cockroaches tasted like shrimp.

Bristowe (1932) saw a Lao at Hua Hin, Thailand, collect *Blatta orientalis* and *Neostylopyga* (=*Stylopyga*) *rhombifolia*. In that district and in Korat the Laos eat cockroaches, but in most districts they are not touched because they "stink." In all districts, children appeared to collect cockroach eggs [oöthecae] for frying.

The Australian aborigines eat cockroaches as well as other insects, and in some localities in China and Japan, *Periplaneta americana* and *Periplaneta australasiae* are eaten (Bodenheimer, 1951).

Brygoo (1946) reported that he had known a commandant of the colonial army who ate cockroaches raw with evident pleasure, joining the Kissi (a tribe in French Guinea) in this practice. He also stated that the more civilized Annamites (Annamese?) ate cockroaches only after they had been held in the fire. Coupin (1905) attributed the following recipe to Harris: A succulent dish is made from cockroaches simmered in vinegar all morning and then dried in the sun. The insects, freed of heads and intestines, are then boiled together with butter, farina, pepper, and salt to make a paste which is spread on buttered bread. He intimated that this concoction was appreciated by some Englishmen in London, and that cockroaches were eaten in Ireland also.

> Blatta (Grillon des fourniers) leurs entrailles broyees et cuites dans l'huile, sont bonnes aux douleurs d'oreille.
>
> MATTHIOLE, 16th-century Viennese physician, *in* Paillard (1942).

XII. COCKROACHES IN MEDICINE AND MEDICAL FOLKLORE

The folklore of medicine contains recipes for many strange concoctions that are reputed to cure divers ills. Hence, it is not surprising to find references in medical literature to the therapeutic uses of cockroaches. The effectiveness of most of these remedies is highly questionable and, as Caudell (1916) stated, their use may be based almost entirely on pristine beliefs and popular fallacies. Nevertheless, a summary of the relations of cockroaches to disease would be incomplete without a résumé of this pertinent literature.

Although not strictly a medical usage, it is interesting that in many European countries the cockroach was honored and respected and even considered to be a protector of life. It was therefore the custom to take some of these insects into new dwellings. In Finland cockroaches were allowed to live and multiply freely in many prosperous homes and they were not supposed to be killed, particularly by burning. (Rytkönen, 1945.)

Takahashi (1924) reported that the Formosans removed the head and digestive organs of *Periplaneta americana*, placed salt in the body, and then fried and ate the insect. This, they said, aided the digestive process. They also cooked the hard, dark feces of this cockroach as a medicine for their children. Ealand (1915) reported that this same species was used in homeopathy in Europe. Pliny (cited by Blanchard, 1837) advised mixing the entrails of "Blatta" with oil as a cure for various ailments. There seems to be some doubt, however, whether Pliny's "Blatta" was a cockroach; Blanchard (1837) cited the conviction of Latreille that it was a species of *Blaps*, a beetle. This identification is moot.

The diseases and disorders reputedly cured by cockroaches and the specific uses of these insects in medicine are listed below. We make no attempt to evaluate the medical worth of the recommended treatments. However, the use of cockroaches to treat certain diseases has received some clinical support. This usage will be discussed at the end of the following list.

Albuminuria.—See discussion.

Antihydropin.—The diuretic principle of the cockroach; see discussion below.

Antispasmodic.—Webster (1834), surgeon on H. M. Sloop *Chanticleer,* was told by Capt. William Owen, of the British Navy, that an infusion of cockroaches was a most powerful antispasmodic. "Marquart's Pharmaceutische Zoologie" also lists this use (Geiger, 1839), apparently using Webster as a source.

Arteriosclerosis.—See discussion.

Boils.—Pliny (*in* Blanchard, 1837) recommended crushed "Blatta" as a cure. "Merck's 1907 Index" lists an oily decoction of *Blatta orientalis* as an external treatment for boils. This and other uses taken from Merck (1907) are also cited by Illingworth (1915).

Bright's disease.—See discussion. The use of cockroaches as a cure is cited in "Merck's 1907 Index."

Cirrhosis of liver.—See discussion.

Constipation.—Sloane (1725) reported that the Indians in Jamaica drank ashes of cockroaches as a physic.

Diaphoresis.—Usage cited in "Merck's 1907 Index." See discussion also.

Diuresis.—See discussion. Usage listed in "Merck's 1907 Index." Recent publications still list the use of dried, powdered *Blatta orientalis* as a diuretic: (1) 16th revised edition of "Stedman's Practical Medical Dictionary" (Taylor and Taylor, 1946); (2) 22nd edition of "The American Illustrated Medical Dictionary" (Dorland, 1951).

Dropsy.—Usage listed in "Merck's 1907 Index."

Earache.—Dioscorides (*in* Blanchard, 1837) stated that the entrails of the Sylph (possibly a cockroach, according to Blanchard), when mixed with oil and put into the ear, cured earache. Pliny (*in* Blanchard, 1837) also stated that the fat of certain "Blatta," when ground with oil of roses, was very good for earaches. Paillard (1942) cited the use, by Matthiole, a 16th-century Viennese physician, of the entrails of *Blatta,* crushed and boiled in oil, for the treatment of sore ears.

Heart disease.—See discussion.

Indigestion.—Lafcadio Hearn, in the New York Tribune, January 3, 1886, reported that the Negroes in Louisiana used cockroaches fried in oil with garlic for indigestion (Weiss, 1925).

Influenza.—Clausen (1954) cited the following item from the New York Times, November 12, 1944. During an epidemic of influenza in Iquitos, Peru, one of the most commonly used remedies was an infusion of red Iquitos cockroaches steeped in pisco, a fiery Peruvian liquor.

Itching.—Pliny (*in* Blanchard, 1837) recommended crushed "Blatta" as a cure.

Nephritis.—See discussion.

Pericarditis.—See discussion. The powdered, medicinal form of *Blatta orientalis* was sold in Europe as Pulvis Tarakanae as a remedy for pericarditis (Ealand, 1915). Weiss (1947) cited similar information.

Peritonitis.—See discussion.

Pleurisy.—See discussion. Same cited information as for pericarditis (Ealand, 1915; Weiss, 1947).

Scabbing.—Pliny (*in* Blanchard, 1837) recommended crushed "Blatta" as a cure.

Scrofula.—Blanchard (1837) cited Pliny's statement that the "Blatta" with wings and feet cut off cured scrofula.

Sting-ray injuries.—Russell and Lewis (1956) list macerated cockroaches as one of the substances that have been used in the treatment of sting-ray injuries. They also state that "certain aborigines perfused the wounds produced by venomous fishes with the extracts of macerated cockroaches and fish livers." They suggest that the rather high concentrations of enzymes, coenzymes, and carriers related to the oxidative cycle within insect muscle might possibly influence changes provoked by a venom.

Tetanus.—Webster (1834) was told by Captain Owen that ". . . the infusion of cockroaches is useful in tetanus, and that his [Captain Owen's] surgeon in the Eden, Dr. Birnie, had used it with beneficial effect." Webster went on to state, however, that a Dr. Hall tried it at Maranham in a case of tetanus without beneficial results. This same usage is listed in "Marquart's Pharmaceutische Zoologie" (Geiger, 1839). Weiss (1925) cited the following item by Lafcadio Hearn in the New York Tribune, January 3, 1886: the Negroes in Louisiana used cockroach tea for tetanus, supplemented by a poultice of boiled cockroaches over the wound.

Tuberculosis.—See discussion.

Tumors.—Pliny (*in* Blanchard, 1837) recommended crushed "Blatta" as a cure.

Ulcers.—Pliny (*in* Blanchard, 1837) stated that "Blatta" is good for ulcers deemed incurable. Sloane (1725) stated that the Indians in Jamaica bruised cockroaches, mixed them with sugar, and applied the concoction to ulcers and cancers to cause them to suppurate. "Merck's 1907 Index" lists the external use of *Blatta orientalis* for ulcers.

Warts.—External use of *Blatta orientalis* is listed in "Merck's 1907 Index."

Whooping cough.—Webster (1834) stated that an infusion of cockroaches was used in Bermuda as an antispasmodic in whooping cough. "Marquart's Pharmaceutische Zoologie" also lists this use in Bermuda for choking coughs (Geiger, 1839). Radbill (1945) reported the following beliefs of the Nantikoke (Nanticoke?) Indians: As many cockroaches were secured as there were children affected with whooping cough. Each cockroach was named after a child who placed it in a bottle which was then tightly corked. The sickness was believed to pass with the death of the insect. During this period, it was necessary to keep the child's bowels open or the charm might react and kill him. Radbill also reported that a person in the city was advised to put a cockroach in a thimble, tie it in a cloth, and wear it around the neck, "You will never whoop after wearing it." The same information is given by Weiss (1946).

Worms.—Sloane (1725) reported that in Jamaica, cockroaches were given to children as a vermifuge.

Discussion.—The action of dried Tarakanen, *Blatta orientalis,* as a diuretic has the benefit of some clinical usage to support it. The remedy was tested extensively in St. Petersburg, by Dr. P. Bogomolow (1876). This was not the first use of cockroaches as a diuretic, however, because Bogomolow reported that a Dr. Kuprianow had submitted the following thesis as part of his doctoral dissertation: "Die blatta orientalis ist ein sicheres Diureticum in der Gabe von einem Gran" and also that cockroaches had been used successfully by peasants in Russia as a folk remedy for dropsy. Pavlovskii and Shtein (1931) mention that powder and decoctions of *B. orientalis* were introduced by S. P. Botkin as a diuretic in scientific medicine.

Bogomolow (1876) treated nine patients with dried cockroaches, in powder form, as a tincture, and as an infusion. The diseases included nephritis (4 cases), arteriosclerosis (4), Bright's disease (3), cirrhosis of the liver (1), and heart disease (1). In all cases, urine excretion increased; the amount of albumin in the urine decreased (5 cases); edema of hands and feet as well as ascites quickly disappeared; body weight decreased; in four cases there was increased sweating; digestion was not upset and the kidneys were not irritated. Bogomolow (1876) isolated, in crystalline form, what he considered to be the diuretic principle of cockroaches and designated it antihydropin.

Unterberger (1877) used *Blatta orientalis* to treat children with nephritis after scarlatina (4 cases) and measles (1 case). In all cases, after a few days there was a shrinkage of the edematous conditions; body weight decreased; excretion of urine increased; amount of albumin became moderate (4 cases); kidneys and intestine were not irritated.

Koehler (1878) prescribed Tarakanen for 13 patients with the following diseases: arteriosclerosis (1 case), atherosis and angina pectoris (1), nephritis (4), exudative pleurisy (1), pernicious anemia (1), heart disease (1), exudative pericarditis (1), and Bright's disease (3). In all cases there was increased excretion of sweat and urine; edema and ascites were reduced or completely disappeared; albumin was reduced (2 cases) or eliminated (5 cases); stomach and intestine were not irritated.

Fronmüller (1878) used powdered *Blatta orientalis* as a diuretic in treating patients with lung tuberculosis (3 cases), bronchitis (1), exudative pleurisy (1), and albuminuria (1). Five of the six patients showed increased urine output; there was no digestive disturbance; it was concluded that the stronger doses of *Blatta* were strikingly effective and were not bad to take.

Budde (1878) used powdered *Blatta* to treat patients with albuminuria (2 cases) and nephritis (3 cases). He was unable to conclude that the therapy was effective. There was not a distinct increase in urine excretion or sweating, and the excretion of albumin remained unchanged.

Wyschinski (1879) used *Blatta* in treating patients with dropsy (7 cases), cirrhosis of the liver (2), organic heart disease (4), and Bright's disease (1). Excretion of urine increased in the patients with cirrhosis of the liver. The results with the other patients were negative, and Wyschinski questioned whether antihydropin from *Blatta* had produced the effects claimed by Bogomolow and Unterberger.

Kurz (1879) reported that he used *Blatta* in treating a man with nephritis and a girl with chronic peritonitis and ascites. The urine output increased in both patients; the amount of albumin in the man's urine was reduced relatively but the absolute amount remained unchanged; the circumference of the girl's abdomen was reduced 3 cm.

Steinbrück (1881) in his dissertation reported exhaustively on the use of *Blatta* as a diuretic. He examined the earlier literature thoroughly and included detailed case histories of 15 of his own patients to whom he had administered *Blatta.* The diseases included nephritis (10 cases), edema of the face and palpitation of the heart (1), tuberculosis (1), mitral insufficiency (1), and two cases with healthy kidneys. He was able to verify increased diuresis 14 times in the 15 patients. In 12 patients with albuminuria there was a reduction of albumin in six cases, no effect in two, and in four cases the amount of albumin increased. Steinbrück did not observe an increase in sweating following doses of *Blatta.* He concluded that the principal effect of powdered cockroach was as a diuretic.

Bogomolow (1882) reported on 70 more cases of dropsy in which he administered *Blatta*. The edema was caused in 15 instances by heart failure, in 52 instances by kidney disease, and in 3 cases by liver disease. In 19 cases Bogomolow observed sweating; in 61 cases the volume of urine was increased significantly; in 13 instances diarrhea was increased by augmented transudation through the walls of the gut. No irritation or other unfavorable symptom was seen.

Tschernyschew (1882) investigated the physiological effects of an organic acid that he obtained from *Blatta orientalis*. In frogs there was an increasing retardation of heart action in which the heart remained in diastole with the ventricles distended with blood. The effect was not accomplished through the central nerve system but was a result of paralysis of the heart and its motor ganglion. In warm-blooded animals small doses retarded the pulse and large doses stopped heart action. The first effect appeared to depend on excitation of an inhibitory apparatus, but the latter appeared to depend on possible paralysis of the inhibitory apparatus, with some participation of the motor nerve of the heart. The acid effected strong diuresis in which the secretory elements of the kidney were stimulated.

The flurry of interest in cockroaches as a remedy for dropsy was confined to a relatively brief period. Although the professional medical papers describing this use appeared in Europe, interest in the subject was reflected in the lay press in the United States at the same time (Anonymous, 1877, 1877a, 1879, 1881; Landerer, 1879). After 1883, the medicinal use of cockroaches dropped from the literature, except for occasional references, until quite recently.

In 1933, in Helsinki, Vartiainen et al. reinvestigated the diuretic effects of *Blatta orientalis*. These workers examined the effects of the cockroach on the excretion of urine in rabbits. Powdered cockroach was administered by mouth and also subcutaneously as an infusion. Urine excretion was measured partly as excreted by rabbits kept in metabolic cages, partly by withdrawal by catheter from the bladder, and partly by taking urine from canulae inserted in the ureters of narcotized rabbits. Although some animals did not respond, there was sufficient increase in the excretion of urine in others to convince the authors that *B. orientalis* possesses diuresis-increasing effects, even though these may not have been particularly strong.

Apropos of the reputed diuretic properties of cockroaches, it is noteworthy that Stutinsky (1953) has reported evidence for an *antidiuretic* substance in the brain and retrocerebral complex of *Blaberus fuscus*. These organs from male cockroaches were ground to a powder. An extract of the powder, when injected into rats, caused a reduction in the quantity of urine eliminated. However, tests to determine possible oxytocic, vasopressor, or antidiuretic effects with corpora cardiaca from *Periplaneta* and *Leucophaea* were inconclusive (Vogt and Hild *in* Scharrer, 1955). Scharrer (1955) suggests that further tests seem necessary to substantiate the positive results obtained with extracts of *Blaberus*.

It is not out of place to mention the work of Scharrer (1945, 1949, 1951, 1953) on the development of cancer in *Leucophaea maderae*. She found that gastric cancer can be induced experimentally in this cockroach by severing the recurrent nerve; branches from this nerve innervate the foregut, stomach, salivary glands, and salivary reservoir. Roughly 75 percent of the operated insects developed tumors, the stomach being the most frequently affected organ. The digestive organs of an insect are structurally comparable to those of higher animals, and studies of this kind, employing the Madeira cockroach, may have significance in aiding our understanding of cancer in mammals.

> If a black beetle [*Blatta orientalis*] enters your room, or flies against you, severe illness and perhaps death will soon follow.
>
> Maryland superstition,
> Cowan (1865).

XIII. DISEASES INCORRECTLY ATTRIBUTED TO COCKROACHES

Cockroaches have been suspected of causing certain diseases or disseminating several disease agents which, on subsequent investigation, have been found to have other causes or vectors.

Beriberi.—Van der Scheer (1900, 1900a) believed that this vitamin-deficiency disease was caused by a parasite that lived in the intestine where it formed a toxin that caused degeneration of the nerves. He suspected that part of the life cycle of the parasite was passed in *Blatta orientalis*. Melville-Davison (1911) came to a similar conclusion. He believed that an amoeba which lived in the intestine of the cockroach caused the disease.

Bright's disease.—Caudell (1916) cited a case in which this disease was believed to have been caused by drinking soda water in which a cockroach had decayed.

Cancer.—Caudell (1916) quoted a Professor Nordlyset who claimed in 1913 that cancer was caused by drinking water in which cockroaches had oviposited. Fibiger (1913) and Fibiger and Ditlevsen (1914) demonstrated that *Periplaneta americana* is a vector of the rat nematode *Gongylonema neoplasticum* which they thought was in some way related to cancer in rats (see p. 27). Cordier (1933) suggested that *Entamoeba blattae,* an amoeba found in the intestines of cockroaches, was a causal agent of cancer.

Kala azar.—Before the vector of this leishmaniasis was believed to be the sand fly, cockroaches were suspected of being possible vectors (Young, 1924). Examinations of dissected cockroaches, including *Blatta orientalis,* taken in endemic areas in the Sudan (Archibald, 1923) and in southern India (Turkhud et al., 1926) were negative for the parasites.

Malaria.—Coronado (*in* Cao, 1898) stated without evidence in an 1897 paper that cockroaches, among other insects, spread this mosquito-borne disease.

Pellagra.—Jennings and King (1913) reported negative results in an attempt to incriminate cockroaches in the cause and spread of this deficiency disease.

Scurvy.—Melville-Davison (1911) attributed this deficiency disease to a gregarine found in the intestines of the cockroach. The symptoms of the disease, he thought, were caused by a toxin generated by the protozoan.

XIV. COCKROACHES VERSUS HOUSE FLIES

"The common housefly, loaded with all kinds of bacteria, benign and pathogenic, . . . offers no more danger from acute infectious diseases than does the common house roach. . ." (Longfellow, 1913). These words are as true today as they were when written. However, the domestic cockroaches have yet to achieve generally the unenviable reputation of the filth flies as carriers of infectious agents, in spite of this quotation from a recent U. S. Public Health Service publication (1952): "Equally important as disease carriers are flies and roaches." Yet both can and do carry similar disease-producing viruses, bacteria, protozoa, and helminths. Cockroaches and house flies are potential health hazards to man because they feed on both human feces and human food. Their relative importance as vectors is largely related to their abundance and the access each has to feces or other infective material and food or human contact. Flies, diurnal, more active, and at times apparently more numerous than cockroaches, frequently contaminate food during its preparation or after it has been served. Cockroaches, nocturnal, less active, and less obvious than house flies, usually contaminate unprotected food in dark storage areas or food left exposed overnight. Unfortunately it has always been easier to tolerate the cockroach, which shuns daylight, than to ignore the ubiquitous house fly, which breaks bread with us each meal.

In his discussion of the medical importance of flies, West (1951) stated that, "There is acceptable laboratory proof for the transmission of approximately thirty diseases (or parasitic organisms) by *Musca domestica* and related forms." This number was not increased in the more recent review by Lindsay and Scudder (1956) on nonbiting flies and disease. Cockroaches, by way of comparison, have been shown to harbor, naturally or experimentally, about 40 species of pathogenic bacteria alone; of these, at least 25 species are Enterobacteriaceae, organisms largely responsible for gastroenteritis in man. In addition, cockroaches have been shown to be intermediate hosts for many pathogenic helminths and to carry helminth eggs, viruses, protozoa, and fungi. Obviously, the number of disease agents transmitted is not alone a true measure of the relative importance of a vector. In citing these figures, we are not implying that cockroaches are medically more important than filth flies. Which vector is more important is academic, as there is little likelihood that the question can ever be resolved.

Although modern sewers do not promote fly breeding, they are ideal habitats for cockroaches where these insects may breed and become contaminated with feces and from which they may spread into nearby buildings (see pp. 10, 15). However, where the disposal of human waste is more primitive, filth flies may be the important vectors. Feces deposited on the soil certainly attract more flies than they do cockroaches. Feces deposited in privies may be visited more readily by cockroaches than by flies, according to the particular situation.

Sanitary pit privies have in the past reduced the fly menace, as flies in general tend to shun dark places and the deeper the pit, the fewer the flies (Fair *in* Rosenau, 1940). However, this is no longer wholly true. Kilpatrick and Bogue (1956) observed that, contrary to the general opinion prior to 1950, exceedingly heavy emergence of house flies has recently been recorded from active privy pits. This they attributed to a physiological change in house-fly behavior that they correlated with the development in the fly population of resistance to the insecticide dieldrin.

Dark privy pits might be expected to be ideal cockroach shelters, as attractive to these insects as sewers. Dow (1955) and Kilpatrick and Bogue (1956) have reported that in the southwest United States cockroaches were very prevalent in privy pits that had not been treated with insecticides. The ecology of cockroaches in privies has yet to be explored. Such a study should yield interesting information. Haines and Palmer (1955) observed seasonal fluctuations in populations of two species of *Periplaneta* in privies in southwestern Georgia.

The evidence for the transmission of infectious agents by both flies and cockroaches is largely circumstantial because most of the evidence is indirect. Rarely is either insect the only means of transmitting a disease agent, except when serving as an obligate intermediate host for an endoparasite (e.g., *Pycnoscelus surinamensis* as host of the chicken eyeworm). When other means of transmission are present it is difficult, if not impossible, to prove conclusively that specific outbreaks of disease were caused by pathogens transmitted by insects. Lindsay and Scudder (1956) cited only a few instances of proven correlations between disease morbidity and fly populations, but the experiments they discussed are highly convincing. It is obvious that closely controlled experiments are needed to prove the relationship between mechanical vectors and the morbidity of specific diseases. It is not our thesis that filth-bearing insects are the most important means of disseminating enteric disease organisms. We recognize that all sources of pathogens, including insects, play greater or lesser roles in epidemiology. Sabin (1951) has stressed that ". . . one cannot apply 'unitarian' epidemiological hypotheses and concepts in dealing with an infectious agent that is predominantly stool-borne." This statement applies with equal validity to the mechanical transmission of other infectious agents as well.

> There is sufficient direct and indirect evidence to warrant further study of the cockroach as a vector of disease and to initiate stronger measures designed to exterminate this insect, especially in hospitals and public eating establishments.
>
> JANSSEN and WEDBERG (1952).

XV. CONCLUSIONS

The existing evidence, which is presented in detail in the following appendices, should be sufficient to convince all but the most skeptical that cockroaches are highly dangerous, potential vectors of disease agents. At least 18 species of domiciliary cockroaches have been incriminated, naturally or experimentally, in the transmission of infectious agents or have been claimed to bite man. Most of these species will eat the feces of humans and domestic and exhibition animals. Several of the commonest species (*Periplaneta americana, P. australasiae, P. brunnea, P. fuliginosa, Blatta orientalis,* and *Blattella germanica*) have been captured repeatedly in sewers, cesspools, septic tanks, or privies. Several species have been found breeding in refuse dumps and have been found migrating from both sewers and dumps into nearby buildings. The predilection of cockroaches for human food and the contamination of food, dishes, and food preparation surfaces by cockroaches are notorious. Thus the mechanism exists for the transference of disease organisms by cockroaches to man and his animals.

Although natural transmission of viruses by cockroaches has not yet been proved, four strains of poliomyelitis virus have been found occurring naturally in wild-caught cockroaches. In addition, cockroaches can harbor experimentally four strains of poliomyelitis virus, Coxsackie, mouse encephalomyelitis, and yellow-fever viruses.

About 40 species of pathogenic bacteria have been isolated from naturally contaminated cockroaches. About 90 isolations of natural invasions in cockroaches with these organisms have been made. These and the following figures include only the reports by each investigator of the first isolation of an organism from each species of cockroach. Subsequent isolations of the same organism from the same species of cockroach by the same investigator are not included. In over 100 experimental inoculations of cockroaches with about 40 species of pathogenic bacteria, these organisms were recovered from the insects' feces, intestinal contents, or body surface. About 25 of the pathogenic bacteria are Enterobacteriaceae. A number of other bacteria of doubtful pathogenicity or of doubtful taxonomic status have also been isolated from naturally invaded cockroaches.

Two species of fungi that are sometimes associated with pathological conditions have been isolated from naturally contaminated cockroaches. One species of pathogenic fungus retained its pathogenicity after experimental passage through cockroaches.

So far, only one species of protozoa that is definitely pathogenic to man has been found occurring naturally in cockroaches. It was isolated three times by different investigators. Three species of pathogenic protozoa have been used at least 15 times to inoculate cockroaches experimentally.

The eggs of 7 species of pathogenic helminths have been found naturally in cockroaches 11 times. The eggs of 4 of these species and of 5 additional species have been fed experimentally to cockroaches 19 times. Cockroaches have been found to serve naturally as the intermediate hosts of 12 species of helminths in about 43 observations. Cockroaches were used successfully as intermediate hosts for 11 of these species and also for 11 other species in about 44 experiments.

There is no question about the ability of cockroaches to carry pathogens in or on their bodies. There is, however, some question about the epidemiological significance of this fact. Most of the evidence is circumstantial. The role of cockroaches as intermediate hosts of helminths has been established. Although cockroaches undoubtedly are vectors of the agents of viral and bacterial diseases, with very few exceptions their relations to specific outbreaks of disease have not been determined. This area of research has not received the attention it deserves. Demonstrating correlations between house flies and incidence of intestinal disease has been difficult (see Lindsay and Scudder, 1956). Linking cockroaches with the actual transmission of similar disease agents will be no easier.

Various workers have, as a result of their investigations, expressed their concern about cockroaches and disease. Morischita and Tsuchimochi (1926) stated, ". . . we are led to conclude that the cockroaches commonly found in our island [Formosa] may play a fairly important role in the dissemination of infectious diseases and helminthiasis and must not be overlooked from the sanitary point of view." Tejera (1926) concluded that cockroaches are insects which the hygienist must consider as possible disseminating agents of pathogenic germs, and, consequently, as transmitters of sickness to man.

Antonelli (1930) stated that from his investigations he was certain that considerable epidemiological importance should be attributed to the cockroach which, as a permanent danger, should be fought without quarter. Arizumi (1934) stated, "In my opinion the cockroaches, at least the two *Periplaneta* species examined, are eminently apt to spread, besides other pathogenic bacilli, also the Leprosis bacillus wherever they visit and deposit their feces." Mackerras and Pope (1948) concluded, "We have adduced sufficient evidence to justify intensive control measures in any area where both cockroaches and *Salmonella* infections are found."

Bitter and Williams (1949) concluded. "Because of the lack of conclusive evidence that roaches can transmit disease, these insects have been regarded with tolerance by a large portion of the population, especially in areas where roach control is difficult. The results cited above suggest that such tolerance is unwarranted and that every effort should be made to suppress the cockroach and to protect food and kitchen utensils from contact with its feces. Roach control is clearly of the highest importance in households that include infants."

Graffar and Mertens (1950) stated, "Up to the present time, cockroaches were generally considered repugnant but completely inoffensive insects. This opinion must be reformed, and it is expedient, in the hospitals at least, to waste no effort in destroying them." Eads et al. (1954) stated, "Both flies and cockroaches are outstanding among the omnivorous insects which are of significance in the contamination of food and water as a result of the intimacy and constancy of their association with both the food and the excreta of man and animals."

Cockroaches are tough, resilient insects with amazing endurance and the ability to recover rapidly from almost complete extermination. They will probably always be with us, and we can only temporarily reduce their numbers. But, as in all battles, recognition of a common enemy is essential to successful combat. We hope that this review has so strongly identified cockroaches with the dissemination of infectious agents that these insects will no longer be regarded as only minor annoyances. The acceptance of cockroaches as serious vectors of disease organisms is at least the first step in any organized campaign of extermination.

The specific measures to be taken to control cockroaches are beyond the scope of this review. However, the currently recommended chemical control measures and sanitary practices may be obtained from the following sources: the U. S. Department of Agriculture, U. S. Public Health Service, various state Agricultural Experiment Stations, and similar governmental agencies in other countries.

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> La *Periplaneta americana,* habitée par un nombre encore plus considérable de parasites végétaux et animaux, devient à ce point de vue encore plus digne d'être étudiée. . . . Le pauvre bête est une vraie ménagerie ambulante.
>
> MAGALHÃES (1900).

APPENDICES

The plants and animals are listed by phylum, class, order, and family in the order adopted by the taxonomic sources we have followed, but in alphabetical order by genus and species. In listing the authors of the species, we have followed the current usage of specialists in the field; for the helminths the original describer, the reviser, and the dates of both are given; for the bacteria and fungi the describer and reviser are listed; for the protozoa the original describer is given.

Each organism, in so far as we have been able to determine, is listed by its current name. To reduce the number of entries for each organism, we have synonymized the names reported by earlier authors with the names now in use. The only synonymy given is that which identifies the organism by the name used by the author of the paper cited; no attempt was made to prepare complete taxonomic synonymies.

Under the name of each organism the associated cockroaches are listed as being natural or experimental vectors. The name of each cockroach is followed by the country in which the observation was made, the authority, and comments on the invasion. Unidentified cockroaches associated with specific records are indicated by the word "Cockroaches." Question marks following the names of organisms or countries indicate tentative or questionable identifications.

APPENDIX A: VIRUSES

PATHOGENIC VIRUSES ASSOCIATED WITH COCKROACHES

POLIOMYELITIS VIRUSES

The disease caused by these viruses is usually mild, with upper respiratory or gastrointestinal symptoms. The central nervous system may be affected with an accompanying paralysis of voluntary muscles (Howe *in* Rivers, 1948).

Lansing strain

Experimental vectors.—Blattella germanica, U.S.A. (Hurlbut, 1949, 1950) : Mouse-adapted virus was inoculated into the hemocoeles of the insects. The virus was present in 22 surviving cockroaches after 15 days. Virus was not found in the cockroach feces or eggs. Emulsions of whole insects produced typical paralysis in mice when inoculated intracerebrally. The following authors incorrectly cited Hurlbut's host cockroach as *Periplaneta americana:* Syverton and Fischer (1950), Fischer and Syverton (1951a), Findlay and Howard (1951), and Hsiang et al. (1952).

Periplaneta americana, U.S.A. (Hsiang et al., 1952) : The virus was recovered from the feces of the cockroaches on the first day only, after they had been fed virus in an emulsion of cotton-rat brain. No virus could be detected in cockroach tissues within 24 hours after the virus meal. The authors suggest that virus inactivation might result from metabolic effect or from rapid excretion of the virus from the gut of the cockroach.

Brunhilde type, Minnesota and Mahoney strains

Experimental vectors.—Periplaneta americana, U.S.A. (Fischer and Syverton, 1951; Syverton et al., 1952) : After a single feeding this cockroach acquired, maintained, and excreted these viruses over a period of 16 days (7 to 15 days [Syverton et al., 1952]). Sufficient virus was recovered to paralyze and kill the recipient animals.

Columbia SK virus

Disease.—This virus is pathogenic for cotton rats, mice, golden hamsters, guinea pigs, and monkeys (Findlay and Howard, 1951).

Experimental vectors.—*Blattella germanica* and *Periplaneta americana* (Findlay and Howard, 1951): A suspension of mouse brain infected with this virus was injected into the hemocoeles of the cockroaches. After 72 hours and 120 hours, virus was detected in triturated bodies of *P. americana,* but not of *B. germanica,* up to 8 days after the viral meal.

Four unspecified strains

Natural vectors.—*Blattella germanica* (see below), *Periplaneta americana* (see below), and *Supella supellectilium,* U.S.A. (Syverton et al., 1952): Four strains of poliomyelitis virus were isolated from four lots of cockroaches captured on the premises of paralytic poliomyelitis patients from two States. The premises were representative of good and poor sanitary environments.

One lot of *Blattella* (identified to genus) from Pharr, Tex., may have included *B. vaga* as well as *B. germanica,* as both species are now known to be found there (R. P. Dow, p.c.). Of the two, *B. germanica* is the species most likely to be found in houses, but *B. vaga,* usually a field cockroach, may invade houses in great numbers during dry seasons (Flock, 1941). The specimens of one lot of *Periplaneta* caught in Pharr, Tex., although reported as *P. americana* (Syverton et al., 1952), may have included *P. brunnea* as well (Dow, 1955).

COXSACKIE VIRUSES

Type 4, subgroup A

Disease.—The Coxsackie or "C" viruses are responsible for human diseases diagnosed clinically as nonparalytic poliomyelitis, "summer grippe," aseptic meningitis, epidemic myalgia, pleurodynia, and, probably, Bornholm disease (Fischer and Syverton, 1951a).

Experimental vectors.—*Periplaneta americana,* U.S.A. (Fischer and Syverton, 1951a): After consuming a single meal containing this virus, the cockroaches excreted daily, over a period of 15 days, sufficient virus to paralyze and kill test mice.

MOUSE ENCEPHALOMYELITIS VIRUS

GD VII strain

Experimental vectors.—*Periplaneta americana,* U.S.A. (Syverton and Fischer, 1950): The insects were fed single meals containing this virus. Over a period of 7 days, sufficient virus was present daily in the cockroaches' feces to paralyze and kill test mice.

YELLOW-FEVER VIRUS

Disease.—An infection of the hemapoietic system; mosquitoes are the only blood-sucking arthropods that have been shown to play a part in the epidemiology of yellow fever (Theiler *in* Rivers, 1948).

Experimental vectors.—Blatta orientalis (Trop. Dis. Bull., 1942, p. 65, *in* Brumpt, 1949): According to Brumpt, the virus lasted less than 2 days in this insect. We have checked the reference given by Brumpt but found no mention of cockroaches and virus.

Blattella germanica (Findlay and MacCallum, 1939): Yellow-fever virus injected into the insects' abdomens retained its activity for at least 15 days. When yellow-fever virus was introduced into the stomachs of Indian monkeys (*Macaca mulatta*) and African monkeys (*Cercopithecus aethiops*), the virus passed into the blood stream and caused fatal infections in the Indian monkeys.

NEGATIVE FINDINGS

The following cockroaches (U.S.A., Texas) were examined for viral invasions, with negative results, by Eads et al. (1954): *Blatta orientalis, Blattella germanica, Periplaneta americana,* and *Supella supellectilium.*

NEWCASTLE DISEASE VIRUS

California strain No. NC 194-5-6-7

Disease.—Avian pneumoencephalitis.

Experimental vector.—Periplaneta americana, U.S.A. (Gallardo et al., 1957): The virus could not be recovered in the feces after feeding to the cockroaches.

APPENDIX B: BACTERIA

Most of the bacteria listed below are pathogenic to humans, but some are primarily of veterinary importance. Species that are normally nonpathogenic but which apparently acquired pathogenicity (to laboratory animals) on passage through the cockroach have also been included.

Where it has been possible to synonymize the names of the bacteria, as used in the references cited, we have followed Bergey's Manual of Determinative Bacteriology, sixth edition (Breed et al., 1948). The disease entity and habitat of each organism were obtained from Breed et al. (1948), Smith et al. (1948), and Dubos (1948), or other indicated sources. The taxonomic arrangement follows that of Breed et al. (1948).

Part I contains positive associations of cockroaches with valid species of bacteria. Part II contains positive associations of cockroaches with pathogenic bacteria whose taxonomic position is uncertain. Part III contains negative findings.

PART I. PATHOGENIC [8] BACTERIA ASSOCIATED WITH COCKROACHES

Phylum SCHIZOPHYTA

Class SCHIZOMYCETES

Order EUBACTERIALES

Family PSEUDOMONADACEAE

Pseudomonas aeruginosa (Schroeter) Migula

Synonymy.—Bacillus pyocyaneus.

Common name.—Blue pus organism.

Disease.—Cause of various lesions in humans and other animals, urinary tract infections. Habitat: Polluted water, sewage.

Natural vectors.—Blaberus craniifer, U.S.A. (Wedberg et al., 1949): Organism isolated from feces.

Blatta orientalis, U.S.A. (Olson and Rueger, 1950; T. A. Olson, p. c.): From laboratory-reared cockroaches.

Blattella germanica, U.S.A. (Janssen and Wedberg, 1952): Organ-

[8] Certain of these bacteria are considered to be nonpathogenic or of doubtful or low pathogenicity by some authors.

ism isolated from feces and alimentary canal. (Olson and Rueger, 1950: T. A. Olson, p. c.): From laboratory-bred cockroaches.

Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from intestinal tract. (Olson and Rueger, 1950; T. A. Olson, p. c.): From laboratory-bred cockroaches.

Experimental vectors.—Blattella germanica, U.S.A. (Herms and Nelson, 1913): Cockroach picked up organism on tarsi and inoculated three agar plates, also transferred organism to sugar.

Cockroach, U.S.A. (Longfellow, 1913): Organism isolated from feet and viscera of cockroaches allowed to feed on inoculated food.

Pseudomonas eisenbergii Migula

Synonymy.—B. fluorescens non liquefaciens.

Disease.—Pathogenic to guinea pigs and rabbits (Cao, 1906). Nonpathogenic (Breed et al., 1948).

Natural vectors.—Blatta orientalis, Italy (Cao, 1906): Organism isolated from intestinal contents.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1906): Strain D of the above organism, isolated from soil, acquired moderate virulence in the feces of the cockroaches and produced abscesses and death in guinea pig.

Pseudomonas fluorescens Migula

Synonymy.—Bacillus fluorescens liquefaciens.

Disease.—Strains B, C, D, and F reported by Cao to be pathogenic to guinea pigs. Normally found in soil, water, sewage, feces. Nonpathogenic (Breed et al., 1948).

Natural vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): From intestinal contents. (Spinelli and Reitano, 1932): From intestinal tract.

Periplaneta americana, U.S.A. (Gier, 1947).

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): Insects that had fasted were fed bacterial colonies. Cultures from feces were pathogenic when injected into guinea pigs and rabbits.

Periplaneta americana, U.S.A. (Gier, 1947): Organism pathogenic to the cockroach when injected.

Vibrio comma (Schroeter) Winslow et al.

Synonymy.—"Vibrione del colèra" of Cao; *Vibrio cholerae.*

Disease.—Asiatic cholera. Habitat: Intestinal contents of cholera patients and carriers.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898; Spinelli and Reitano, 1932): After experimental feedings, the cholera vibrios passed unharmed through the digestive tract of the insect. Cholera vibrios survived in the insects' intestinal tracts for 15 days and were found in their feces 86 hours after being ingested (Spinelli and Reitano, 1932).

Blattella germanica, Orient (Toda, 1923): 94 cockroaches (collected from Japanese ocean liners) were fed *V. comma* in bread. The organism was recovered from 15 percent of the insects, from feces or from the intestines after death. The feces contained viable vibrios up to 3 days after the infective meal. Germany (Jettmar, 1927): Cockroaches fed cholera organisms showed a higher mortality than those fed plague bacilli.

Periplaneta americana, Philippine Islands (Barber, 1914): Feces containing vibrios were obtained from 8 cockroaches 6 hours after an experimental feeding with feces from a cholera patient. The organism appeared in enormous numbers in the feces for at least 2 days thereafter and in smaller numbers 79 hours after ingestion. There was no loss of virulence for guinea pigs after the vibrios had been in the insects' intestines 29 hours. Regurgitated food contained vibrios. Cholera vibrios in cockroach feces will survive on human food for at least 16 hours after discharge from the insect. Netherlands (Akkerman, 1933): In 12.7 percent of the cockroaches there were vibrios in the feces 24 hours after feeding. One insect excreted vibrios in its feces 3 days after feeding. Formosa (Morischita and Tsuchimochi, 1926): 25 insects were fed on a culture of cholera vibrios. Intestinal contents of groups of 5 were positive 3.5 and 12 hours after feeding. After 24 hours, 3 of 5 were positive; after 48 hours, 2 of 5 were positive; after 68 hours, all were negative. Fecal examinations of 10 cockroaches were positive 5 to 34 hours after feeding; feces excreted after 48 to 53 hours were partly positive; after 57 hours all feces were negative except 1 positive at 67 hours. The average ratio of positive feces was 16.3 percent. Intestines were negative for *V. comma* after 68 or 70 hours.

Periplaneta australasiae, Formosa (Morischita and Tsuchimochi, 1926): One specimen that was fed *V. comma* excreted feces positive for the organism.

Vibrio metschnikovii Gamaléia

Synonymy.—"Vibrione di Metschnikow" of Cao.

Disease.—Choleralike disease of chickens, pigeons, and other animals.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): The organism passed unchanged through the gut of this cockroach and was excreted in the feces. In some experiments, attenuated cultures of this organism regained their full virulence on passage through the cockroach (Cao, 1906).

Family MICROCOCCACEAE

Micrococcus aurantiacus (Schroeter) Cohn

Source.—Usually isolated from infections; may be pathogenic; found in milk, cheese, and dust.

Natural vectors.—Blattella germanica, U.S.A., Connecticut (Janssen and Wedberg, 1952): Organism isolated from feces and alimentary canal.

Micrococcus citreus Migula

Synonymy.—Staphylococcus citreus.

Disease.—Pathogenic; isolated from pus; found on skin and mucous membranes of vertebrates (Breed et al., 1948). Nonpathogenic (Wilson and Miles, 1955).

Natural vectors.—Cockroaches, U.S.A. (Longfellow, 1913): Organism isolated from legs and feces.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): Organism not recovered in the feces.

Micrococcus epidermidis (Winslow and Winslow) Hucker

Disease.—Parasitic rather than pathogenic; found on skin and mucous membranes.

Natural vectors.—Blattella germanica, U.S.A., Connecticut (Janssen and Wedberg, 1952): Organism isolated from feces and alimentary canal.

Micrococcus pyogenes var. albus (Rosenbach) Schroeter

Synonymy.—Staphylococcus albus.

Disease.—Occurs in wounds, boils, abscesses. Pathogenic. Habitat: Skin and mucous membranes.

Natural vectors.—Blaberus craniifer, U.S.A., Connecticut (Wedberg et al., 1949): Organism isolated from feces.

Blatta orientalis, U.S.A., Iowa, (Tauber, 1940; Tauber and Griffiths, 1942): Organism isolated from hemolymph.

Blattella germanica, U.S.A. (Herms and Nelson, 1913; Herms, 1939; Janssen and Wedberg, 1952): Organism isolated from the legs, antennae, and feces.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898): Failed to recover the organism. U.S.A. (Tauber and Griffiths, 1942): Organism toxic to the cockroach when injected.

Micrococcus pyogenes var. aureus (Rosenbach) Zopf

Synonymy.—*Staphylococcus aureus.*

Disease.—Pathogenic. The cause of boils, abscesses, suppuration in wounds. Habitat: Skin and mucous membranes.

Natural vectors.—*Blaberus craniifer,* U.S.A., Connecticut (Wedberg et al., 1949): Organism isolated from feces.

Blatta orientalis, Italy (Cao, 1906): Organism isolated from intestinal contents. Cao in an earlier work (1898) failed to recover this organism from the cockroach.

Blattella germanica, U.S.A. (Herms, 1939): Organism isolated from the antennae.

Cockroaches, U.S.A. (Longfellow, 1913): Organism isolated from the legs.

Micrococcus spp.

Disease.—These organisms were obtained from pus or were designated as staphylococci (i.e., pathogenic micrococci [Blair *in* Dubos, 1948]).

Natural vectors.—*Blatta orientalis,* Italy (Spinelli and Reitano, 1932). Germany (Jettmar, 1935): Organisms isolated from intestinal tract.

Blattella germanica, Germany (Jettmar, 1935): Hemolytic staphylococci were isolated from the outer surfaces of 19 insects captured in a hospital operating room.

Experimental vectors.—*Blattella germanica,* on shipboard (Morrell, 1911): Two specimens were fed staphylococcic pus. The organisms were recovered in the feces, and cultures on agar were obtained from these. Germany (Vollbrechtshausen, 1953): Cultures of staphylococci (obtained from the clothing louse) were injected, orally and anally, into cockroaches. Colonization and propagation in the intestines of the cockroaches lasted up to 6 to 8 weeks after heavy injections. The organism was recovered from the feces of one insect 180 days after the injection.

Family NEISSERIACEAE

Neisseria meningitidis (Albrecht and Ghon) Holland

Common name.—Meningococcus.

Disease.—Cerebrospinal fever.

Experimental vectors.—Cockroaches, U.S.A. (Longfellow, 1913): After feeding, the organism was recovered in a few cases from the viscera and outer surface of the body; however, the results were not as conclusive as were Longfellow's findings with pneumococcus.

Veillonella parvula (Veillon and Zuber) Prévot

Synonymy.—*Micrococcus parvulus.*

Disease.—Normally a harmless parasite in natural cavities of man and other animals, but it may occasionally be pathogenic.

Natural vectors.—*Periplaneta americana,* U.S.A. (Hatcher, 1939): Organism isolated from feces.

Family LACTOBACTERIACEAE

Diplococcus pneumoniae Weichselbaum

Synonymy.—"Diplobacillo di Fränkel" of Cao.

Common name.—Pneumococcus.

Disease.—Commonest cause of lobar pneumonia. Habitat: Respiratory tract of man and animals.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898): Organism killed in the cockroach's gut.

Cockroaches, U.S.A. (Longfellow, 1913): After feeding on the organism, 3 out of 10 cockroaches had the bacterium on legs or abdomens. Smears of the opened bodies of all 10 insects showed from a few to a number of pneumococcus colonies in each.

Pneumococcus, Type I, No. 1231

Disease.—Pathogenic to mice (Vollbrechtshausen, 1953).

Experimental vectors.—*Blattella germanica,* Germany (Vollbrechtshausen, 1953): 25 cockroaches injected orally or anally with pneumococci in a serum bouillon. Pneumococci appeared in the feces within 5 hours after the injection and were excreted over a period of 3 days. Experiment repeated with 50 cockroaches. The number of introduced pneumococci decreased in the intestines until, after 5 days, the test insects no longer showed such bacteria.

Streptococcus faecalis Andrewes and Horder

Source.—Occurs in inflammatory exudates; in blood stream in subacute endocarditis; European foul-brood of bees. Found in milk and milk products, especially cheese.

Natural vectors.—*Blatta orientalis,* Poland (Nicewicz et al., 1946): Organism isolated from the alimentary tract.

Blattella germanica, U.S.A. (Steinhaus, 1941): Organism isolated from the midintestine.

Periplaneta americana, England (Shrewsbury and Barson, 1948): Organism cultivated from the alimentary tract.

Cockroaches (presumably *B. orientalis, B. germanica,* and/or *P. americana*), Egypt (El-Kholy and Gohar, 1945): Organism isolated from outer body surfaces, intestines, and suspensions of macerated insects.

Streptococcus liquefaciens Sternberg emend. Orla-Jensen

Source.—Found in blood in subacute endocarditis. Foul-brood of bees. Found in feces, and in dairy and other food products.

Natural vectors.—*Blatta orientalis,* Poland (Nicewicz et al., 1946): Organism isolated from alimentary tract.

Streptococcus pyogenes Rosenbach

Synonymy.—*Streptococcus pyogenes longus;* "Streptococco piogene" of Cao.

Disease.—Organism occurs in human infections of many varied types.

Natural vectors.—*Blatta orientalis,* Italy (Cao, 1906): Organism isolated from feces; in pure culture it caused only local suppuration in guinea pigs or rabbits.

Experimental vectors.—Cockroaches, U.S.A. (Longfellow, 1913): Organism isolated from legs and viscera.

Streptococcus sp. (pyogenic group)

Synonymy.—The exact species used by Jettmar (1935) is not known, but he refers to a hemolytic *Streptococcus* of the beta type. According to Breed et al. (1948), such an organism would probably fall in the pyogenic group.

Disease.—Streptococci of the pyogenic group occur in human infections of many varied types.

Experimental vectors.—*Blatta orientalis,* Germany (Jettmar, 1935): On the second day after ingesting an infective meal, the cockroaches excreted hemolytic streptococci in their feces.

Streptococcus sp. (viridans group)

Synonymy.—The species used by Jettmar (1935) is not known, but he refers to a *Streptococcus* of the alpha type which formed colonies with green patches on blood agar. According to Breed et al.

(1948), and Smith et al. (1948), streptococci like the above would probably fall in the *viridans* group.

Disease.—Streptococci of the *viridans* group occur in pus, abscesses, and in the human mouth, throat, and nasopharynx.

Experimental vectors.—*Blatta orientalis,* Germany (Jettmar, 1935): Organism isolated from the hindgut and feces in almost pure culture. A mouse was successfully infected through subcutaneous injection.

Streptococcus spp.

Disease.—Some species of *Streptococcus* are highly pathogenic, and for that reason these undetermined species are listed here.

Natural vectors.—*Blatta orientalis,* Germany (Jettmar, 1935): Cultures from the hindgut contained short chains of streptococci.

Blattella germanica, U.S.A. (Janssen and Wedberg, 1952): Organism isolated from the feces and alimentary canal. Germany (Jettmar, 1935): 19 specimens, captured in the operating room of a hospital, were found to be externally contaminated with streptococci which produced green colonies on blood agar.

Cockroaches, U.S.A. (Longfellow, 1913): A streptococcus that hemolyzed human blood was isolated from the insects' viscera.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898): The streptococci did not pass through the gut of this insect after an infective feeding.

Family CORYNEBACTERIACEAE

Corynebacterium diphtheriae (Flügge) Lehmann and Neumann

Synonymy.—"Bacillus Klebs-Loeffler" of Longfellow; "Bacillo di Löffler" of Cao.

Disease.—Diphtheria in man.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898): Organism could not be recovered from the feces.

Cockroaches, U.S.A. (Longfellow, 1913): Organism recovered from legs of cockroaches exposed to sterile food that Longfellow had inoculated with *C. diphtheriae.*

Family ENTEROBACTERIACEAE

Escherichia coli (Migula) Castellani and Chalmers

Synonymy.—*Bacillus coli; B. coli communis; Bacterium coli.*

Disease.—Causes infections of genitourinary tract. Invades circulation in agonal stages of diseases. Habitat: Intestine of man and other vertebrates.

Natural vectors.—Blatta orientalis, Italy (Cao, 1898, 1906). France (Sartory and Clerc, 1908). Italy (Spinelli and Reitano, 1932). Europe (Jettmar, 1935). Poland (Nicewicz et al., 1946).

Blattella germanica, U.S.A. (Steinhaus, 1941).

Periplaneta americana, U.S.A., Texas (Bitter and Williams, 1949, 1949a).

Cockroach, U.S.A. (Longfellow, 1913).

Cockroaches (presumably *B. orientalis, B. germanica,* and/or *P. americana*), Egypt (El-Kholy and Gohar, 1945).

Organism isolated from feces of *B. orientalis,* from intestinal contents of all hosts, and from outer surfaces of bodies or suspensions of whole, undetermined cockroaches.

Experimental vectors.—Blattella germanica, Germany (Vollbrechtshausen, 1953); Organisms injected into the insects' intestinal tracts in a serum and salt solution. Highest concentrations of bacteria killed the insects, but most insects survived the lowest concentration. The test organism was recovered from the feces during the first 14 days.

Klebsiella pneumoniae (Schroeter) Trevisan

Synonymy.—"Bacillo di Friedländer" of Cao.

Disease.—Pneumonia. Associated with infections of respiratory, intestinal, and genitourinary tracts of man. Has been isolated from soil, water, and milk.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): This organism passed through the insects' guts unchanged in virulence.

Paracolobactrum aerogenoides Borman, Stuart and Wheeler

Source.—Human gastroenteritis. Habitat: Surface water, soils, intestine of man and other animals.

Natural vectors.—Blattella germanica, U.S.A. (Janssen and Wedberg, 1952): Organism isolated from feces and alimentary canal.

Periplaneta americana, U.S.A. (Bitter and Williams, 1949): Organism isolated from intestinal tract. Doubtful pathogenicity.

Paracolobactrum coliforme Borman, Stuart and Wheeler

Source.—Human gastroenteritis. Habitat: Soils, surface water, intestinal tract of man and other animals.

Natural vectors.—Blattella germanica, U.S.A. (Janssen and Wedberg, 1952): Organism isolated from feces and alimentary canal.

Periplaneta americana, U.S.A. (Bitter and Williams, 1949): Organism isolated from intestinal tract.

Paracolobactrum spp.

Source.—All species of this genus isolated from human gastroenteritis. Habitat: As preceding species.

Natural vectors.—Blatta orientalis, Blattella germanica, and *Periplaneta americana,* U.S.A. (Olson and Rueger, 1950; T. A. Olson, p. c.): The organisms were isolated from laboratory-reared cockroaches.

Periplaneta americana, U.S.A. (Bitter and Williams, 1949a).

Proteus mirabilis Hauser

Source.—Gastroenteritis. Habitat: Putrefying materials, infusions, abscesses (Breed et al., 1948). *Proteus* bacilli appear to be responsible for a number of inflammatory and suppurative processes in man (Wilson and Miles, 1955).

Natural vectors.—Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from intestines. Doubtful pathogenicity.

Proteus morganii (Winslow et al.) Rauss

Synonymy.—"Bacillus Morgan" of El-Kholy and Gohar.

Source.—Summer diarrhea in infants.

Natural vectors.—Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from the intestine. Doubtful pathogenicity.

Cockroaches (presumably *Blatta orientalis, Blattella germanica,* and/or *P. americana*), Egypt (El-Kholy and Gohar, 1945): Organism isolated from suspensions of whole cockroaches.

Proteus rettgeri (Hadley et al.) Rustigian and Stuart

Source.—Sporadic and epidemic gastroenteritis. Some choleralike diseases of birds, fowl typhoid.

Natural vectors.—Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from intestines. Doubtful pathogenicity.

Proteus vulgaris Hauser

Synonymy.—Bacillus proteus vulgaris.

Source.—Urinary-tract infections, abscesses. Habitat: Feces, putrefying materials.

Natural vectors.—Blaberus craniifer, U.S.A. (Wedberg, et al., 1949) : Organism isolated from feces.

Blatta orientalis, Italy (Spinelli and Reitano, 1932) : Organism isolated from intestinal tract.

Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a) : Organism isolated from intestinal tract. Doubtful pathogenicity.

Cockroaches, U.S.A. (Longfellow, 1913) : Organism isolated from the legs.

Proteus spp.

Disease.—All four species of this genus are possibly pathogenic; see preceding species.

Natural vectors.—Blatta orientalis and *Periplaneta americana,* U.S.A. (Olson and Rueger, 1950; T. A. Olson, p. c.). These organisms were isolated from laboratory-reared cockroaches.

P. americana, U.S.A. (Bitter and Williams, 1949) : Organisms isolated from intestines. Doubtful pathogenicity.

Salmonella anatis (Rettger and Scoville) Bergey et al.

Synonymy.—Salmonella anatum.

Disease.—Intestinal infections in chickens and man. Widely distributed in man and domestic animals.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954) : Organism isolated from cockroaches collected in sewer manholes.

Salmonella choleraesuis (Smith) Weldin

Synonymy.—B. suipestifer of Pavlovskii.

Disease.—Occasionally causes acute gastroenteritis and enteric fever in man.

Experimental vectors.—Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948) : The organism, when fed in bread and human feces, passed through the insects unchanged.

Salmonella enteritidis (Gaertner) Castellani and Chalmers

Synonymy.—B. Gärtneri of Pavlovskii.

Disease.—First isolated from human feces in an epidemic of food poisoning. Also a pathogen of domestic and wild animals.

Experimental vectors.—Blatta orientalis, U.S.S.R. (Rozengolts and I͡udina *in* Pavlovskii, 1948) : Cockroaches were infected per os. The organism could be observed in the intestinal tracts and feces up to the fourth day. In the insects' intestinal canals, the organism changed under influence of the host, but after it was subcultured or passed through mice, the modified strain regained its original properties.

Blattella germanica, U.S.A. (Olson and Rueger, 1950; T. A. Olson, p. c.): The organism was recovered from the feces within 2 days after feeding. U.S.S.R. (Rozengolts and I͡udina *in* Pavlovskii, 1948): See comments under *B. orientalis.*

Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948): The organism was fed in bread and human feces; it passed through the cockroach unchanged.

Salmonella morbificans (Migula) Haupt

Synonymy.—*Salmonella bovis-morbificans.*

Disease.—Gastroenteritis, septicemia in cattle.

Natural vectors.—*Periplaneta americana,* Australia (Mackerras and Mackerras, 1948): This record may have included *Periplaneta ignota* which was not recognized at that time as distinct from *P. americana* (Mackerras and Pope, 1948). Organism isolated from the guts of cockroaches captured in hospital wards in which cases of gastroenteritis were occurring. During the epidemic, there were three invasions in 16 cockroaches collected in childrens' wards, but none in 146 cockroaches from other hospitals or outside in the same period, or in flies (Mackerras and Mackerras, 1949). Dr. I. M. Mackerras (p. c.) has confirmed that the isolations attributed to "cockroaches" in the 1949 paper are the same as those that were reported for *P. americana* in the 1948 paper.

Experimental vectors.—*Nauphoeta cinerea, Periplaneta australasiae Periplaneta ignota,* and *Supella supellectilium,* Australia (Mackerras and Pope, 1948): All the above cockroaches were invaded by this organism after feeding on sucrose broth cultures. Isolation of the organism was made from the feces or guts after death. The longest period of infection was 19 days, in *P. ignota.*

Salmonella paratyphi (Kayser) Castellani and Chalmers

Synonymy.—"Paratifa A" of Pavlovskii.

Disease.—Enteric fever in man.

Experimental vectors.—*Polyphaga saussurei,* U.S.S.R. (Zmeev *in* Pavlovskii, 1948): The organism, when fed in bread and human feces, passed through the insect unchanged.

Salmonella schottmuelleri (Winslow et al.) Bergey et al.

Synonymy.—Bacillus para-typhosus, B. "Paratifa B" of Pavlovskii.

Disease.—Natural pathogen of man which causes enteric fever.

Natural vectors.—Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from intestinal tract of cockroaches captured either at sewer manholes or in a private home.

Experimental vectors.—Periplaneta americana, Gold Coast Colony (Macfie, 1922): Organism was not recovered from feces after feeding to cockroach.

Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948): The organism, when fed in bread and human feces, passed through the insect unchanged.

Salmonella sp. (Type Adelaide)

Synonymy.—Salmonella adelaide.

Disease.—Isolated from two fatal cases resembling typhoid fever.

Experimental vectors.—Nauphoeta cinerea, Periplaneta australasiae, Periplaneta ignota, and *Supella supellectilium,* Australia (Mackerras and Pope, 1948): The above organism was recovered from the feces or guts of all these cockroaches. The longest invasion encountered was 42 days in *N. cinerea.*

Salmonella sp. (Type Bareilly)

Synonymy.—Salmonella bareilly.

Disease.—Natural pathogen of man; causes gastroenteritis and enteric fever. Widely distributed in fowls.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from macerated suspensions of cockroaches that had been captured in sewer manholes.

Salmonella sp. (Type Bredeny)

Synonymy.—Salmonella bredeny.

Disease.—Human gastroenteritis, abscesses. Also found in hogs and chickens.

Natural vectors.—Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from the intestinal tracts of cockroaches captured either at sewer manholes or in a private home.

Salmonella sp. (Type Derby)

Synonymy.—Salmonella derby.

Disease.—Isolated from human feces; presumably it could cause gastroenteritis as all known species of *Salmonella* are pathogenic for warm-blooded animals, including man (Breed et al., 1948).

Experimental vectors.—Nauphoeta cinerea, Periplaneta australasiae, and *Supella supellectilium,* Australia (Mackerras and Pope, 1948): This organism was recovered from the feces or guts of these cockroaches. The longest invasions lasted 20 days in *N. cinerea* and 30 days in *S. supellectilium.*

Salmonella sp. (Type Kentucky)

Synonymy.—Salmonella kentucky.

Disease.—Isolated from chicken with coccidiosis and ulcerative enteritis; also found in many species of fowl and in hogs and man.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Salmonella sp. (Type Kottbus)

Synonymy.—Salmonella kottbus.

Disease.—Acute gastroenteritis.

Experimental vectors.—Periplaneta australasiae, Australia (Mackerras and Pope, 1948): Three cockroaches were contaminated in the laboratory during tests with other species of *Salmonella.* The invasion lasted 18 days in one cockroach.

Salmonella sp. (Type Meleagris)

Synonymy.—Salmonella meleagridis Brunner and Edwards.

Disease.—Isolated from man, fowl, snakes.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Salmonella sp. (Type Montevideo)

Synonymy.—Salmonella montevideo.

Disease.—Organism isolated from humans, from an ape with fatal enterocolitis, and from chickens and powdered eggs.

Experimental vectors.—Periplaneta americana, U.S.A. (Jung and Shaffer, 1952): The organism survived in the gut fairly regularly and persisted for at least 7 days when the insects had ingested feces containing approximately 10^4 or more viable *S. montevideo* (strain B-33). A second strain of this organism (5327) had less ability to persist in the cockroaches' guts.

Salmonella sp. (Type Newport)

Synonymy.—Salmonella newport.

Disease.—Food poisoning in man. Widely distributed in man, cattle, hogs, chickens, snakes.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Salmonella sp. (Type Oranienburg)

Synonymy.—Salmonella oranienburg.

Disease.—Gastroenteritis in man. Also from chickens, quail, powdered eggs, hogs.

Natural vectors.—Periplaneta americana, U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from intestinal tracts of two cockroaches captured either at sewer manholes or in a private home. U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Experimental vectors.—Blatta orientalis, Blattella germanica, and *Periplaneta americana,* U.S.A. (Olson and Rueger, 1950): From fecal isolations, the organism was found to survive for 20 days in *B. orientalis,* 12 days in *B. germanica,* and 10 days in *P. americana.* However, the oriental cockroach was positive (post mortem examination) 42 days after an experimental feeding, even though the feces were contaminated only during the first 20 days. The *Salmonella* remained viable on the pronotal surface of *P. americana* for as long as 78 days. Fecal pellets from an experimental American cockroach remained infective 199 days. In a recent letter, Dr. Olson informed us that *S. oranienburg* had survived in feces of *P. americana* for 4 years and 115 days.

Salmonella sp. (Type Panama)

Synonymy.—Salmonella panama.

Disease.—Human food poisoning. Habitat: Widely distributed; found in reptiles, hogs, chickens, as well as man.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Salmonella sp. (Type Rubislaw)

Synonymy.—Salmonella rubislaw.

Disease.—Enteritis in child. Also found in snakes.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Salmonella sp. (Type Tennessee)

Synonymy.—Salmonella tennessee.

Disease.—Presumably a cause of food poisoning. Found in turkeys, powdered eggs, man.

Natural vectors.—Periplaneta americana, U.S.A. (Eads et al., 1954): Organism isolated from cockroaches captured in sewer manholes.

Salmonella typhimurium (Loeffler) Castellani and Chalmers

Synonymy.—Bac. Breslau of Pavloskii.

Disease.—Food poisoning in man. Found in mice, snakes.

Natural vectors.—Blattella germanica, Belgium (Graffar and Mertens, 1950): Isolated from a cockroach captured in a hospital ward during an epidemic of gastroenteritis. The epidemic was stopped by extermination of the cockroaches.

Nauphoeta cinerea, Australia (Mackerras and Mackerras, 1948): Organism isolated from the gut of an insect captured in hospital wards where cases of *Salmonella* infection were occurring.

Experimental vectors.—Blaberus craniifer, U.S.A. (Wedberg et al., 1949): Massive amounts of this organism passed through the digestive tract and were recovered in the feces up to 12 days thereafter.

Blatta orientalis, U.S.S.R. (Rozengolts and I͡udina *in* Pavlovskii, 1948): After the organism was fed to the cockroaches, it was found in the intestinal tracts and feces up to the fourth day. The organism in the insects' intestinal tracts was changed, but after it was subcultured or passed through mice it regained the properties of the original strain.

Blattella germanica, Belgium (Graffar and Mertens, 1950): After a meal containing *S. typhimurium,* the digestive tracts of the cockroaches contained numerous *Salmonella* up to 10 days and some still contained pathogens on the fourteenth day. The presence of the pathogens on the exoskeleton was irregular after the fourth day, but many were still present up to the tenth day. U.S.A. (Olson and Rueger, 1950): The organism was recovered from the digestive tract 9 days after the original inoculative feeding. U.S.A. (Janssen and Wedberg, 1952): When *S. typhimurium* was fed to the cockroaches in sufficient numbers, positive cultures could be obtained from the feces up to the seventh day and from the alimentary canals up to the eleventh day after feeding. U.S.A. (Beck and Coffee, 1943): These workers reported that *B. germanica* did not disseminate the organism.

U.S.S.R. (Rozengolts and Iudina *in* Pavlovskii, 1948): Same comments as reported by these workers under *B. orientalis.*

Nauphoeta cinerea, Australia (Mackerras and Pope, 1948): Viable *Salmonella* excreted in the cockroach feces up to 16 days after inoculative feeding. In a laboratory colony of this cockroach, which had been fed on a culture of *S. typhimurium,* the entire immature insect and the intestines of adults were positive on the third, fifteenth, and twenty-fifth days after feeding. The organism was also isolated from paper from the culture jar, and from agar plates on which some of the cockroaches were allowed to walk.

Periplaneta americana, U.S.A. (Beck and Coffee, 1943): The organism is capable of being disseminated by this cockroach which apparently harbors it in the intestine as well as mechanically on the appendages. (Jung and Shaffer, 1952): This organism survived in the gut of *P. americana* fairly regularly and persisted for at least 7 days when the insects had ingested human feces containing approximately 10^4 or more viable *S. typhimurium* (strain 5609).

Periplaneta australasiae and *Supella supellectilium,* Australia (Mackerras and Pope, 1948): Organism recovered from the feces or guts from two of three *P. australasiae* and from two of two *S. supellectilium.*

Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948): The organism was fed mixed with bread and human feces. It passed unchanged through the insect. Mice fed with the intestines of *P. saussurei,* which had been infected per os, died and the organism was reisolated from the mice.

Salmonella typhosa (Zopf) White

Synonymy.—"Bacillo del tifo" of Antonelli (1930). *Bacillus typhosus.* Eberth's bacillus. "Palochki briushnogo tifa" of Pavlovskii.

Disease.—Typhoid fever.

Natural vectors.—*Blatta orientalis,* Italy (Antonelli, 1930, 1943): The organism was isolated from the legs of cockroaches captured in the homes of people who had contracted typhoid. The cockroaches had easy access to open latrines in which typhoid patients voided feces. The organism was also recovered from cockroach feces on bread and cheese collected in the same homes.

Cockroaches, U.S.A. (Englemann, 1903): Englemann described an outbreak of typhoid in Chicago and presumed cockroaches to be carriers; however, no evidence was given to support this view.

Experimental vectors.—*Blaberus craniifer,* U.S.A. (Wedberg et al., 1949): Attempts to pass the typhoid organism through this cockroach were unsuccessful. Massive doses of the organism were fed, but in no instance could it be isolated from the feces or digestive tract.

Blatta orientalis, Italy (Spinelli and Reitano, 1932): The organism was isolated from the feces and intestinal tract; it survived in the insect's gut for 9 days. Some of the organisms were recovered from the feces 3 days after the experimental meal had been ingested. U.S.A. (McBurney and Davis, 1930): Cockroaches, starved under sterile conditions for 72 hours and then fed *S. typhosa* for 120 hours, gave colonies which only once could be confirmed as *S. typhosa* by the agglutination test and reactions on sugar broths. However, organisms resembling *S. typhosa* were obtained from cockroaches fed *S. typhosa;* no such organisms were obtained prior to the experimental feeding. No tests were made to determine the virulence of *S. typhosa* that had passed through the cockroaches' intestines. U.S.S.R. (Rozengolts and I͡udina *in* Pavlovskii, 1948): The organism was found in the intestines of insects up to the twenty-third day and in the feces up to the eleventh day. However, after the third day the organism became less frequent.

Blattella germanica, U.S.A. (Janssen and Wedberg, 1952): Controlled feeding of massive doses of *S. typhosa* failed to produce a single positive stool after 24 hours in all cockroaches tested. Only 2 of 45 stools passed within the first 18 hours after the feeding were positive. The presence of a lethal agent responsible for the destruction of *S. typhosa* could not be revealed. Germany (Jettmar, 1927): Cockroaches fed typhoid cultures showed a higher mortality than those fed plague bacilli. U.S.S.R. (Rozengolts and I͡udina *in* Pavlovskii, 1948): Same comments as reported by these authors under *B. orientalis.*

Periplaneta americana, Gold Coast Colony (Macfie, 1922): The organism could not be recovered after feeding. Netherlands (Akkerman, 1933): Organism isolated from the gut, up to 2 days, and in the feces up to 3 days after feeding. Formosa (Morischita and Tsuchimochi, 1926): The feces of 40 out of 50 cockroaches fed *S. typhosa* contained this organism within 3 hours after feeding and for about 3 days thereafter. U.S.A. (T. Olson, p. c.): Organisms recovered in feces 5 days after feeding; water in containers was contaminated by mouth contact after 5 days.

Periplaneta australasiae, Formosa (Morischita and Tsuchimochi, 1926): All three insects that were fed *S. typhosa* excreted this organism in their feces within 3 hours and for about 3 days thereafter.

Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948): The organism was fed together with bread and human feces. It passed through the insect unchanged.

Cockroaches (presumably *Blatta orientalis, Blattella germanica,* and/or *Periplaneta americana*), Egypt (El-Kholy and Gohar, 1945): *S. typhosa* isolated from macerated insects and from plates over which the cockroaches had walked after they had received an inoculated meal.

Cockroaches, U.S.A. (Coplin, 1899): Cockroaches, which were allowed to walk over a culture of the organism, transferred *S. typhosa* to agar plates both from the feet and the ventral surface of the body. U.S.A. (Longfellow, 1913): Organism isolated from intestine and outer surface of body. Venezuela (Tejera, 1926): Typhoid organism isolated from feces 24 and 48 hours after the cockroaches had eaten an inoculated meal.

Serratia marcescens Bizio

This species of bacteria is normally found in water, soil, milk, foods, and insects. It has been isolated from cockroaches several times and is known to be toxic to insects. Dr. T. Olson (p. c.) isolated, from a species of *Periplaneta* received in a shipment from the south, a strain of *S. marcescens* which was toxic to mice when administered intraperitoneally.

Shigella alkalescens (Andrewes) Weldin

Disease.—Dysentery in man.

Natural vectors.—*Periplaneta americana,* U.S.A. (Bitter and Williams, 1949, 1949a): Organism isolated from the intestinal tract.

Shigella dysenteriae (Shiga) Castellani and Chalmers

Synonymy.—*B. dysenteriae* Shiga of Pavlovskii.

Disease.—Dysentery in man and monkeys.

Experimental vectors.—*Blatta orientalis,* Italy (Spinelli and Reitano, 1932): The dysentery organisms passed unharmed through the digestive tract and were isolated from the intestinal tract and feces 6 days and 96 hours, respectively, after an experimental meal; the organism was also regurgitated.

Periplaneta americana, Formosa (Morischita and Tsuchimochi, 1926): Feces of 30 cockroaches fed a culture of this organism were 100 percent contaminated. Feces excreted 48 hours after feeding were mostly positive, and those after 58 hours were entirely negative. At dissection after 70 hours, the contents of the digestive tracts were all sterile. Cockroaches killed after 48 hours still contained the organism.

Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948): The organism was fed mixed with bread and human feces. It passed through the insect unchanged.

Shigella paradysenteriae (Collins) Weldin

Synonymy.—Bacillus dysenteriae (Flexner) of Macfie. *B. flexneri* of Pavlovskii.

Disease.—Dysentery in man; summer diarrhoea in children.

Natural vectors.—Shelfordella tartara, Tadzhikistan (Zmeev, 1940): The organisms were isolated in a viable state from the stomach of the cockroach. This cockroach occurs in houses in Central Asia where it may play some part in maintaining domestic foci of the disease. Pavlovskii (1948) stated that Zmeev isolated Flexner's dysentery bacillus from four cockroaches of this species caught in a food cupboard in a hospital.

Experimental vectors.—Periplaneta americana, Gold Coast Colony (Macfie, 1922): The organism was not recovered in the feces.

Polyphaga saussurei, U.S.S.R. (Zmeev *in* Pavlovskii, 1948): When the organism was fed in bread and human feces, it passed through the insect unchanged.

Cockroaches, Venezuela (Tejera, 1926): The organism was recovered from feces 24 hours after an experimental feeding but not after 4 days.

Family PARVOBACTERIACEAE

Brucella abortus (Schmidt and Weis) Meyer and Shaw

Disease.—Cause of infectious abortion in cattle, mares, sheep, rabbits, guinea pigs, and all other domestic animals except hogs. Causes undulant fever in man.

Experimental vectors.—Periplaneta americana, U.S.A. (Ruhland and Huddleson, 1941): Organism did not remain alive in intestinal tract of cockroach for more than 24 hours.

Malleomyces mallei (Zopf) Pribram

Synonymy.—"Bacillo della morva" of Cao.

Disease.—Glanders in horses, other domestic animals, and man.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): This organism passed unchanged through the gut with the feces and retained its virulence.

Pasteurella multocida (Lehmann and Neumann) Rosenbusch and Merchant

Synonymy.—"B. del colera dei polli" of Cao (1906) was interpreted by Pierce (1921) and Steinhaus (1946) as *Bacterium cholerae gallinarum.* Hühnercholerabacterien. *Pasteurella avicida.*

Disease.—The cause of hemorrhagic septicemia in birds and mammals; chicken cholera.

Experimental vectors.—*Blatta orientalis,* Germany (Küster, 1902, 1903): In 1902 Küster found that the organism passed through the intestine of the insect without losing its virulence; but in 1903, after he fed the organism to cockroaches it was not recovered. Italy (Cao, 1906): Cao found that the bacterium of chicken cholera, which had lost virulence, regained part of its virulence after passage through the cockroach's intestine.

Pasteurella pestis (Lehmann and Neumann) Holland

Synonymy.—"Bacillo della peste bubbonica di Kitasato e Yersin" of Cao.

Disease.—Causative organism of plague in man, rats, other rodents. Infectious for mice, guinea pigs, and rabbits.

Natural vectors.—*Blatta orientalis,* Hong Kong (Hunter, 1906): Insects collected from plague-infected foci contained *P. pestis.* Transmission of plague by flea bites and feces is now well established. Presumably for cockroaches to serve as vectors of this disease, they would have to contaminate wounds (bites?) with infected, regurgitated material or infected feces, or be eaten by the host.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898). Germany (Küster, 1903). Cao found that the organism passed through the gut of the insect unchanged in virulence. Küster found that after fresh cockroach feces had been injected into a rat, the animal died of plague; feces over 24 hours old were not infectious.

Blattella germanica, Germany (Jettmar, 1927): Cockroaches remained alive while being fed *P. pestis* for one month. The organism lost its virulence in the intestine of the insect, and it was not possible to infect guinea pigs with fresh feces from bacteria-fed cockroaches.

Leucophaea maderae and *Periplaneta americana,* Philippine Islands (Barber, 1912): In one experiment, 11 *P. americana* and 15 *L. maderae* were inoculated in the leg with a virulent strain of *P. pestis.* Eleven of these insects died within 2 days; six of the dead insects showed pure *P. pestis* cultures. In another experiment, 61 cockroaches were inoculated with virulent *P. pestis.* Nine of these showed, at necropsy, pure cultures of bacilli morphologically resembling *P. pestis.*

Massive doses of *P. pestis* failed to infect most of the insects when injected into the body.

Cockroaches, Australia (Pound, 1907) : Pound suspected that control guinea pigs in his laboratory became infected with plague by eating food contaminated by cockroaches. In the laboratory, rats may be infected with plague by ingesting the bacteria (Rosenau, 1940).

Family BACILLACEAE

Bacillus anthracis Cohen emend. Koch

Synonymy.—"Bacillo del carbonchio" of Cao. Milzbrandbacillen of Küster.

Disease.—Cause of anthrax in man, cattle, sheep, and swine.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898, 1906) : Organism passed through the gut unchanged. It was excreted in the feces for a month after a single feeding. Attenuated *B. anthracis* regained full virulence in some experiments but not in others (Cao, 1906). Germany (Küster, 1903) : Virulence was proved by injection of recovered organism into white mice.

Bacillus subtilis Cohn emend. Prazmowski

Disease.—After passage through the cockroach's intestine, the bacterium became pathogenic to laboratory animals (Cao, 1898). Normally found in soil and decomposing organic matter.

Natural vectors.—*Blaberus craniifer,* U.S.A. (Wedberg et al., 1949) : From feces.

Blatta orientalis, Italy (Cao, 1898, 1906) : From intestinal contents. (Spinelli and Reitano, 1932) : Feces. France (Sartory and Clerc, 1908) : Feces. Poland (Nicewicz et al., 1946) : Feces.

Cryptocercus punctulatus, U.S.A. (Hatcher, 1939) : From feces.

Periplaneta americana, England (Shrewsbury and Barson, 1948) : Intestinal tract.

Cockroaches, U.S.A. (Longfellow, 1913) : Outer part of body and intestinal tract.

Experimental vectors.—*Blatta orientalis,* Italy (Cao, 1898, 1906) : Organism recovered from intestinal tract.

Clostridium feseri Trevisan

Synonymy.—"Bacillo del carbonchio sintomatico" of Cao.

Disease.—Cause of black leg or symptomatic anthrax in cattle and other animals. Habitat: Probably manured soil.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): Organism passed unchanged through the gut with the feces and retained its virulence.

Clostridium novyi (Migula) Bergey et al.
or
Clostridium sporogenes (Metchnikoff) Bergey et al.

Synonymy.—"Bacillo dell'edema maligno" of Cao. Steinhaus (1946) considered Cao's organism to be *C. sporogenes.* Smith et al. (1948) stated that *C. novyi* was isolated in 1894 from guinea pigs with "malignant edema" and that it will probably never be settled whether *C. sporogenes* is identical with Koch's bacillus of malignant edema. Obviously there is no way of properly identifying Cao's bacillus of malignant edema.

Source.—Gaseous gangrene; "malignant edema." Habitat: Probably manured soil.

Natural and experimental vectors.—Blatta orientalis, Italy (Cao, 1898): Isolated from feces of naturally invaded cockroach. Experimentally the organism also passed unchanged through the gut with feces and retained its virulence.

Clostridium perfringens (Veillon and Zuber) Holland

Synonymy.—Clostridium welchii.

Disease.—Gaseous gangrene. Habitat: Feces, sewage, soil.

Natural vectors.—Cockroaches (presumably *Blatta orientalis, Blattella germanica,* and/or *Periplaneta americana*), Egypt (El-Kholy and Gohar, 1945): Isolated from whole suspensions of the cockroaches. The organism that was isolated from the insects killed inoculated guinea pigs.

Clostridium tetani (Flügge) Holland

Synonymy.—"Bacillo del tetano" of Cao.

Disease.—Lockjaw or tetanus. Habitat: Soils, human and horse feces.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): Organism passed through the gut unchanged in virulence, but the tetanus-toxin itself was destroyed in the intestine.

Clostridium spp.

Disease.—About half the derived species of *Clostridium* are pathogenic (Reed *in* Dubos, 1948).

Natural vectors.—*Periplaneta americana,* England (Shrewsbury and Barson, 1948): Seven strains of *Clostridium* spp. were isolated from the alimentary tract.

Order ACTINOMYCETALES

Family MYCOBACTERIACEAE

Mycobacterium avium Chester

Common name.—Avian tubercle bacillus.

Synonymy.—"Tuberkuleznykh kultur (ptichii)" of Pavlovskii.

Disease.—Tuberculosis in chickens, other birds, and less frequently in pigs.

Experimental vectors.—*Blatta orientalis,* U.S.S.R. (Ekzempliarskaia *in* Pavlovskii, 1948): When fed a culture of *M. avium,* the cockroaches voided the organism in their feces for up to 2 months. The organism aparently increased in virulence to guinea pigs by passage through the cockroach.

Mycobacterium lacticola Lehmann and Neumann (?)

Disease.—The organism gave a slight reaction when inoculated into the skin of a guinea pig (Leibovitz, 1951).

Natural vectors.—*Periplaneta americana,* U.S.A., Texas (Leibovitz, 1951): Organism, tentatively identified as *M. lacticola,* was isolated from macerated intestines of cockroaches that had been captured in sewers.

Mycobacterium leprae (Armauer-Hansen) Lehmann and Neumann

Disease.—Hansen's disease, leprosy. Habitat: Skin of man, leprous nodules, nasal mucosa.

Natural vectors.—*Blattella germanica,* Southern Rhodesia and Kenya (Moiser, 1945, 1946, 1946a; Anonymous, 1946): Of 230 cockroaches, mostly *B. germanica,* caught in native huts in Rhodesia, 55 were positive for Hansen's bacilli. Hansen's bacilli lasted an average of 14¾ days in the cockroach, though they remained unchanged in the feces for much longer, up to 16 months. Moiser observed small, acid-fast, oval bodies in about 70 percent of the cockroaches examined. Similar bodies have been observed in man, and Moiser thinks that they may be a stage in the development of *M. leprae* in the cockroach.

Periplaneta americana and *Periplaneta australasiae,* Formosa (Arizumi, 1934, 1934a): Of 67 cockroaches caught in serious-case wards in the leprosy sanatorium near Taihoku, 26.8 percent carried *M.*

leprae-like, acid-fast bacilli in their guts. Of 105 cockroaches caught in the slight-case wards, 12.3 percent carried this bacillus.

Cockroaches, Venezuela (Tejera, 1926): Acid-resistant bacteria similar to *M. leprae* were found in cockroaches captured in leprosy colony at Cabo Blanco, but this bacterium was never encountered in cockroaches captured elsewhere. Belgian Congo (Radna, 1939): Three of eight cockroaches captured in the hut of a leprosy patient were found to excrete *M. leprae* in their feces over a period of 10 days after capture.

Experimental vectors.—Blatta orientalis, Europe (Paldrock *in* Klingmüller, 1930): After 14 days, leprous bacilli were still abundant in the feces. Nyasaland (Lamborn, 1940): In one experiment, 38 cockroaches were fed for 9 days on a crust removed 6 months earlier from the ear of a leprous patient. Feces, passed immediately after this food was removed, contained large clusters of short filamentous bacilli, presumably the leprous organism. Ten additional cockroaches were allowed to feed on a dressing just removed from a leprous sore. *M. leprae* was definitely found in feces passed on the third day after removal of this food. Acid-fast particles were recovered on the fifth, eighth, twelfth, fourteenth, and twenty-first days.

Blattella germanica, Europe (Paldrock *in* Klingmüller, 1930): The cockroaches still excreted the bacilli in the feces 14 days after feeding on leprous nodules. Southern Rhodesia and Kenya (Moiser, 1945, 1946, 1946a, 1947; Anonymous, 1946): Cockroaches were fed corn meal inoculated with material from ulcerating nodules containing *M. leprae.* These bacilli were recovered in large numbers from the guts (up to the nineteenth day after feeding) and from dried feces of the insects. The bacilli remained morphologically unchanged in dried feces for several months. The bacilli were found in the feces of a series of five cockroaches, each fed the powdered dry feces of its predecessor.

Nauphoeta cinerea, Nyasaland (Lamborn, 1940): Thirty-four newly born cockroaches fed for 3 days on a dressing removed from a leprous sore. Globi were found in abundance in feces passed on the third day. Acid-fast organisms were recovered at intervals over a period of 66 days. Similar results were obtained with 10 other cockroaches. Feces of a control series of cockroaches remained free of acid-fast organisms.

Periplaneta americana, Gold Coast Colony (Macfie, 1922): The insects were fed scrapings from the nose of a leper. *M. leprae* appeared in the feces for 2 days after the meal. The organism appeared to pass unharmed through the intestine of the cockroach.

Periplaneta americana and *Periplaneta australasiae,* Formosa (Arizumi, 1934, 1934a): When fed an emulsion of leprous nodules, the cockroaches began to excrete *M. leprae* in their feces within 8 hours. This excretion of bacilli continued for 94 hours, but showed the highest positive infection 20, 32, and 44 hours after feeding. Morphologically the bacilli appeared to be unharmed by passage through the gut.

Cockroaches, Belgian Congo, Pawa (Radna, 1939): Three cockroaches were fed on leprous material and Hansen's bacilli were isolated from their feces. Venezuela (Tejera, 1926): Cockroaches were fed with material containing a large quantity of *M. leprae;* the intestinal contents were positive up to the eleventh day for acid-fast bacilli morphologically identical to *M. leprae.* India, Calcutta (Leprosy Research Department, 1948): Cockroaches whose feces were free of acid-fast bacilli for 3 consecutive days were fed leprous material. Acid-fast bacilli were obtained in decreasing number for 2 weeks thereafter.

Mycobacterium lepraemurium Marchoux and Sorel

Common name.—Rat leprosy bacillus.

Disease.—Endemic disease of rats in various parts of world.

Experimental vectors.—Cockroaches, Belgian Congo (Radna, 1939): The day after feeding on infectious material, the insects excreted acid-fast bacteria in their feces. The feces were diluted in physiological saline and injected into five wild rats. Two of the rats died after 134 and 156 days, respectively. Both had general visceral and ganglionic leprosy.

Mycobacterium phlei Lehmann and Neumann

Disease.—Injection into guinea pigs results in local abscesses. Widely distributed in soils, dust.

Natural vectors.—*Periplaneta americana,* U.S.A., Texas (D. W. Micks, p. c.): Organism isolated from batches of intestinal tracts of these cockroaches taken at random. Micks also found *Mycobacterium* spp. and *M. friedmanii* on the cockroaches. The latter is apparently pathogenic only to cold-blooded animals. U.S.A., Texas (Leibovitz, 1951): Leibovitz isolated an organism that he tentatively identified as *M. phlei* from the macerated intestines of cockroaches collected in sewers.

Mycobacterium piscium Bergey et al.

Synonymy.—"Tuberkuleznykh kultur (rybii)" of Pavlovskii, 1948.

Disease.—Infectious for carp, frogs, lizards, but not for guinea pigs and pigeons (Breed et al., 1948). Leibovitz (1951) found that the organism he isolated produced a marked reaction when inoculated into the skin of a guinea pig.

Natural vectors.—Periplaneta americana, U.S.A., Texas (Leibovitz, 1951): Organism, tentatively identified as *M. piscium,* was isolated from macerated intestines of cockroaches captured in sewers.

Experimental vectors.—Blatta orientalis, U.S.S.R. (Ekzempliarskaia *in* Pavlovskii, 1948): The organism was excreted in the feces for up to 2.5 months after it was fed to the cockroach. The virulence to guinea pigs increased on passage through the cockroach.

Mycobacterium tuberculosis (Schroeter) Lehmann and Neumann

Synonymy.—"Bacillo di Koch" of Cao. "Tuberkuleznykh kultur (chelovecheskii, bychii)" of Pavlovskii.

Common name.—Human tubercle bacillus.

Disease.—Tuberculosis in man; transmissible to rabbits and guinea pigs.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): The organism passed unchanged in virulence through the insect with the feces. Germany (Küster, 1903): Küster fed the insects pure culture of tubercle bacillus in potato mash. After 2 days, he recovered a great mass of *M. tuberculosis* in the feces. He injected some of this excreted material into guinea pigs 3 and 9 days after a feeding. Both died of typical tuberculosis after 2 months. U.S.S.R. (Ekzempliarskaia *in* Pavlovskii, 1948): *M. tuberculosis* var. *hominis* and *M. tuberculosis* var. *bovis,* when fed in culture, were excreted in the feces for up to 2 months thereafter. The virulence (tested in guinea pigs) of these organisms was somewhat weakened by passage through the cockroach.

Blattella germanica, on shipboard (Morrell, 1911): *M. tuberculosis* was present in the feces within 24 hours after the insect had fed on sputum from a tuberculous patient.

Periplaneta americana, Gold Coast Colony (Macfie, 1922): The feces of cockroaches fed tuberculous sputum were examined daily. Feces passed from the second to fifth day contained tubercle bacilli; from the sixth to the fourteenth day, when examinations were stopped, no more tubercle bacilli were detected.

Cockroaches, Venzeuela (Tejera, 1926): A group of 30 cockroaches were fed sputum containing *M. tuberculosis,* over a 3-day period. Ninety percent of the feces excreted over several days contained typical acid-fast bacilli. Some of these insects, when killed 40 days later, contained bacilli morphologically identical to *M. tuberculosis.* U.S.A. (Read, 1933) : The insects were fed tuberculosis sputum for 48 hours. After the insects had been fed, their digestive tracts were ground and injected into guinea pigs; these animals developed typical tuberculous lesions.

Mycobacterium spp.

Disease.—Most species in this genus are animal parasites.

Natural vectors.—*Periplaneta americana,* U.S.A., Texas (D. W. Micks, p. c.; Liebovitz, 1951) : Organism isolated from intestinal tract.

Family ACTINOMYCETACEAE

Nocardia sp. (?)

Disease.—Nocardiosis is an infection, caused by various species of this genus, with symptoms similar to peritonitis, pneumonitis, pseudotuberculosis, meningitis, abscesses.

Natural vectors.—*Periplaneta americana,* U.S.A., Texas (Leibovitz, 1951) : Organism, tentatively identified as *Nocardia* sp., was isolated from macerated intestines of cockroaches that had been captured in sewers.

PART II. PATHOGENIC BACTERIA WHOSE TAXONOMIC POSITION IS UNCERTAIN

The following organisms are either not listed in Breed et al. (1948) or are stated by them to be difficult to classify.

"B. aerobio del pseudoedema maligno" of Cao

Disease.—Pathogenic to rabbits.

Natural vectors.—*Blatta orientalis,* Italy (Cao, 1906) : Isolated from feces.

"B. del pseudoedema maligno" of Cao

Disease.—Pathogenic to guinea pigs.

Natural vectors.—*Blatta orientalis,* Italy (Cao, 1906) : Organism isolated from feces.

"Bacillo proteisimile" of Cao

Disease.—A *Proteus*-like organism pathogenic to guinea pigs and rabbits.

Natural vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): Isolated from the intestinal contents.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1906): Organism that was recovered from feces after being fed to the insects was lethal to guinea pigs within 48 to 60 hours.

"Bacillo del barbone dei bufali" of Cao

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): The bacillus of buffalo cholera retained its virulence after ingestion and passage through the insect.

"Bacillo similcarbonchio" of Cao

Disease.—An anthraxlike bacterium pathogenic to guinea pigs, rabbits, and pigeons.

Natural vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): Isolated from the intestinal contents.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1906): Strains C and D of this organism killed guinea pigs when reisolated from the cockroach's feces.

"Bacillo similtifo" or "Bacillo tifosimile" of Cao

Disease.—A typhoidlike bacterium pathogenic to guinea pigs and rabbits.

Natural vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): Isolated from the intestinal contents.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1906): Organism acquired pathogenicity on passage through intestinal tracts of cockroaches after being fed to the insects in a liver infusion. The bacteria survived in the intestines for 2 to 3 months.

Paracolon bacilli

Source.—May cause clinical dysentery. Strains of paracolon bacilli have been isolated from cases of enteritis in man, food poisoning, infections of genitourinary tract, powdered eggs, and fatal infections in chickens, turkeys, and snakes.

Natural vectors.—Cockroaches (presumably *Blatta orientalis, Blattella germanica,* and/or *Periplaneta americana*), Egypt (El-Kholy and Gohar, 1945): Organisms isolated from suspensions of macerated whole insects.

Sarcina alba "patogena" of Cao

Disease.—Pathogenic to guinea pigs and rabbits. The organism differed from *Sarcina alba* only in its pathogenic properties.

Natural vectors.—Blatta orientalis, Italy (Cao, 1898, 1906): Organism isolated from the intestinal contents; it retained its virulence after passage through the cockroach.

Sarcina "bianca" and "gialla" of Cao

Disease.—After passage through the gut of the cockroach, the white and yellow *Sarcina* became pathogenic to guinea pigs and rabbits.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898).

Spirochaeta periplanetae Laveran and Franchini

Disease.—Possibly pathogenic to white mice.

Natural vectors.—Blatta orientalis, France (Laveran and Franchini, 1920a): Of five white mice inoculated with the contents of the digestive tubes of cockroaches inoculated with the spirochaete, one died 24 hours and another 48 hours after inoculation; two others became infected and one was unaffected. However, the pathogenicity of this organism is questionable, inasmuch as the entire intestinal contents of the insect were inoculated into the mice.

Streptococcus microapoika Cooper, Keller, and Johnson

Disease.—From throat and feces of children with enteritis.

Natural vectors.—Blatta orientalis, Poland (Nicewicz et al., 1946): Organism isolated from alimentary tract.

Streptococcus non-hemolyticus II Holman

Disease.—Isolated from various human and animal infections.

Natural vectors.—Periplaneta americana, England (Shrewsbury and Barson, 1948): Organism isolated from alimentary tract.

PART III. NEGATIVE FINDINGS

The following organisms were not recovered after they were fed to cockroaches.

Actinomyces asteroides (Eppinger) Gasperini

[=*Streptothrix eppingeri* Rossi-Doria (Dodge, 1935).]

Disease.—Organism found in brain abscess and in peritonitis (Dodge, 1935).

Cockroach.—Blatta orientalis (Cao, 1898).

Actinomyces carneus (Rossi-Doria) Gasperini

Disease.—Organism reported from a case of chronic bronchitis; pathogenic to rabbit and guinea pig (Dodge, 1935).

Cockroach.—*Blatta orientalis* (Cao, 1898).

Neisseria gonorrhoeae Trevisan

Disease.—Gonorrhoea and other infections in man.

Cockroach.—*Periplaneta americana* (Macfie, 1922).

Spirochaeta crocidurae Leger (I) and Spirochaeta hispanica de Buen (II)

Diseases.—(I) Blood parasite of a shrew-mouse in Senegal; (II) cause of Spanish and Moroccan relapsing fever.

Cockroaches, Tunisia(?) (Wollman, 1927; Wollman et al., 1928): Cockroaches externally contaminated with the blood parasites were macerated and injected into peritoneum of a rat. No spirochaetes were found in the blood of this rat.

The following cockroaches were examined for pathogenic bacterial infections, with negative results, by Eads et al. (1954) in Texas:

Blatta orientalis, 54 insects in 15 pools from sewer manholes.

Blattella germanica, 118 insects in 5 pools from food establishments.

Periplaneta americana, 70 insects in 5 pools from food establishments.

Supella supellectilium, 235 insects in 11 pools from food establishments.

APPENDIX C: FUNGI

PATHOGENIC FUNGI ASSOCIATED WITH COCKROACHES

Phylum THALLOPHYTA

Class FUNGI IMPERFECTI

Order MONILIALES

Family MONILIACEAE

Aspergillus fumigatus Fresenius

Disease.—Aspergillosis, an inflammatory infection of the sinuses, bronchi, lungs, and sometimes other parts of the body (Smith et al., 1948).

Natural vectors.—Blatta orientalis, France (Sartory and Clerc, 1908): Organism isolated from the insects' intestinal contents.

Aspergillus niger van Tieghem

Disease.—This species is predominantly saprophytic but is occasionally parasitic in the human ear (Dodge, 1935).

Natural vectors.—Periplaneta americana, U.S.A., Texas (O. B. McShan, 1953): Organism isolated from the feces of cockroaches collected in a grain elevator basement at the Galveston docks.

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): The organism passed unchanged through the gut of the insects.

Geotrichum candidum Link

Synonymy.—Oidium lactis (Dodge, 1935).

Disease.—Geotrichosis, an infection producing lesions in the mouth, intestinal tract, bronchi, and lungs (Conant et al., 1954).

Experimental vectors.—Blatta orientalis, Italy (Cao, 1898): The organism retained its pathogenicity after passing through the gut.

NEGATIVE FINDINGS

The following organism was not recovered in the cockroaches' feces after feeding experiments.

Histoplasma capsulatum Darling

Disease.—Histoplasmosis, an infectious mycosis that usually results in a pulmonary disease of man.

Cockroach.—*Periplaneta americana,* U.S.A., Texas (O. B. McShan, 1953): 24 hours after the insects had been fed an inoculated meal, they showed no evidence of fungus invasion as determined by fecal cultures and inoculation into mice. The organism could be detected in the cockroaches' intestinal contents 30 minutes after inoculation, but thereafter all pools were negative.

APPENDIX D: PROTOZOA

PATHOGENIC PROTOZOA ASSOCIATED WITH COCKROACHES

Information on the diseases caused by protozoa was taken from Chandler (1949) and Faust (1955). The classification follows Kudo (1954).

Phylum PROTOZOA

Class MASTIGOPHORA

Order PROTOMONADINA

Family TRYPANOSOMATIDAE

Herpetomonas periplanetae Laveran and Franchini

Disease.—Possibly pathogenic to white mice.

Natural vectors.—*Blatta orientalis,* Italy (Laveran and Franchini, 1920): The contents of the digestive tract of *B. orientalis,* containing *H. periplanetae,* were injected into eight white mice; five mice died. The pathogenicity of this organism is questionable, inasmuch as the entire intestinal contents were injected rather than a pure culture of the protozoan.

Order POLYMASTIGINA

Family TRICHOMONADIDAE

Trichomonas hominis (Davaine)

Disease.—The pathogenicity of *T. hominis* has not been proved, but it is often associated with persistent diarrhea, for which it may or may not be responsible.

Experimental vectors.—*Blatta orientalis,* South Africa (Porter, 1918): The cockroaches ingested this organism by feeding on infected human feces. *T. hominis* passed unchanged through the insects' intestines and was successfully transferred to rats. Italian Somaliland (Mariani and Besta, 1936): Human *Trichomonas,* presumably *T. hominis,* and *Chilomastix* were fed to cockroaches on bread. The flagellates were present in 60 percent of the cockroaches examined in the first 48 hours, in 25 percent of the insects after 10 days, and in 10 percent after 20 days. In a second experiment these flagellates were present in 66 percent of the cockroaches after 3 days, and in 33 percent after 10 days.

Periplaneta americana, South Africa (Porter, 1918): See comments under *B. orientalis.* U.S.A. (Hegner, 1928): *T. hominis,* ingested with human feces, was destroyed in the crop of the insect within 2 to 5½ hours. No flagellates were found in the insects after 2 days; very few survived until they reached the intestine.

Family HEXAMITIDAE

Giardia intestinalis (Lambl)

Synonymy.—Giardia lamblia; Lamblia intestinalis.

Disease.—Although a majority of persons harboring *G. intestinalis* are asymptomatic, others have a persistent diarrhea.

Experimental vectors.—Blatta orientalis, South Africa (Porter, 1918): The cockroaches were fed on human excrement that contained *G. intestinalis.* Cysts of this protozoan passed unchanged through the cockroaches and were recovered from their feces. These same cysts, when fed to rats, caused diarrhea.

Blattella germanica, Brazil (Pessoa and Correa, 1927): Adults and nymphs were fed cysts of *G. intestinalis.* These cysts were recovered from feces up to 5 days after feeding. The greatest number of living cysts was found 48 hours after feeding.

Eurycotis floridana, U.S.A. (Young, 1937): Experiments showed that cysts fed to adults and nymphs reached the insects' colons within 2 hours.

Leucophaea maderae, Brazil (Pessoa and Correa, 1927): Nymphs only of this species were used. Thirty-four living cysts were found in the feces up to 7 days after feeding.

Periplaneta americana, South Africa (Porter, 1918): See comments following *B. orientalis.* Gold Coast Colony (Macfie, 1922): In two experiments, cysts of *G. intestinalis,* fed in human feces, passed through the cockroaches' intestines apparently unharmed and unchanged. Brazil (Pessoa and Correa, 1927): Live cysts were found in the feces up to 5 days after feeding. Two specimens regurgitated a milky fluid, up to one-half hour after feeding, that contained live cysts. U.S.A. (Young, 1937): See comments under *E. floridana.* Cysts remained in the insects' intestines as long as 12 days, but the viability of these cysts was not tested.

Periplaneta brunnea, U.S.A. (Young, 1937): See comments under *E. floridana* and after Young under *P. americana.*

Cockroaches, Venezuela (Tejera, 1926): A group of 30 cockroaches were fed human feces containing many cysts and mobile forms of *G. intestinalis*. Within 24 hours the feces of 8 of 10 cockroaches contained cysts. Cysts were present in the feces of all insects examined after 48 hours. Of 10 cockroaches killed after 8 days, 2 had mobile *G. intestinalis* in the intestines. Argentina (Bacigalupo *in* Tejera, 1926, p. 256): Cysts of *G. intestinalis* were eliminated by cockroaches in the same form as ingested.

Giardia sp.

Natural vectors.—Cockroaches, Venezuela (Tejera, 1926): Cysts morphologically identical to those of *Giardia* (species not determined) were found in the intestinal contents of 5 percent of the cockroaches captured in latrines.

Class SARCODINA

Order AMOEBINA

Family ENDAMOEBIDAE

Entamoeba histolytica Schaudinn

Synonymy.—Endamoeba histolytica; Entamoeba dysenteriae. (Kudo, 1954, separated *Entamoeba* from *Endamoeba* by nuclear characteristics.)

Disease.—Amoebic dysentery in man.

Natural vectors.—Periplaneta americana and/or *Blattella germanica*, Cairo, Egypt (DeCoursey and Otto, 1956): 9 of 217 cockroaches collected in restaurants contained cysts morphologically resembling *E. histolytica*. Of 44 cockroaches collected in 2 villages, 5 contained this protozoan.

Cockroaches, Venezuela (Tejera, 1926): Cysts resembling those of *E. histolytica* were found in the intestinal contents of cockroaches captured in the sewer of a hospital and in a kitchen near a latrine. Two young cats were fed milk containing feces from some of these cockroaches; both cats in a few days passed feces which contained amoebae of the Schaudinn type.

Cockroaches (presumably including *Blatta orientalis, Blattella germanica, Periplaneta americana, Periplaneta australasiae,* and *Supella supellectilium*). Peru (Schneider and Shields, 1947): One hundred cockroaches were captured and the legs and intestinal contents of each were cultured. No protozoa were found on the legs, but *E. histolytica* was found in 7 percent of the cultures of intestinal tracts.

Experimental vectors.—Blatta orientalis. Italian Somaliland (Mariani and Besta, 1936) : Vegetative and precystic forms of *E. histolytica* were found in 33 percent of the cockroaches examined 24 to 48 hours after they had fed on bread inoculated with this organism. A few cystic forms were found in one of the cockroaches after 10 days.

Periplaneta americana, Gold Coast Colony (Macfie, 1922). Cockroaches used in this experiment were carefully examined for amoebic invasions because some of these insects at Accra had been found naturally invaded (whether by *E. histolytica, E. coli,* or both is not clear). Cysts of *E. histolytica* were found in the feces of seven of nine cockroaches fed human feces containing cysts of this organism. The cysts appeared to be unharmed by passage through the insects; they were seen in the feces for only 1 to 3 days. U.S.A. (Frye and Meleney, 1936) : The cockroaches were fed on a culture of cysts mixed with rice flour and sugar. Cysts were first found in the feces 16 to 20 hours after the cysts had been eaten. Development of this protozoan was obtained from cysts collected in cockroach feces after 48 hours.

Cockroaches, Venezuela (Tejera, 1926) : Nymphal cockroaches were fed feces containing numerous cysts and mobile forms of *E. histolytica.* After 24 hours, the feces of 6 of 20 cockroaches contained cysts. After 48 hours, the feces of 8 of another 20 cockroaches contained cysts. Three days later, 6 cockroaches of another group produced cysts. The cysts were verified as dysenteric amoebae by feeding contaminated cockroach feces to three kittens. A few days latter, the kittens showed unmistakable signs of dysentery and typical dysenteric amoebae were found in their feces.

Class CILIATA

Order SPIROTRICHA

Family BURSARIIDAE

Balantidium coli (Malmsten)

Disease.—Dysentery and diarrhea in man and monkeys.

Experimental vectors.—Cockroaches, Venezuela (Tejera, 1926) : 30 cockroaches were fed hog feces containing many *B. coli* cysts. After 24 hours, 4 of 10 cockroaches passed cysts in their feces. After 48 hours, the feces of 8 of 10 cockroaches contained cysts. Typical *B. coli* cysts were found in the intestines of the remaining 10 insects. A monkey (*Cebus capucinus*) was infected with *B. coli* by eating cockroach intestinal contents that contained cysts. Dysentery developed with attendant diarrhea. Numerous *B. coli* were recovered from the contents of the monkey's colon.

APPENDIX E: HELMINTHS

Information on the helminthic diseases was taken from Chandler (1949) and Faust (1955). The classification follows Hyman (1951, 1951a).

Parts I and II contain positive associations of cockroaches with helminths. Part III contains doubtful records, and Part IV contains negative findings.

PART I. PATHOGENIC HELMINTHS WHOSE EGGS HAVE BEEN CARRIED BY COCKROACHES

Phylum PLATYHELMINTHES

Class TREMATODA

Order DIGENEA

Family SCHISTOSOMATIDAE

Schistosoma haematobium (Bilharz, 1852) Weinland, 1858

Common name.—The vesical blood fluke.

Disease.—Vesical schistosomiasis or vesical bilharziasis, endemic hematuria.

Experimental vectors.—Periplaneta americana, Gold Coast Colony (Macfie, 1922): The eggs passed unharmed through the insect and appeared in the feces the following day.

Class CESTODA

Order TAENIOIDEA

Family HYMENOLEPIDIDAE

Hymenolepis sp.

Disease.—Tapeworm infections.

Natural vectors.—Periplaneta americana, Formosa (Morischita and Tsuchimochi, 1926): Eggs of this worm were often found in feces and intestinal contents of cockroaches captured in the animal house of the Government Research Institute.

Polyphaga saussurei, Tadzikhistan (Zmeev, 1936): In two instances, a single egg of *Hymenolepis* sp. was found in the cockroaches' intestines. In one, the egg was deformed while in the other it was undamaged. In the area where these insects were collected, numerous rats (*Nesokia indica*) were commonly infected with *Hymenolepis diminuta.*

Family TAENIIDAE

Taenia saginata Goeze, 1782

Common name.—The beef tapeworm.

Disease.—Beef tapeworm infections.

Experimental vectors.—Periplaneta americana, Gold Coast Colony (Macfie, 1922): The eggs passed unharmed through two of four cockroaches; in one only shrunken eggs were seen, and in the fourth no eggs were found. There were few eggs in the human feces used in these experiments.

Family Unknown

Undetermined tapeworm eggs

Natural vectors.—Polyphaga saussurei, Tadzhikistan (Zmeev, 1936): Eggs similar to cestode eggs (Taenioidea) found in humans were found in the intestine and appeared to be uninjured. Several cestode eggs were found in 2 of 154 cockroaches which had been collected in ruined houses heavily contaminated with feces.

Phylum ASCHELMINTHES

Class NEMATODA

Order OXYUROIDEA

Family OXYURIDAE

Enterobius vermicularis (Linnaeus, 1758) Leach in Baird, 1853

Common name.—Human pinworm or seatworm.

Disease.—Enterobiasis or oxyuriasis.

Natural vectors.—Blatta orientalis, U.S.S.R. (Sondak, 1935): In the 412 cockroaches examined, one egg was isolated from the rectum of a specimen caught in a buffet.

Blattella germanica, U.S.S.R. (Sondak, 1935): In the 788 cockroaches examined, one egg was isolated from the rectum of a specimen caught in a bakery and another in a specimen caught in a factory kitchen.

Order ASCAROIDEA

Family ASCARIDAE

Ascaris lumbricoides Linnaeus, 1758

Common name.—Giant intestinal roundworm.

Disease.—Ascariasis.

Natural vectors.—*Periplaneta americana,* South Africa, Vrededorp (Porter, 1930): One specimen contained ova of *Ascaris lumbricoides* or *Ascaris suum* Goeze, 1782 (=*Ascaris suilla*), which indicates the ingestion of human or pig feces by the cockroach.

Experimental vectors.—*Periplaneta americana,* Gold Coast Colony (Macfie, 1922): The eggs passed unharmed with the feces of the insects for a day or two after feeding. In one experiment, feces passed 4 days after ingestion of the inoculated meal contained eggs which had developed slightly. India, Western Bengal (Chandler, 1926): The cockroaches were fed human feces containing eggs of *Ascaris* (species not mentioned but presumably *lumbricoides*). Small numbers of eggs were recovered in the feces.

Periplaneta americana, Periplaneta australasiae, Neostylopyga (=*Dorylaea*) *rhombifolia,* Formosa (Morischita and Tsuchimochi, 1926): Human feces containing *Ascaris* eggs were fed to these cockroaches; 15 of 32 *P. americana,* 6 *P. australasiae,* and 6 *N. rhombifolia* excreted viable eggs 1 to 4 days (*P. americana*) or 1 or 2 days after the inoculated meal. Eggs in cockroach feces that had remained dry for some hours developed when cultured.

Ascaris sp.

Disease.—Parasite of mammals.

Natural vectors.—*Blatta orientalis,* Somaliland (Mariani and Besta, 1936): 1 of 93 cockroaches examined contained ova of an undetermined species of *Ascaris.*

Order STRONGYLOIDEA

Family ANCYLOSTOMIDAE

Ancylostoma caninum (Ercolani, 1859) Hall, 1913

Disease.—Common hookworm of dogs and cats in temperate climates.

Experimental vectors.—*Periplaneta americana,* Netherlands (Akkerman, 1933): Cockroaches were fed dog feces containing eggs of *A. caninum* and *A. ceylanicum* or banana mixed with eggs of both worms. Five of ten cockroaches fed dog feces and four of eight cockroaches fed eggs in banana passed feces from which one to seven hookworm larvae were cultured. At least seven other cockroaches passed from 3 to 14 viable hookworm eggs within 24 hours after feeding; one of these passed 23 eggs in the feces 3 days after feeding. In conclusion, Akkerman doubted the conception of Chandler (1926) (see *Necator americanus*) concerning the destruction of hookworm eggs in the proventriculus of the cockroach.

Ancylostoma ceylanicum (Looss, 1911) Leiper, 1915

Diease.—Hookworm of dogs and, rarely, in man (Brumpt, 1949).

Experimental vectors.—*Periplaneta americana,* Gold Coast Colony (Macfie, 1922): The eggs passed unharmed through the gut and were recovered in the feces. Netherlands (Akkerman, 1933): See comments under *Ancylostoma caninum.*

Ancylostoma duodenale (Dubini, 1843) Creplin, 1845

Common name.—Old World hookworm.

Disease.—Human hookworm infection of temperate climates in Eastern Hemisphere.

Natural vectors.—*Periplaneta americana,* South Africa (Porter, 1929, 1930): The cockroach acted as a mechanical carrier in the gold mines. Ninety-seven cockroaches were examined from four mines; 8.2 percent of the insects contained viable hookworm eggs and larvae.

Experimental vectors.—*Periplaneta americana,* Gold Coast Colony (Macfie, 1922): The eggs passed unharmed through the gut and appeared in the feces for 1 to 3 days after the inoculative meal. Many eggs in the feces contained living embryos.

Necator americanus (Stiles, 1902) Stiles, 1906

Common name.—Tropical hookworm.

Disease.—Human hookworm infection of warm climates.

Natural vectors.—*Periplaneta americana,* India, western Bengal (Chandler, 1926): The American cockroach ingested the ova of *N. americanus* that were present in human feces in mines. Though a few eggs passed through the gut in a viable condition, most were destroyed in the proventriculus. Chandler concluded that the cockroach played an important role in *controlling* hookworm infection so long as other food was not available and the human stools were not concentrated too much in one area. However, in contrast to this conclusion, see Macfie (1922) below, Porter (1929, 1930) under *An-*

cylostoma duodenale, Akkerman (1933) under *Ancylostoma caninum*, and Morischita and Tsuchimochi (1926) under Hookworms.

Experimental vectors.—*Periplaneta americana*, Gold Coast Colony (Macfie, 1922): The eggs passed unharmed through the gut. See also comments after Macfie under *Ancylostoma duodenale*.

Hookworms

Disease.—Human hookworm infections.

Experimental vectors.—*Periplaneta americana*, *Periplaneta australasiae*, and *Neostylopyga rhombifolia*, Formosa (Morischita and Tsuchimochi, 1926): 9 of 21 *P. americana*, 3 of 7 *P. australasiae*, and 3 of 6 *N. rhombifolia*, when fed with hookworm eggs, excreted viable eggs for 1 to 3 days after feeding. In fresh cockroach feces that were not yet dry, the eggs showed good development and often contained larvae which soon hatched.

Family TRICHOSTRONGYLIDAE

Trichostrongylus sp.

Disease.—Intestinal parasites of birds, ruminants, and man.

Natural vectors.—*Blatta orientalis*, Somaliland (Mariani and Besta, 1936): 1 of 93 cockroaches examined contained ova of this parasite.

Order TRICHUROIDEA

Family TRICHURIDAE

Capillaria hepatica (Bancroft, 1893) Travassos, 1915

Common name.—The capillary liver worm.

Disease.—Tissue parasite in the liver of domestic and wild mammals and occasionally in man.

Experimental vectors.—*Blatta orientalis*. According to Giordano (1950), the eggs of *C. hepatica* can pass unchanged through the intestinal tract of the oriental cockroach, and therefore this insect could be a vector. Neveu-Lemaire (1933, 1938) considered *Periplaneta americana* as a probable vector of the eggs of this worm; there is no direct evidence to support this view, as far as we know.

Trichuris trichiura (Linnaeus, 1771) Stiles, 1901

Common name.—Human whipworm.

Disease.—Trichocephaliasis or trichuriasis.

Natural vectors.—*Blatta orientalis*, Somaliland (Mariani and Besta, 1936): Of 93 cockroaches examined, 4 contained ova of human whipworm. U.S.S.R. (Sondak, 1935): In the 412 cockroaches examined, one egg was isolated from the rectum of a specimen caught in a dining room.

Blattella germanica, U.S.S.R. (Sondak, 1935): In the 788 cockroaches examined, one egg was found in the rectum of a specimen caught in a buffet.

Periplaneta americana, Gold Coast Colony (Macfie, 1922): A single egg, indistinguishable from that of *T. trichiura,* was found in 1 of 30 cockroaches captured in the laboratory, where there was little or no opportunity for the insects to feed on human feces. Formosa (Morischita and Tsuchimochi, 1926): Eggs of this worm were often found in the feces and intestinal contents of cockroaches in the animal house of the Government Research Institute.

Experimental vectors.—Periplaneta americana, Gold Coast Colony (Macfie, 1922): Numerous eggs passed through the gut unharmed and appeared in the feces the next day; some of the eggs had developed slightly. India, western Bengal (Chandler, 1926): After having fed on human feces containing *Trichuris* eggs (species not mentioned but presumably *trichiura*), the cockroaches excreted small numbers of these eggs in their feces.

Periplaneta americana, Periplaneta australasiae, and *Neostylopyga rhombifolia,* Formosa (Morischita and Tsuchimochi, 1926): In feeding experiments, 8 of 11 *P. americana,* all 7 *P. australasiae,* and 4 *N. rhombifolia* passed viable eggs the following day and for 3 days thereafter.

PART II. PATHOGENIC HELMINTHS FOR WHICH COCKROACHES SERVE AS INTERMEDIATE HOSTS

Phylum ACANTHOCEPHALA

Order ARCHIACANTHOCEPHALA

Family OLIGACANTHORHYNCHIDAE

Prosthenorchis elegans (Diesing, 1851) Travassos, 1915

Disease.—Intestinal parasite of the definitive hosts.

Natural intermediate hosts.—Blattella germanica, France (Brumpt and Urbain, 1938, 1938a; Brumpt et al., 1939): 40 percent of *B. germanica* in the monkey house of the Museum of Natural History of Paris were infected with larvae of *P. elegans* and *P. spirula* (Brumpt and Urbain, 1938, 1938a). A similar heavy infestation was found in cockroaches in the menagerie of the Jardin des Plantes, where many parasitized lemurs and monkeys died. The epizootics were stopped only by exterminating the cockroaches (Brumpt and Urbain, 1938a; Brumpt et al., 1939).

Experimental intermediate hosts.—The following were apparently infected with both *P. elegans* and *P. spirula: Blaberus fuscus* and *Leucophaea maderae,* Netherlands (Brumpt and Desportes, 1938): Both species successfully infected.

Blatta orientalis and *Periplaneta americana,* Netherlands (Brumpt and Desportes, 1938): The worms did not develop in either species of cockroach.

Natural definitive hosts.—Monkeys (*Callithrix chrysolevea, Saimiri sciurea, Midas rosalia, Mystax rosalia, Mystax ursulus,* and *Oedipomidas aedipus*) (Brumpt and Urbain, 1938). Lemurs (*Lemur fulvus, L. fulvus albifrons, L. mongos, L. macao,* and *L. catta*), *Cebus apella,* and *Cheirogaleus major* (Brumpt et al., 1939).

Experimental definitive hosts.—The following were infected by feeding on *B. germanica* that contained larvae of both *P. elegans* and *P. spirula:* Baboon (*Papio papio*), cat, hedgehog (*Erinaceus europaeus*), macaque (*Macacus rhesus*), fox (*Vulpes vulpes*), and badger (*Meles meles*) (Brumpt and Urbain, 1938, 1938a).

Prosthenorchis spirula (Olfers in Rudolphi, 1819) Travassos, 1917

Disease.—Intestinal parasite of the definitive hosts.

Natural intermediate hosts.—*Blattella germanica,* France (Brumpt and Urbain, 1938, 1938a; Brumpt et al., 1939): See comments following these citations under *Prosthenorchis elegans.* Netherlands (van Thiel and Wiegand Bruss, 1946, 1948): 5 of 11 cockroaches were naturally infected in a monkey house.

Experimental intermediate hosts.—*Blattella germanica,* Netherlands (van Thiel and Wiegand Bruss, 1946, 1948): 13 of 17 insects were infected with from 1 to 3 or 6 to 12 larvae in different stages of development.

Periplaneta americana, Netherlands (van Thiel and Wiegand Bruss, 1946, 1948): The parasite did not develop in any of the 45 cockroaches of this species that were fed infective meals.

See also species experimentally infected with *Prosthenorchis elegans.*

Natural definitive hosts.—Monkeys (*Midas rosalia, Cebus apella, Callithrix jacchus*), coati (*Nasua narica*), lemurs (*Perodicticus potto, Lemur coronatus, Lemur fulvus*), and *Inuus sylvanus* (Brumpt and Urbain, 1938). Chimpanzee (van Thiel and Wiegand Bruss, 1946).

Experimental definitive hosts.—See under *Prosthenorchis elegans.*

Family MONILIFORMIDAE

Moniliformis moniliformis (Bremser in Rudolphi, 1819) Travassos, 1915, and/or Moniliformis dubius Meyer, 1932

Synonymy.—The nomenclature of the *Moniliformis* found in man is confusing. According to Chandler (1949), the only species found in man is *M. dubius.* Faust (1955) stated that the only species found in man is *M. moniliformis.* Both were apparently referring to the same organism. Meyer (1932) made *Gigantorhynchus moniliformis, in* Magalhães (1898), and *Moniliformis moniliformis* Bremser, *in* Travassos (1917), synonyms of *Moniliformis travassosi* Meyer, 1932. Chandler (1941) made *Moniliformis travassosi* Meyer, 1932, *Moniliformis* sp. of Chandler (1921), and *Moniliformis* sp. of Southwell (1922) synonyms of *Moniliformis dubius.* Hyman (1951a) stated that *M. moniliformis* is a variable form inhabiting many small mammals and that *M. dubius* is cosmopolitan in rats. According to Chandler (1949), the form of *Moniliformis* found in wild rodents in Europe is not identical with that found in rats in the United States and South America. The reader is referred to Van Cleave (1946) for a discussion of this problem.

Disease.—The worm is a cosmopolitan parasite in the small intestine of rodents; it occasionally infects man.

Natural intermediate hosts.—The following records apparently refer to *M. dubius:*

Periplaneta americana, Brazil (Magalhães, 1898): Only 3 to 4 percent of the insects examined were infected; one cockroach contained five encapsulated larvae in an advanced state of development. Brazil (Travassos, 1917): Larvae found in body cavity. Gold Coast Colony (Southwell, 1922): 30 cysts of the worm were collected from two cockroaches. India (Pujatti, 1950): 18 percent of 78 cockroaches contained acanthellas. U.S.A., Texas (Burlingame and Chandler, 1941; Moore, 1946): Naturally infected cockroaches were collected in the Houston Zoological Garden. These cockroaches were between 80 and 90 percent infected (Moore, 1946).

Periplaneta australasiae, India (Pujatti, 1950): 8 percent of 86 cockroaches were infected. (Pujatti did not find the parasite in 152 specimens of *Blattella germanica.*)

The following records apparently pertain to *M. moniliformis:*

Periplaneta americana, Argentina (Bacigalupo, 1927, 1927a, 1928): In these records, 8 percent of 38 cockroaches and 10 percent of 78 cockroaches were infected. Brazil (Pessoa and Correa, 1929): 1½ to 2 percent of the cockroaches examined were infected. Algiers (Seurat, 1912): From 1 to 30 worm larvae were found free in the abdomens of the cockroaches. Burma, Rangoon (Subramanian, 1927): Innumerable larvae were encysted in the body cavity. South Africa (Porter, 1930): The larvae were found in one cockroach. Madras (Sita, 1949).

Experimental intermediate hosts.—The following records apparently pertain to *M. moniliformis:*

Blaberus fuscus, Netherlands (Brumpt and Urbain, 1938a): This species was refractory to infestation. Brumpt (1949) apparently refers this record to *Blaberus atropos.*

Blatta orientalis and *Leucophaea maderae,* France (Brumpt and Urbain, 1938a): These cockroaches were easily infected. Argentina (Bacigalupo, 1928): Bacigalupo could not get the parasite to develop in *B. orientalis.*

Blattella germanica, France (Brumpt and Urbain, 1938a). Argentina (Bacigalupo, 1928): Bacigalupo could not get the parasite to develop in this host.

Periplaneta americana, Japan (Yamaguti and Miyata, 1942). France (Brumpt, 1949). Madras (Sita, 1949).

The following records apparently pertain to *M. dubius:*

Blattella germanica, Japan (Yamaguti and Miyata, 1942).

Periplaneta americana, Japan (Yamaguti and Miyata, 1942). U.S.A. (Chandler, 1941; Moore, 1946).

Development in intermediate host.—The eggs, when ingested by *P. americana,* hatched in the midgut within 24 to 48 hours. The larvae which were at first free in the lumen of the gut passed through the gut wall in the course of 10 to 12 days and dropped into the hemocoele or became embedded in fat tissue. The infective acanthella appeared about 7 to 8 weeks after infection. The encysted larvae remain dormant in the body cavity of the cockroach until it is eaten by a definitive host. (Moore, 1946.) Chandler (1949) found over 100 cystacanths of *M. dubius* in the body cavity of *P. americana.*

Natural definitive hosts.—Rodents such as rat, mouse, hamster, hedgehog, and squirrel; the parasite is sometimes found in man. (Burlingame and Chandler, 1941.)

Experimental definitive host.—Cotton rat (*Sigmodon hispidus*) (Moore, 1946).

Development in definitive host.—The cyst which contains the larva dissolves in the host's stomach. The freed larvae pass into the small intestine and attach themselves to the intestinal wall. (Burlingame and Chandler, 1941; Moore, 1946.)

Moniliformis kalahariensis Meyer, 1931

Disease.—Intestinal parasite of the definitive host.

Natural intermediate hosts.—*Blattella germanica,* India, Bombay (Meyer, 1931, 1932).

Definitive hosts.—Hedgehog (*Erinaceus frontalis*); bird (*Pterocles namaqua*), Africa (Meyer, 1931, 1932).

Phylum ASCHELMINTHES

Class NEMATODA

Order OXYUROIDEA

Family SUBULURIDAE

Subulura jacchi (Diesing, 1861) Railliet and Henry, 1914

Disease.—Intestinal parasite of primates.

Experimental intermediate hosts.—*Blaberus fuscus* (Thunberg) [sic], France (Chabaud and Larivière, 1955): Both encapsulated larvae and larvae free in the body cavity were found in the same cockroach. The free larvae grew more rapidly. At 25°C. infective larvae appeared in about 12 days. The infective third-stage larvae underwent a contraction that rendered them almost spherical. Attempts to infect *Periplaneta americana* were negative.

Definitive hosts.—Wistiti, *Hapale jacchus* (L.), in captivity. Other South American primates.

Order SPIRUROIDEA

Family THELAZIIDAE

Oxyspirura mansoni (Cobbold, 1879) Ransom, 1904

Synonymy.—*Oxyspirura parvovum* Sweet, 1910, the Australian eyeworm of poultry, may be the same as *O. mansoni,* as there is some question as to the validity of *O. parvovum* (Tryon, 1926).

Disease.—Eyeworm infection in poultry.

Common name.—Manson's eyeworm of poultry; chicken eyeworm, tropical eyeworm.

Natural intermediate hosts.—*Pycnoscelus* (=*Leucophaea*) *surinamensis,* Australia (Fielding, 1926, 1927, 1928, 1928a). U.S.A., Florida (Sanders, 1927, 1928, 1929; Shealy, 1927). Formosa (Kobayashi, 1927). Antigua (Hutson, 1938, 1943). Hawaii (Illingworth, 1931; Schwabe, 1950, 1950a, 1950b, 1951). The Japanese quail (*Coturnix coturnix japonica*) is commonly infected with eyeworms, but *Pycnoscelus* was not found to be a food for this bird in Hawaii;

either the bird eats this cockroach, or there is another unknown host for the eyeworm (Schwartz and Schwartz, 1949).

Experimental intermediate hosts.—*Periplaneta americana,* Antigua (Hutson, 1943): The eyeworms developed to the infective stage in *P. americana* when injected into the body cavity. However, these cockroaches could not be infected by eating fowl feces because the feces were toxic and killed all cockroaches tested within 2 weeks. The American cockroach undoubtedly is not a vector of the eyeworm in nature for this reason.

Pycnoscelus surinamensis, U.S.A., Florida (Sanders, 1929): The cockroaches became infected with the eyeworm after having had access for 72 hours to the freshly voided feces of a chicken severely infested with the eyeworm. Australia (Fielding, 1927, 1928a). Hawaii (Schwabe, 1951).

Development in intermediate host.—*Pycnoscelus* becomes infected by eating bird feces containing embryonated eggs or first-stage larvae of the eyeworm. First-stage larvae migrate through the wall of the midgut into the hemocoele where they burrow into the fat body. Second-stage larvae encyst on the alimentary tract, particularly around the rectum and entangled in the malpighian tubules. The tracheated cyst wall is secreted by the cockroach; the cyst is filled with fluid and the enclosed larva is able to move about in it. The encysted larva molts again between the forty-fifth and fiftieth days. During the period of ecdysis, most of the parasites free themselves from the cysts and wander in the body cavity of the host. The complete developmental period requires about 51 days, and the third-stage larvae are infective to birds. (Schwabe, 1951.)

The eyeworm may remain alive for some time in dead cockroaches (Sanders, 1928), and may live up to 72 hours in cockroaches killed by insecticides (Schwabe, 1950b); Schwabe (1950) emphasized the importance of preventing birds from eating dead cockroaches.

Effect of worm on intermediate host.—Sanders (1929) believed that penetration of the intestine by large numbers of migrating larvae at one time is sufficient to kill the insect in some cases.

Natural definitive hosts.—Chicken, turkey, peafowl (*Pavo cristatus*), English sparrow (*Passer domesticus*), mynah bird (*Acridotheris tristis*), Chinese dove (*Streptopelia chinensis*), Japanese quail (*Coturnix coturnix japonica*), pheasant (*Phasianus torquatus torquatus* and *P. vesicolor vesicolor*), Argus pheasant (*Argusianus argus argus*), and Siamese fireback pheasant (*Diardigallus diardi*) (Schwabe, 1951). Ducks (Fielding, 1926).

Infected wild birds are not important reservoir hosts in dissemination of the eyeworm because their feces are too scattered to be eaten to any great extent by vector cockroaches (Schwabe, 1951).

Experimental definitive hosts.—In Florida the following wild birds were experimentally infected: Blackbird (*Agelaius phoeniceus phoeniceus*), bobolink (*Dolichonyx oryzivorus*), loggerhead shrike (*Lanius ludovicianus ludovicianus*), Florida jay (*Aphelecoma cyanea*), and the pigeon (Sanders, 1928, 1929).

The eyeworms will develop to maturity in the eyes of guinea pigs (Fielding, 1927) and white rats (Schwabe, 1951); but when placed in the mouths of these rodents, the larvae were unable to reach the eyes.

Development in the definitive host.—Host birds eat the cockroach containing infective third-stage larvae. The larvae (pl. 6) leave the cockroach host in the bird's crop and migrate up the esophagus to the roof of the mouth, then through the nasolacrimal ducts into the eyes. Infestation of the eyes of chickens has been produced within 20 minutes after they had eaten infected cockroaches (Sanders, 1928, 1929). Larvae placed in the mouths of 4-week-old chicks were observed to enter the eyes several minutes later (Schwabe, 1951). The worms molt within a few days to fourth-stage larvae, and after about 3 weeks they molt into adult worms. The sexually mature worms are found beneath the nictitating membranes, in the conjunctival sacs, and nasolacrimal ducts of the bird. The adult females begin to lay eggs in the host's eyes about 11 days after becoming mature. The eggs are washed down the nasolacrimal ducts with the eye fluid into the mouth, swallowed, and passed out with the feces. (Schwabe, 1951.)

Illingworth (1931) found as many as 205 worms in the eyes of a single chick, and Schwabe (1950a) states that the approximate maximum number of worms found in the eyes of a single bird is 200.

Effect of worm on definitive host.—In heavy infestations (60 worms per eye), the eye shows signs of irritation; there is continuous winking and the bird rubs its head on its wing feathers. Other symptoms include lacrimation, nasal discharge, white corneal opacity, and inflammation of the nictitating membrane. The bird may scratch its eye with its foot, lacerating the outer surface of the eyelids, and finally become blind. Less marked disturbances occur in mild infestations. (Sanders, 1929.)

Blindness and advanced pathologic changes found in the eyes of heavily infected birds are possibly the result of secondary viral or bacterial infections which may be further complicated by the death and decomposition of the worms in the eyes (Schwabe, 1950a).

Distribution.—China, Mauritius, Brazil, Hawaii, Jamaica, Florida

(Sanders, 1929). Australia, Indo-China, Guam, Rabaul, Reunion (Fielding, 1928). British West Indies (Hutson, 1938, 1943). Formosa (Kobayashi, 1927). Samoa (Alicata *in* Schwabe, 1951). The geographical distribution of *O. mansoni* closely agrees with the distribution of its intermediate host, *P. surinamensis* (Fielding, 1928; Sanders, 1929; Schwabe, 1951).

It is interesting that Ransom (1904), over 20 years before the intermediate host was independently discovered by Fielding (1926), Sanders (1927), and Kobayashi (1927), observed that the eyeworm had been reported only from localities on or near the seacoast. He predicted that this restricted distribution indicated ". . . that certain conditions, peculiar to the seashore but yet unknown, are necessary to enable the parasite to complete the cycle of its development." The distribution of the intermediate host is circumtropical on islands or in coastal countries (Schwabe, 1949), thus effectively limiting the spread of the parasite to the localities noted by Ransom.

Family SPIRURIDAE

Agamospirura parahormeticae Pessoa and Correa, 1929

Disease.—Pessoa and Correa (1929) were unable to obtain development of encysted larvae that were fed to white rats. They suggested that the worm may be parasitic in birds.

Natural intermediate hosts.—*Parahormetica bilobata* Saussure, Brazil, São Paulo (Pessoa and Correa, 1929): Encysted larvae were found in the visceral cavity.

Definitive host.—Unknown.

Gongylonema ingluvicola Ransom, 1904

Disease.—Parasite in esophagus of birds.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Cram, 1935): Larvae of the parasite encysted in the cockroach's body cavity.

Definitive host.—Mountain quail (*Oreortyx picta*).

Gongylonema neoplasticum (Fibiger and Ditlevsen, 1914) Ransom and Hall, 1916

Synonymy.—*Spiroptera* sp. Fibiger, 1913; *Spiroptera neoplastica* Fibiger and Ditlevsen, 1914; *Spiroptera* (*Gongylonema*) *neoplastica* Fibiger and Ditlevsen, 1914 (Hall, 1916). *Gongylonema orientale* Yokagawa (Brumpt, 1949).

Disease.—Parasites in the walls of the esophagus, tongue, and forestomach of the definitive hosts.

Natural intermediate hosts.—*Blatta orientalis,* Netherlands, Amsterdam (Baylis, 1925): About one in seven cockroaches (*Periplaneta americana* and *B. orientalis*) contained larvae.

Blattella germanica, U.S.A., Minnesota (Hitchcock and Bell, 1952).

Periplaneta americana, Denmark and Saint Croix (Fibiger, 1913, 1913a; Fibiger and Ditlevsen, 1914). Netherlands, Amsterdam (Baylis, 1925). About one in seven cockroaches (*P. americana* and *Blatta orientalis*) was found to contain the parasite larvae. Surinam (Baylis, 1925). Argentina (Bacigalupo, 1930). England (Leiper, 1926). South Africa (Porter, 1930). U.S.A., Minnesota (Hitchcock and Bell, 1952): Several hundred cockroaches (*P. americana* and *Blattella germanica*) were caught at a rendering plant; 90 percent of these contained encysted larvae. Formosa (Yokagawa, 1924, 1925, 1925a): Cockroaches (*P. americana* and *P. australasiae*) in the vicinity of Taihoku were about 30 percent parasitized.

Periplaneta australasiae, Formosa (Yokagawa, 1924, 1925, 1925a).

Experimental intermediate hosts.—*Blattella germanica,* Denmark (Fibiger and Ditlevsen, 1914). U.S.A., Minnesota (Hitchcock and Bell, 1952). France (Brumpt, 1949).

Blatta orientalis, Denmark (Fibiger and Ditlevsen, 1914).

Periplaneta americana, Denmark and St. Croix (Fibiger, 1913; Fibiger and Ditlevsen, 1914). U.S.A., Minnesota (Hitchcock and Bell, 1952).

Development in intermediate host.—The cockroach becomes infected by feeding on rat feces containing embryonated eggs (pl. 7, right) of the worm. The hatched larvae migrate through the digestive tract and encyst in the muscles of the thorax and legs. The infected cockroaches are then capable of infecting rats (Fibiger and Ditlevsen, 1914).

Definitive hosts.—Wild rats (*Rattus norvegicus* and *Rattus rattus*), and in laboratory rats, white mice, rabbits, and guinea pigs (Fibiger and Ditlevsen, 1914).

Development in definitive host.—The rat becomes infected by eating cockroaches containing encysted nematode larvae (pl. 7, left). The nematode larvae leave the cyst and enter the squamous-celled epithelium of the fundus of the stomach and also the epithelium of the esophagus, tongue, and mouth. After about 2 months, the female worms lay eggs which are voided with the rat feces (Fibiger and Ditlevsen, 1914).

Gongylonema pulchrum Molin, 1857

Common name.—Gullet worm.

Synonymy.—*Gongylonema scutatum* (Müller, 1869) Railliet, 1892 (Baylis et al., 1926; Lucker, 1932; Alicata, 1937; Brumpt, 1949). *Gongylonema hominis* Stiles, 1921 (Faust, 1939; Chandler, 1949). The taxonomic status of the *Gongylonema* species obtained from various definitive hosts is uncertain because authors disagree as to the characters used for species determination (Faust, 1939).

Disease.—Parasite of esophagus and mouth cavity of vertebrate hosts including man.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Ransom and Hall, 1915, 1916, 1917; Stiles and Baker, 1927; Schwartz and Lucker, 1931; Lucker, 1932; Alicata, 1934a, 1935). Europe (Baylis et al., 1925, 1926, 1926a; Sambon, 1926).

Parcoblatta sp. (Alicata, 1934, 1935).

Attempts to infect *Blatta orientalis* were negative (Sambon, 1926; Baylis et al., 1925).

Development in intermediate host.—Eggs eaten by *B. germanica* hatched within 24 hours and the larvae developed to the infective third stage in about 32 days. The third-stage larvae encysted in the muscles of the cockroach (Alicata, 1935). The infective larvae of the *Gongylonema* of ruminants can emerge spontaneously from the cockroach if the insect is killed and placed in water. The larvae are capable of living for 4 to 11 days in water and are a possible source of infection for the definitive host. If an infected cockroach drowns in shallow water, the worms will be liberated as the insect begins to decompose. Although the worms sink to the bottom, in shallow water they may be ingested by humans or other animals while drinking. (Baylis et al., 1926a.)

Natural and experimental definitive hosts.—White rat, rabbit, rats, swine, sheep, goat, ox, camel, fallow deer, buffalo, zebu, chevrotain, guinea pig, wild boar, horse, donkey, macaque, *Ateles* sp., *Pithecus entellus,* man; some human records in Ward (1916), Stiles (Anonymous, 1921), Sambon (1925), and Chandler (1949). Records of the occurrence of this parasite in man are reviewed by Waite and Gorrie (1935) and Johnston (1936).

Development in definitive host.—Cockroaches containing infective larvae are eaten by the primary host. In the guinea pig, the third-stage larvae penetrate the tissue at the junction of the stomach and esophagus; the larvae usually enter the esophageal wall where they migrate under the linings of the esophagus and the oral cavity. (Alicata, 1935.)

Distribution.—Africa, Asia, Australia, Europe, United States (Alicata, 1935).

Gongylonema sp. (?)

Synonymy.—The larvae found by Magalhães (1900) to be similar to *Filaria rytipleurites* probably belong here (Seurat, 1916).

Disease.—Parasites of esophagus and mouth cavity of vertebrates including man.

Natural intermediate hosts.—*Periplaneta americana,* Brazil (Magalhães, 1900): Encysted larvae of the parasite were found in the insect's body cavity.

Microtetrameres helix Cram, 1927

Disease.—Stomach parasite of birds.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Cram, 1934).

Development in intermediate host.—Eggs fed to the cockroaches developed to third-stage larvae in 26 to 68 days.

Definitive hosts.—Crow, pigeon.

Protospirura bonnei Ortlepp, 1924

Disease.—Parasite of rats.

Natural intermediate hosts.—*Leucophaea maderae,* Venezuela, Caracas (Brumpt, 1931): The larval nematode is sometimes very abundant in this cockroach.

Experimental intermediate hosts.—*Blatta orientalis, Blattella germanica,* and *Leucophaea maderae* (nymphs), France, Paris (Brumpt, 1931).

The parasite does not seem to develop in *Blaberus giganteus, Periplaneta americana,* and *P. australasiae* (Brumpt, 1931).

Definitive host.—Norway rat (*Rattus norvegicus*).

Effect of worm on definitive host.—The worm apparently does not alter the histology of the stomach mucosa of the rat which does not seem to show any clinical signs of infection.

Protospirura columbiana Cram, 1926

Disease.—Parasite of esophagus, stomach, and upper intestine of rats.

Experimental intermediate host.—*Blattella germanica,* U.S.A. (Cram, 1926).

Definitive host.—Norway rat (*Rattus norvegicus*).

Protospirura muricola Gedoelst, 1916

Disease.—Stomach parasite of rats and primates.

Natural intermediate hosts.—*Leucophaea maderae,* Panama (Foster and Johnson, 1938, 1939): 96 percent of 135 cockroaches were infected. Only cockroaches caught in the vicinity of the monkey cages contained spiruroid larvae; cockroaches caught elsewhere were not infected. Five other species of cockroaches that were examined were not infected.

Development in intermediate host.—The cockroaches acquired the parasite by ingesting eggs in the feces of the definitive host. Infective larvae were found in discoidal cysts mainly in the thorax, around the crop, and at the bases of the large muscles of the first pair of legs. An average of over 100 cysts per dissection per day's catch was not unusual.

Definitive hosts.—Rats are the normal hosts for this nematode, but the worm apparently can adapt to the following primate hosts: White-faced monkey (*Cebus capucinus*), Darien black spider monkey (*Ateles dariensis* Goldman), and Canal Zone night monkey (*Aotus zonalis* Goldman).

Development in definitive host.—The monkeys become infected by eating Madeira cockroaches that contain encysted larvae. The worms live in the esophagus and stomach and cause injury by obstruction, tissue invasion, and secondary infection. Infections may be fatal, particularly to white-face monkeys; 20 deaths of experimental monkeys have been ascribed to protospiruriasis.

Seurocyrnea colini (Cram, 1927) Cram, 1931

Synonymy.—*Cyrnea colini* Cram, 1927.

Disease.—Parasite in proventriculus of birds.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Cram, 1931, 1931a, 1933a). It is possible that cockroaches found in fields and woods serve as normal hosts (Cram, 1931, 1931a).

Development in intermediate host.—The eggs ingested by the cockroach hatch and the larvae leave the digestive tract and develop in the body cavity. The larvae do not appear to encyst but develop to the third stage in the tissues and apparently mature after 18 days in the insect.

Definitive hosts.—Bobwhite quail (*Colinus virginianus virginianus* and *Colinus virginianus texanus*), turkey, prairie chicken (*Tympanuchus americanus americanus*), sharp-tailed grouse (*Pedioecetes phasianellus compestris*). (Cram, 1931.)

Spirura gastrophila (Müller, 1894) Seurat, 1913

Synonymy.—*Filaria rytipleurites* Deslongchamps, 1824; *F. rytipleurites* as used also by Galeb (1878); *Spirura talpae* as used by Seurat (1911); and *Spiroptera sanguinolenta* as used by Grassi (1888) and Roger (1906, 1907) (Seurat, 1911, 1916). See discussion under *Spirocerca sanguinolenta,* p. 109.

Disease.—Parasite in alimentary canal of vertebrate animals.

Natural intermediate hosts.—*Blatta orientalis,* Europe (?) (Deslongchamps, 1824, *in* Seurat, 1911): The larval worm was found encysted in the abdomen of the insect. Italy (Grassi, 1888). Algeria (Seurat, 1911, 1916): 4 of 17 cockroaches harbored fourth-stage larvae of this parasite; there were 15 cysts in one insect.

Periplaneta americana, Brazil (Pessoa and Correa, 1929): Four cysts were found in one cockroach and one cyst in another.

Experimental intermediate hosts.—*Blatta orientalis,* France (Galeb, 1878): The cockroaches fed on feces from infected rats; embryos of the nematode hatched in the digestive tract of the insect, pierced the intestinal wall, and became encysted in the fat body. Infected cockroaches were fed to white rats; nematodes were recovered in the rat after 8 days.

Cockroaches ("cafards"), Algeria (Roger, 1906, 1907): Cysts were obtained from the abdominal cavities after the cockroaches had ingested the parasites. Roger did not complete the experiment by feeding the infected cockroaches to dogs.

Definitive hosts.—Hedgehog (*Erinaceus algirus* Duv.), fox, lizard, chameleon (Seurat, 1916). Dog, cat, mongoose (Hall, 1929).

Tetrameres americana Cram, 1927

Disease.—Parasite in proventriculus of poultry.

Natural intermediate hosts.—*Blattella germanica,* U.S.A. (Cram, 1931b; Dr. Eloise B. Cram, p. c.): Control chickens in experiments with this worm became infested with immature, therefore recently acquired, nematodes. As *B. germanica* was the only arthropod in evidence, it was presumed to be the vector. Hawaii (Alicata, 1938, 1947).

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Cram, 1931b): Eggs of the nematode developed in the cockroach to third-stage larvae and were recovered in 40 days. Attempts to infect *Periplaneta australasiae* were unsuccessful (Cram, 1937).

Natural definitive hosts.—Chicken, bobwhite quail (*Colinus virginianus*) (Cram, 1931a).

Experimental definitive hosts.—Duckling of domestic duck, ruffed grouse (*Bonasa umbellus*), pigeon (Cram, 1931a).

Tetrameres pattersoni Cram, 1933

Disease.—Parasite in glandular stomach of bobwhite quail.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Cram, 1933): Third-stage larvae had encysted in the muscles of the legs and head and in the body cavity within 24 days after an infective meal.

Definitive host.—Bobwhite quail (*Colinus virginianus*).

Family PHYSALOPTERIDAE

Physaloptera hispida Schell, 1950

Disease.—Stomach parasite in the definitive hosts; it causes chronic ulcers.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Schell, 1952, 1952a). Attempts to infect *Periplaneta americana, Periplaneta australasiae,* and *Parcoblatta pensylvanica* failed (Schell, 1952).

Development in intermediate host.—Eggs ingested by the cockroach hatch in the midgut and the larvae pass on to the colon where they penetrate the peritrophic membrane and invade the epithelium. The invaded epithelial cells are destroyed. The larva undergoes two molts and encysts within the tissues of the colon or rectum. The infective stage was reached in 30 to 35 days, and the larva was infective for the definitive host even after 4-months' encystment in the cockroach. (Schell, 1952, 1952a.)

Natural definitive hosts.—Cotton rat (*Sigmodon hispidus littoralis* Chapman).

Experimental definitive hosts.—Norway rat (*Rattus norvegicus*) and albino rat (Schell, 1952).

Development in definitive host.—Infective larvae which were fed to cotton rats grew rapidly and developed in the pyloric region of the stomach. The worms reached sexual maturity within 73 to 90 days, after which embryonated eggs were detected in the rats' feces. The parasites caused formation of chronic ulcers although infected animals exhibited no noticeable external symptoms. (Schell, 1952.)

Physaloptera maxillaris Molin, 1860

Disease.—Parasite in alimentary tract.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Hobmaier, 1941).

Development in intermediate host.—Eggs eaten by cockroaches reached the infective larval stage in 4 to 6 weeks.

Definitive hosts.—Skunk, badger, mink, raccoon (Schell, 1952).

Physaloptera praeputialis v. Linstow, 1889

Disease.—Parasite in alimentary tract of definitive host.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Petri and Ameel, 1950).

Definitive hosts.—Various species of *Felis, Canis, Lynx, Urocyon, Vulpes,* and *Genetta* (Mildred A. Doss, p. c.).

Physaloptera rara Hall and Wigdor, 1918

Disease.—Parasite in alimentary tract of definitive hosts.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A., Kansas (Petri and Ameel, 1950; Petri, 1950): Petri suggests that wood roaches might be intermediate hosts in nature.

Development in intermediate host.—Eggs ingested by the cockroach developed to encysted third-stage larvae, attached to the hind gut, primarily the rectum. The larvae migrated to the outside layers of the gut but did not pass into the hemocoele.

Definitive hosts.—Cat, dog, coyote.

Physaloptera turgida Rudolphi, 1819

Disease.—Parasite in alimentary tract of definitive host.

Experimental intermediate hosts.—*Blattella germanica,* U.S.A. (Alicata, 1937; Schell, 1952).

Development in intermediate host.—First- and second-stage larvae are encysted in the tissue surrounding the body cavity (Alicata, 1937). Schell (1952), however, stated that the larva did not penetrate the digestive tract of the cockroach and never entered the hemocoele.

Definitive host.—Opossum (*Didelphis virginiana*) (Alicata, 1937).

PART III. DOUBTFUL RECORDS OF THE TRANSMISSION OF HELMINTHS BY COCKROACHES

Hymenolepis diminuta (Rudolphi, 1819) Blanchard, 1891

Stiles and Hassall (1926) and Tubangui (1931) cite *Blatta orientalis* and *Blattella germanica* as intermediate hosts for this rat tapeworm which is not uncommon in man. Faust (1939), Blakiston's new Gould medical dictionary (Jones et al., 1949), and Giordano (1950) list *Periplaneta americana* as well as the above two species of cockroaches as intermediate hosts of this tapeworm. Faust (1955) states that cockroaches, among other insects, may serve as the intermediate hosts and cites Oldham (1931) as the source of this information. However, Oldham (1931) pointed out the lack of experimental evidence for claims that cockroaches serve as host for this cestode. Joyeux (1920) and Riley and Johannsen (1938), using *B. orientalis* and *B. germanica,* and Chandler (1922), using *B. germanica* and *P. americana,* could not infect these cockroaches with *H. diminuta.* Zmeev (1936) in Tadzikhistan found two specimens of *Polyphaga saussurei,* each of which contained an egg of *Hymenolepis* sp.; these insects were found where there were numerous rats that were infected with *Hymenolepis diminuta.*

Inermicapsifer madagascariensis (Davaine in Grenet, 1870) Baer, 1956

Synonymy.—Raillietina madagascariensis. Davainea madagascariensis.

Blanchard (1899, footnote p. 214) stated that it seemed to him that cockroaches (*Periplaneta americana* and *Blatta orientalis*) could be looked upon with suspicion as vectors of this cestode. The following statements probably trace back to Blanchard. Wellman (1910) stated that the tapeworm *Davainea* was thought to be disseminated by cockroaches. Castellani and Chalmers (1919) suggested that the cysticercus may be found in *Blatta orientalis* or *Periplaneta americana.* Fox (1925), Faust (1939), and Mackie et al. (1945) stated that species of *Periplaneta* are believed to be intermediate hosts of this tapeworm. However, we have been unable to locate direct evidence that supports these suggestions. Joyeux and Baer (1936), Chandler (1949), Faust (1955), and Baer (1956) did not mention cockroaches as possible intermediate hosts for this cestode.

Spirocerca sanguinolenta (Rudolphi, 1819) Seurat, 1913

Synonymy.—Spiroptera sanguinolenta Rudolphi, 1819.

Grassi (1888) believed that he showed that *Blatta orientalis* served in Sicily as the intermediate host of this spiruroid parasite of dogs. (See also Railliet, 1889; Nuttall, 1899; Roger, 1906, 1907.) However, Faust (1928), working in China, could not infect *B. orientalis, Periplanta americana,* or *Periplaneta australasiae* by feeding them the eggs of this nematode, and he found a dung beetle to be the insect host. Dung beetles are listed as intermediate hosts of *S. sanguinolenta* by Chandler (1949). Faust believed that Grassi was probably dealing with another spiruroid parasite of which the dog is an abnormal host. This conclusion probably applies equally well to the work of Roger

(1906, 1907). See also Seurat (1911, 1916) and the section on *Spirura gastrophila*, p. 106.

Gordius aquaticus Linnaeus, 1758

Leidy (1879) identified a 9-inch-long nematode found in a cockroach (*Blatta orientalis*?) as probably being *Gordius aquaticus*. Stiles and Hassel (1894) list *Blatta* sp. as a host for this worm. Ransom (*in* Pierce, 1921) stated that *G. aquaticus* may be an accidental parasite of man. However, the Gordiaceae, or horsehair worms, live as parasites in *insects* until almost mature and emerge from the insects to become free-living adults, reproducing in water or soil (Chandler, 1949). Although this worm may accidentally be swallowed with drinking water, it should not be considered a parasite of man.

PART IV. NEGATIVE FINDINGS

The helminths listed below are only those for which cockroaches have been shown experimentally not to be intermediate hosts. Negative findings with helminths for which other cockroaches have been shown to be intermediate hosts are cited above.

Cockroaches were unsuitable intermediate hosts for the following cestodes, or were found uninfected in nature:

Diphyllobothrium latum (Linnaeus, 1758) Lühe, 1910

Definitive host.—Fish.

Cockroach.—*Blattella germanica*. Degenerated eggs of the tapeworm were isolated from the insect's rectum (Sondak, 1935).

Hymenolepis exigua Yoshida, 1908

Definitive host.—Poultry.

Cockroach.—*Pycnoscelus surinamensis*. Ten cockroaches collected in a poultry yard were dissected and examined for cysticercoid stages (Alicata and Chang, 1939).

Hymenolepis nana (v. Siebold, 1852) Blanchard, 1891

Definitive host.—Man.

Cockroaches.—*Neostylopyga rhombifolia, Periplaneta americana,* and/or *Periplaneta australasiae*. (Morischita and Tsuchimochi, 1926.)

Cockroaches were unsuitable intermediate hosts for the following nematodes:

Angiostrongylus cantonensis (Chen)

Definitive hosts.—Wild and laboratory rats.

Cockroaches.—*Blattella germanica, Pycnoscelus surinamensis, Periplaneta ignota.* (Mackerras and Sandars, 1955.)

Cheilospirura hamulosa (Diesing, 1851) Diesing, 1861

Definitive hosts.—Chicken, turkey.

Cockroaches.—*Blattella germanica* (?). (Cram, 1931a, 1931b.) *Pycnoscelus surinamensis.* (Alicata, 1938a.)

Cheilospirura spinosa Cram, 1927

Definitive hosts.—Ruffed grouse, bobwhite quail.

Cockroach.—*Blattella germanica* (?). (Cram, 1929, 1931a.)

Dispharynx spiralis (Molin, 1858) Gedoelst, 1916

Definitive hosts.—Hungarian partridge, ruffed grouse, bobwhite quail, turkey, chicken, pigeon, guinea fowl.

Cockroach.—*Blattella germanica* (?). (Cram, 1931a.)

Skrjabinoptera phrynosoma (Ortlepp, 1922) Schulz, 1927

Definitive host.—Texas horned toad.

Cockroach.—*Blattella germanica.* (Lee, 1955, 1957.)

Spirocerca sanguinolenta (Rudolphi, 1819) Seurat, 1913

Definitive host.—Dogs.

Cockroaches.—*Blatta orientalis, Periplaneta americana, Periplaneta australasiae.* (Faust, 1928.)

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Periplaneta sp. in a sewer manhole in Houma, La. (From Gary, 1950. Courtesy of Public Works Journal Corporation.)

Periplaneta americana congregated on the arched roof and walls of a large sewer in Minneapolis, Minn. Approximately 3,000 cockroaches were present in a space of 12 square feet at the time the picture was taken. (See p. 11 for other details. Photograph by Jess Diggs and Alton Hollenbeck.)

Periplaneta americana (identified by Dr. R. B. Eads) apparently feeding on feces in a sewer manhole in Tyler, Tex. (From Anonymous, 1953. Courtesy of Texas State Department of Health.)

Periplaneta americana crawling through opening in sewer manhole cover in Texas. (See p. 16 for details. Courtesy of Texas State Department of Health.)

Oxyspirura mansoni protruding from a leg of *Pycnoscelus surinamensis.* Part of the nematode still extends into the femur. X 16.
(Preparation stained with Delafield's haematoxylin and mounted in balsam.)

Left, Larvae of *Gongylonema neoplasticum* encysted in the prothoracic muscles of *Periplaneta americana*. *Right*, Egg of *Gongylonema neoplasticum*. X 950. (Photomicrographs by Dr. Claude R. Hitchcock.)

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