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COCKROACHES

THEIR BIOLOGY, DISTRIBUTION AND CONTROL

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World Health Organization
Communicable Diseases Prevention and Control
WHO Pesticide Evaluation Scheme (WHOPES)

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1. Introduction

Cockroaches are an ancient and highly successful form of insect life. They have been in existence since Pennsylvanian (Upper Carboniferous) times. The fossil record indicates that they achieved an optimum body form early in their evolutionary history and have remained a very stable group since that time (Moore *et al.* 1952). Figure 1 is a photograph of a 250 million-year-old fossil insect that is easily recognizable as a cockroach. About 3500 species of living cockroaches have been catalogued (Princis, 1962-1971), but additional species and even new genera are being found and named (Roth & Princis 1971, Roth 1973, 1985, 1989, 1990a, 1990b, 1991a, 1991b, 1991c, 1992, 1993a, 1993b, Fisk & Schal 1981, Grandcolas 1991, 1994a, 1994b, Peck & Roth 1992). Wolda *et al.* (1983) reported that 42% of the species they collected at light traps in Panama were new to science. Thus, the final number will probably far exceed the figure of 4,000 suggested by James & Harwood (1969).

Rehn (1945) pointed out that the majority of cockroach species are not domiciliary pests. In fact the important pest species constitute less than 1.0% of all known cockroach species. The remainder are free-living insects that are found mainly in the tropical regions of the world. They live in a wide variety of situations such as among or under dead or decaying leaves, under the bark of trees, under rubbish or stones, under drift materials near beaches, on flowers, leaves, grass, or brush, in caves or burrows, boring in wood, in the nests of ants, wasps, or termites, or in a semi-aquatic environment (Roth & Willis 1960, Roth 1973). In contrast to the nocturnal habits of most common domiciliary-pest species, many other species are diurnal. Thus, the layman's view of cockroaches, which is based on experience with the few domiciliary species, is unrepresentative of the group as a whole. Indeed, some of the tropical forms are strikingly beautiful insects.

2. The Public Health Significance of Cockroaches

The medical importance of cockroaches may be much greater than is generally recognized (Baumholtz *et al.* 1997). They have been shown to harbour pathogenic bacteria, serve as intermediate hosts for pathogenic helminths, and to carry helminth eggs, viruses, protozoa and fungi affecting man and other vertebrate animals (Roth & Willis 1957a, 1960, Tarshis 1962, Cornwell 1968, James & Harwood 1969, Rueger & Olson 1969, Pul'ver & Savchenko 1973, Klowden & Greenberg 1977, Ash & Greenberg 1980, Cornwell & Mendes 1981, Fotedar *et al.* 1991, Cloarec *et al.* 1992, Kopanic *et al.* 1994). Their habit of feeding on both human food and human faeces illustrates their potential as a health hazard to man. The importance of this point becomes clear when it is realized that cockroaches move freely from building to building or from sewer or privy to human habitation (Haines & Palmer 1955) and that the order in which these movements occurs has no relationship to

human sensibilities or public health considerations. Indeed, casual contact of cockroaches with surfaces is sufficient to foster the spread of bacteria (Cloarec *et al.* 1992, Kopanic *et al.* 1994).

Nevertheless, it has been difficult to prove a direct involvement of cockroaches in disease transmission (Gorham 1969, Burgess 1979, Burgess & Chetwyn 1981, Baumholtz *et al.* 1997). It is obvious that they can harbour and mechanically transmit disease-producing organisms. It is equally obvious that they are present in situations such as hospitals where their involvement in disease transmission is highly probable. The problem arises in proving unequivocally that cockroaches were the vector in instances where other vectors and other means of disease transmission occur simultaneously. The nocturnal habits of the pest species are another complicating factor in obtaining such proof because even their presence may go undetected during a particular disease-transmission episode.

The following species of cockroaches are considered vectors of pathogenic organisms affecting people or have been claimed to bite people (Roth & Willis 1957a): *Blaberus atropos* (Stoll); *Blaberus craniifer* Burmeister; *Blaberus discoidalis* Serville; *Blatta orientalis* Linnaeus; *Blatta (Shelfordella) lateralis* (Saussure); *Blattella germanica* (Linnaeus); (Fernamdez & Lembke 1973); *Eurycotis floridana* (Walker); *Rhyparobia maderae* (Fabricius); *Nauphoeta cinerea* (Olivier); *Neostylopyga rhombifolia* (Stoll); *Periplaneta americana* (Linnaeus); *Periplaneta australasiae* (Fabricius); *Periplaneta brunnea* Burmeister; *Polyghaga saussurei* (Dohrn); *Pycnoscelus surinamensis* (Linnaeus); and *Supella longipalpa* (Fabricius). Two other species listed by Roth & Willis (1957a) have been omitted because of synonymy. The frequency of occurrence of certain other species in waste-disposal areas and in homes, such as *Periplaneta fuliginosa* (Serville), would warrant suspecting them as an additional vector species. All of the above species, with the possible exception of *Blaberus atropos*, are domiciliary to a greater or lesser degree.

Cockroaches have been found to be naturally contaminated with about 40 different species of bacteria that are pathogenic to vertebrates and many other species that are pathogenic have been experimentally introduced into cockroaches (Roth & Willis 1957a, 1960, Burgess *et al.* 1973a, 1973b, 1974, Artyukhina & Evokimov 1973, Ulewicz & Zawistowski 1973, Klowden & Greenberg 1976, Ash & Greenberg 1980, Cornwell & Mendes 1981). Some examples of diseases of man caused by pathogenic bacteria that naturally infect cockroaches are: *Mycobacterium leprae* and leprosy; *Pasteurella pestis* and bubonic plague; *Shigella alkalescens* and dysentery; *Shigella paradysenteriae* and diarrhea in children; *Pseudomonas aeruginosa* and infections of the urinary tract; *Staphylococcus aureus* and boils and abscesses; *Staphylococcus spp.* and puss formation; *Escherichia coli* and infections of the urogenital tract and intestine; *Salmonella schottmuelleri*, *S. bredeney*, and *S. oranienburg* causing enteric fevers and gastroenteritis; *Paracolobactrum aerogenoides, P. coliforme,* and *Salmonella morbificana* causing

gastroenteritis; *Salmonella anatis* and intestinal infections; *Salmonella typhimurium, Escherichia coli, Streptococcus faecallis, Pseudomonus aeruginosa,* and *Clostridium perfringens* and food poisoning; and *Salmonella typhosa* and typhoid fever (Cornwell 1968, Cornwell & Mendes 1981). The most prominent cockroach species involved in the forgoing examples are *Blattella germanica*, *Blatta orientalis, & Periplaneta americana,* which are the three most common pest species. Other species have also been implicated (Rampal *et al.* 1983, Oothuman *et al.* 1989, LeGuyader *et al.* 1989). Additional diseases caused by bacteria and experimentally transmitted by cockroaches include Asiatic cholera, cerebrospinal fever, pneumonia, diphtheria, undulant fever, glanders, chicken cholera, anthrax, black leg, tetanus, rat leprosy, and tuberculosis.

The helminths constitute the second largest group of organisms pathogenic to vertebrates which are transmitted by cockroaches (Roth and Willis 1957a, 1960, Young & Babero 1975, Goddeeris 1980). The eggs of seven species have been found naturally occurring in cockroaches, whereas in experiments the eggs of five other species were passed unharmed through the guts of cockroaches and appeared in the faeces. Some examples of these helminths are *Schistosoma haematobium, Taenia saginata, Ascaris lumbricoides, Ancylostoma duodenale,* and *Necator americanus*. Cockroaches have been shown to be natural intermediate hosts for twelve species of helminths and intermediate hosts experimentally for eleven other species. Some examples are *Hymenolepis nana* (Furukawa 1970), *Moniliformis moniliformis, Gonylonema neoplasticum,* and *Spirura gastrophila*. Perhaps the best known of these worms is *Oxyspirura mansoni*, the eye worm of poultry, for which *Pycnoscelus surinamensis* is one of the natural intermediate hosts (Cornwell 1968). Several authors have also shown that *Periplaneta americana* is a natural intermediate host for *M. moniliformis* (Acholonu & Finn 1974, Brennan & Cheng 1975, Anuar & Paran 1976, Ravindranath & Anantaraman 1977, Oothuman *et al.* 1985). In addition, about 45 species of helminths that are non-pathogenic to vertebrates are known to be primary parasites of cockroaches.

Laboratory studies have shown conclusively that cockroaches may acquire, maintain and excrete certain viruses (Roth & Willis 1957a). Some examples are the Coxsackie virus and several strains of poliomyelitis. They are also suspected of being vectors of infectious hepatitis (Tarshis 1962). Transmission of viral diseases by cockroaches under natural conditions has not been proven but the existing evidence makes them prime suspects. Suto *et al.* (1979) reported the occurrence of a new virus from a laboratory colony of *Periplaneta fuliginosa.*

Although many non-pathogenic protozoa have been associated with cockroaches, only four species considered pathogenic to vertebrates have been reported. The pathogenic species are *Balantidium coli, Entamoeba histolytica, Giardia intestinalis* and *Toxoplasma gondii,* whereas *Trichomonas*

hominis and certain other species are of doubtful pathogenic importance (Roth & Willis 1957a, Wallace 1972, Smith & Frenkel 1978).

The fungi *Aspergillus fumigata* and *A. niger*, sometimes found associated with pathological conditions, have been reported as occurring naturally in cockroaches as are certain yeasts (Henniger & Windisch 1976).

Cases of ill effects due to bodily contact between people and cockroaches have been known for centuries (Baumholtz *et al.* 1997). Dermatitis of the skin, edema of the eyelids and attacks on other body parts have been attributed to cockroaches. Certain species produce secretions which are irritating to some individuals; for example, when seized *Eurycotis floridana* emits an odourous fluid that may irritate sensitive skin. This fluid can be ejected as a spray for a distance of several centimetres. Other species that produce odourous secretions are *Diploptera punctata* and *Rhyparobia maderae.* The blister-raising properties of cockroaches have been attributed to their cuticular grease or to a discharge from the mouth (Roth & Willis 1957a). Allergic reactions to cockroaches are well documented (Helm *et al.* 1990, 1993), especially among certain groups of people (Cornwell 1968, Kang 1976 and Koehler *et al.* 1987). Extensive studies have been done on the nature of the allergens (Fraser 1979, Schou *et al.* 1990). It has been shown that people who exhibit skin and bronchial responses to cockroaches have high levels of cockroach-specific antibodies in comparison with people who do not exhibit similar responses (Kang *et al.* 1979). In one survey it was found that 5-10% of a general population were positive for cockroach allergens in house dust (Birnbaum *et al.* 1991). Laboratory workers who deal with cockroaches may also become sensitized to them (Steinburg *et al.* 1987). The species most frequently involved are *Blattella germanica* and *Periplaneta americana* (Menon *et al.* 1989), but, as mentioned above, other species may be quite important as well.

An unusual situation has been described wherein two species of cockroaches normally excrete compounds which are either mutagenic or carcinogenic (Mullins & Cochran 1973). The species are *Periplaneta americana* and *Rhyparobia maderae*. The compounds excreted are xanthurenic acid, kynurenic acid and 8-hydroxyquinaldic acid, all of which are tryptophan derivatives. These compounds are present in faeces in small but consistent quantities. The dropping of fecal material by cockroaches on human food makes these compounds a potential hazard to human health.

Cockroaches are omnivorous feeders, using their chewing-type mouthparts to feed on a wide variety of foodstuffs in addition to biological wastes such as garbage and sewage (Roth & Willis 1957a, James & Harwood 1969). They are found wherever people prepare or store food for themselves or other animals and they are potential contaminators unless the food is adequately protected (Kurtz & Harris 1961). Although they prefer starchy or sugary foods, they may attempt to feed on almost anything of an organic nature

if more desirable foods are unavailable. Typical foods preferred by domiciliary cockroaches are sugar, candies, chocolate, meat, cheese, milk and bread. However, almost no materials utilized in human consumption are free from contamination by them. In addition, cockroaches feed readily on bookbindings, dead insects, blood, excrement, faeces and miscellaneous kinds of animal or vegetable detritus. In the tropics many free-living cockroaches are primarily detritus feeders, but will also consume other organic matter including bird droppings (Schal & Bell 1982).

Perhaps the most disgusting and potentially dangerous features of cockroach behavior are their habits of regurgitating fluid from their mouth (perhaps partially digested food) and dropping faeces, sometimes at the site where feeding has occurred. They also produce secretions which give a persistent and characteristic odour to areas visited by them. As domestic cockroaches are mainly active at night, many people are unaware of the extent to which they contaminate food, leave nauseating and offensive odours, and are potentially important to human health.

3. The Domiciliary Species of Cockroaches

3.1. General

For convenience all of the pertinent information about a given species has been aggregated in this section. In addition, a key to aid in the identification of the most important genera and species of pest cockroaches is presented in the next section.

Before beginning a discussion of individual species, several introductory remarks are necessary. First, with regard to geographic distribution it is important to recognize that limitations exist. Most of the information that is available is based upon reports in the literature. This can be supplemented by written or verbal communications with various experts and by personal observation. Nevertheless, the available information is far from complete. This means that when a statement is made that a cockroach species is present in a given country or area, it does not necessarily follow that its occurrence is widespread. Indeed, in most instances its distribution will probably be spotty depending upon the availability of food and suitable shelter, opportunity for introduction or spread and other factors. A published study of the distribution of the American cockroach, *Periplaneta americana,* in the United Kingdom amply illustrates the point (Ragge 1965). It was shown that this species occurs in rather limited areas around nearly dozen seaport cities. Obviously, the species has been repeatedly introduced via this route yet has not become universally distributed throughout the British Isles. However, for purposes of this document it will be considered to be established there. On larger landmasses or on island chains, great distances may separate reported instances of occurrence. In these cases the problem is to decide whether the reports represent isolated

populations or are merely poor documentation of a continuous or discontinuous population over the whole region. This kind of information can lead to errors. Thus, in some instances caution and judgment must be exercised in interpreting the data presented.

Another point of interest deals with discussion of the biology, life cycle and/or ecology of a given species on a world-wide basis. In general, the basic biological features of a species will not vary greatly regardless of where it occurs in the world. However, the life cycle may be considerably influenced by where the insects are found. Insects are, of course, cold-blooded animals and within certain limits their life cycle will be shorter at warmer temperatures and longer at cooler temperatures. Similarly, ecological considerations will vary depending on location. Where outside temperatures remain warm year round or during summer, domiciliary cockroaches may be quite independent of humans and may migrate freely without aid. By contrast, where some other feature is limiting, such as water in desert countries, this may be an overriding factor even though the temperature is high. As will become apparent in the pages that follow, for many species adequate information is lacking for a thorough discussion of all of these points.

Finally, it should be mentioned that specific and/or vernacular names associated with domestic cockroach species are often misleading. Vernacular or common names tend to vary from region to region or country to country. In this document such names will be given only when they seem to be generally accepted. Reference should be made to scientific names for positive identification. In addition, specific names, such as *germanica, americana, australasiae,* etc., may be confusing since they do not ordinarily indicate the point of origin of the species. In many instances names of this sort indicate only the country or region from which the early taxonomists first described the species. The point of origin of some species is either known or can be surmised (Rehn 1945); whenever possible, this information is provided.

3.2. The cockroach life cycle

Cockroaches are insects with an incomplete metamorphosis. This means that there are three stages which will commonly be encountered; egg, nymph and adult. The nymphs generally resemble adults except for size and the fact that their wings and genitalia are undeveloped. The eggs of cockroaches are deposited in groups and are surrounded by a more or less hard protective covering. The entire structure is called an ootheca or egg case. The ootheca is formed by the female and upon its completion is deposited in some appropriate location, carried externally by the female (the oviparous species), or carried inside the female's body (the viviparous species) (Roth & Willis 1954). The course which the female follows in this regard is a species characteristic, and has a bearing on the form of the ootheca (Roth 1968). The viviparous species tend to produce flexible, thin-walled oothecae in which the keel is absent or rudimentary. The oviparous species produce oothecae that are complete and

which in many instances are quite resistant to desiccation. Species that deposit their oothecae in natural outdoor situations may prepare holes in the soil, rotting wood or other substrates to receive the oothecae. After deposition of an ootheca, the female usually covers the opening with some appropriate material. However, in domestic situations where usable substrate materials are limited, loose deposition or sticking of the ootheca to a surface normally occurs (McKittrick 1964). From these egg cases the free living and active nymphs emerge. They grow through a series of instars and molts before reaching the adult stage. The most conspicuous change that occurs at this time is the appearance of wings. In some species, however, the wings are either reduced or absent.

A generalized drawing of each of the life stages is presented in Figure 2a. Figure 2b is a representation of some features of cockroach morphology. In addition, attention is drawn to a detailed account of cockroaches which contains an extensive list of references to the older literature (Beier 1974).

3.3. The domiciliary species

3.3.1 *Blattella germanica* (L.) - the German cockroach

Distribution - If any species of cockroach can be spoken of as being cosmopolitan it is this one, as it is found in virtually all parts of the world (Princis 1969). The earlier indication was that it originated in Northeast Africa in the vicinity of the great African lakes in what is now Ethiopia (Rehn 1945). However, more recent work has disputed that claim and now places its origin in tropical Asia (Roth 1985). Its early spread into Asia Minor and Eastern Europe has been reasonably well documented. It is believed to have been introduced into the New World from Europe rather than from Africa or Asia. As its origin indicates, it is present, but not often abundant, in the tropics (Asahina & Hasegawa 1981) and has penetrated well into northern and southern temperate climates. This is truly a remarkable insect species in many ways, not the least of which is its ability to thrive virtually everywhere that humans have taken it. On a world-wide basis it is probably the most important cockroach pest (Rehm 1945).

Description - The German cockroach (Fig. 3a) is one of the smallest domestic cockroaches, measuring 10-15 mm in length. It is a light yellowish-brown colour in males while females are slightly darker. Nymphs are generally black with a light stripe up the mid-dorsum. Both nymphs and adults have two longitudinal, black, parallel bands on the pronotum separated by a lighter stripe. In nymphs the bands and stripe merge with those of the other thoracic segments. The wings of adults cover the entire abdomen of females and all except the abdominal tip in males. The sexes can be separated by the darker colour and stout abdomen of females, and by the much longer supra-anal plate of the males. Males also have conspicuous gland openings on the 7th and 8th

abdominal tergites (Roth 1969a). Oothecae are 7-9 mm long with distinct indentations outlining the individual eggs (Fig. 4a).

Biology and life history - Adult males and females of the German cockroach mature at approximately the same time and usually mate within the first 7-10 days of adult life. Females are apparently receptive to mating as early as 5-6 days after the imaginal molt (Liang & Schal 1993). Males will mate repeatedly, but females usually mate only once (Cochran 1979). An ootheca appears on a mated female within a few days, depending on temperature, and is usually completely formed in 24-48 hr. Unmated females may also produce oothecae but they are sterile (Liang & Schal 1993). Initially, the egg case is formed with the keel pointing upward but after completion it is rotated 90° to the right, in which position it is held by the female until, or just prior to, the time the nymphs hatch (Willis *et al.* 1958). At that time, or shortly thereafter, the empty egg case is dropped by the female. The incubation period is three to four weeks but may be longer depending on temperature. Normal oothecae vary in number of eggs from 37-44, with approximately 90% of them hatching (Ross & Cochran 1970). Females in some strains may produce smaller or larger egg cases. A female will produce four to eight egg cases during her life with the later ones tending to be smaller. First instar nymphs are 2-3 mm in length and are susceptible to desiccation. Nymphs molt 5-7 times over a period of 30-60 days depending on temperature and food supply. Under adverse conditions nymphal development may take more than 100 days (Willis *et al.* 1958). Adults normally live in excess of 100 days but under unfavourable conditions this may be considerably shorter, especially in males. Under controlled conditions some adults can live one year or more. Both nymphs and adults are very active and are capable of rapid running movement. Powered flight probably does not occur, although occasionally a gliding flight may be undertaken.

Ecology - The ecological requisites of this species are warmth, moisture and food, and it may be found wherever these conditions are met. In its association with humans these requirements usually mean that the German cockroach occurs in home kitchens and adjoining food-storage rooms but not other rooms of the home (Cornwell 1968). In apartment complexes it may be present in every room. It is found in restaurants, institutional mess halls, food processing plants, city dumps, on board ships and in a variety of other protected environments. Wright & McDaniel (1973) reported that it occurs in housing areas more frequently than in other situations. Much of its activity appears to be regulated by pheromones (Faulde *et al.* 1990, Sakuma & Fukami 1991). Under laboratory conditions it does well at 30° C, which may be at or near its optimum temperature. However, a great part of its remarkable success is probably attributable to its ability to survive much less favourable conditions. It has been found living in outdoor refuse heaps in the middle of winter in temperate areas (Lucas 1912, Cornwell 1968). It also occurs out of doors, usually as adults or large nymphs (Tsuji & Mizuno 1972) under a variety of conditions which would be expected to bring about its demise. Thus, in spite of its presumed tropical or semitropical origin it is an extremely hardy species. It is a general feeder and

can survive on a wide variety of organic matter. It seems to prefer starchy foods (Mallis 1969).

3.3.2 *Blatta orientalis* L. - the oriental cockroach

Distribution - The distribution of the oriental cockroach is considerably more restricted than that of the German cockroach. It is largely a species of the temperate zones of the world (Cornwell 1968). Its origin has been subject to some debate. Rehn (1945) considered this to be North-Central Africa. Princis (1954) disputed that contention and showed that Southern Russia, in the area around the Black and Caspian Seas, is more likely to be its prehistoric home. Thus, it probably had a rather temperate origin and, perhaps because of this, does not appear to be established in the hot, humid tropics. From Eastern Europe and Asia Minor it apparently spread eastward, northward, and westward. Eventually, it reached the New World, probably via Europe (Rehn 1945). It is now widely distributed in the north temperate regions of the New and Old Worlds, being recorded from as far north as Canada (Hebard 1917) and other northern countries. It is a dominant pest species in United Kingdom (Ragge 1965) and Germany (Peters 1961). Its range probably also extends into the subtropics. In South America it was thought to be limited to Chile and Argentina, into which it was probably introduced from Spain through early shipping (Rehn 1945). More recently, it has appeared in certain seaport cities in Brazil (Silva 1971). It is found infrequently in South Africa, again being limited primarily to seaport areas (Hesse 1971). In spite of its name it is not widely distributed in the Orient (Asahina 1971) although it occurs on mainland China (Robinson & Bao 1988). It is present is South Australia but not in Brisbane (Pope 1953a) nor in Japan (Asahina 1971) and probably not in most of the intervening islands.

Description - *B. orientalis* (Fig. 3b,c) is of intermediate size measuring 20-27 mm in length. The body is uniformly reddish brown to black in colour, with nymphs tending to be the darkest. The sexes are easily separable because adult females have greatly reduced wings and have the appearance of being wingless. Males have wings that cover two thirds or more of the abdomen but they do not fly. All stages lack a footpad (arolium) between their tarsal claws which limits their ability to climb smooth vertical surfaces (Cornwell 1968). Oothecae are 10-12 mm in length, are coloured similarly to nymphs and adults, and lack indentations indicating egg position (Fig. 4d).

Biology and life cycle - This is a relatively long-lived species of cockroach. Under unfavourable conditions of food and temperature its life cycle may require more than two years to complete (Cornwell 1968). Under optimal conditions as little as six months or less may be sufficient (Willis *et al.* 1958). Male nymphs apparently develop more rapidly than do females. When both sexes are present as adults, mating usually occurs within 4-9 days. An ootheca is produced 8-10 days later. Within a day or two of its completion the egg case is dropped by the female and is often left in a protected spot where food is

available. Normally the incubation period requires 40-50 days, but under winter conditions an egg case may lie dormant until warmer temperatures return (Cornwell 1968). Females produce an average of eight egg cases which usually contain 16 eggs each, but may have up to 18. Seven to 10 molts occur in 130-165 days for males and 280-300 days for females when reared as isolated nymphs (Willis *et al.* 1958). Adults live from 35-180 days and perhaps longer (Cornwell 1968). Parthenogenesis sometimes occurs in this species (Roth & Willis 1956).

Ecology - This important domiciliary species likes cooler surroundings. Its preferred temperature range is reported to be 20-29° C (Cornwell 1968). As a result it is customarily found in lower levels of dwellings where the temperature is cooler, such as basements, cellars, crawl spaces, drain pipes and sewers, behind cabinets, inside walls, under floor coverings, etc. Its habitat need not be moist but moisture must be available to the insects, especially at higher temperatures. It is sometimes found in upper levels of buildings which it has reached by following water pipes. Because of its preference for cooler temperatures it is not surprising that this insect is often found out-of-doors and in unheated buildings even in winter months. It apparently finds adequate shelter in refuse dumps, under the bark of trees, under stones and leaves and in similar situations. There are reports that nymphs cease development in winter (Cornwell 1968). This may help account for the excessively long nymphal periods reported above. Occasionally, oriental cockroaches become so abundant in their outdoor habitats that they may almost literally overrun an area (Pul'ver 1973). They are general feeders but have a preference for starchy foods (Rau 1945).

3.3.3 *Periplaneta americana* (L.) - the American cockroach

Distribution - The American cockroach is usually spoken of as being cosmopolitan in its distribution (Princis 1966). This is perhaps slightly misleading because it probably does not extend as far northward as does the German cockroach. It is believed to have originated in tropical Africa from whence it was widely dispersed through commerce. Originally it was probably spread from Africa to South America, the West Indies and southern North America (Rehn 1945). It is presently distributed throughout the tropical and subtropical regions of the world. It is particularly abundant in tropical Africa and on the Indian subcontinent (Nigam 1933). It occurs in China (Robinson & Bao 1988), Thailand (Asahina & Hasegawa 1981) and Malaysia (Oothuman *et al.* 1984). In addition, this is the species of *Periplaneta* which has successfully penetrated into the temperate zones. It is found in numerous states in the USA including northern states (Rehn 1945), United Kingdom (Ragge 1965), southern Japan (Asahina 1961) and many other parts of the northern and southern temperate zones. Thus, it is a virtually cosmopolitan species.

Description - This is a large cockroach with adults measuring about 35-40 mm in length (Fig. 3d). Larger and smaller individuals will occasionally be seen.

Males and females are about the same size, but females have stouter abdomens. The sexes can be separated by this feature as well as by the fact that males have both cerci and styli, whereas females lack styli. All stages are a shining red to chocolate-brown colour. Considerable colour variation occurs in a colony due to the presence of freshly molted individuals whose colour is not fully developed. The adult pronotum has a prominent yellow to buff coloured sub-marginal pattern with a darker interior. Nymphs are uniformly coloured except for an indication of the pronotal pattern in large nymphs. Wings are fully developed in adults of both sexes. They extend slightly beyond the abdomen in males but are approximately as long as the abdomen in females. Oothecae are rather small, measuring about 8 mm in length, and are very dark brown (Fig. 4e).

Biology and life cycle - Although much information is available on the biology and life cycle of the American cockroach, some of it is contradictory. Given here are average values where feasible, with an indication of the extremes. The adults are long-lived averaging one year and probably longer (Gould & Deay 1938). Under adverse conditions they may live about 100 days, whereas at the other extreme an adult life span of two to three years is known (Griffiths and Tauber 1942a). When adult males and females are present together, mating occurs after a seven-day female refractory period (Brousse-Gaury 1978), but parthenogenesis is known to occur in this species (Roth & Willis 1956). An ootheca is produced every 4-10 days. A single feeding may be adequate for the production of several oothecae (Kunkle 1966). One female may deposit 10-90 egg cases with averages of 21 and 59 being reported (Griffiths & Tauber 1942b, Gould & Deay 1938). A female usually carries an ootheca for about 24 hours, after which she deposits it in a carefully selected location. She will often hide it or glue it to some surface. Normal oothecae have 16 eggs in two parallel rows. Reports of up to 28 eggs per egg case occur in the literature, but seem improbable, especially since this is near the normal number for *P. brunnea*, a species that is easily confused with *P. americana*. The incubation period for eggs is 30-45 days with extremes of 24-100 days being reported (Cornwell 1968). Nymphs molt 7-13 times over the course of 5-15 months. The first molts tend to occur at regular intervals, whereas later ones may be irregular. Under adverse conditions nymphs may nearly cease growing (Nigam 1933). This, of course, has the effect of greatly prolonging the nymphal period.

The data available on the American cockroach provide an excellent example of the kinds of variability in life cycle which should be expected when an insect can occur under greatly differing environmental conditions. Without question most of the variability presented above is legitimate and is attributable to variations in temperature and food supply. Particularly where an insect has a long life cycle, such variation will occur and should be considered normal. This example also illustrates the need for knowledge about a particular species under local conditions.

Ecology - The American cockroach prefers warm humid environments as would be expected from its origin. Its preferred temperature is about 28° C, but it is active from 21-33° C. In association with humans they occur in restaurants, food processing plants, grocery stores, bakeries and other places where there is food. Historically they have been of importance as ship galley and cargo-hold pests. They are sometimes associated with latrines, outhouses, sewers, and sewage-treatment plants. While not a common household kitchen pest, they do occur in this situation. They are general feeders and can survive on almost any organic matter (Cornwell 1968).

In warm regions they can and do live outside throughout the year. In temperate climates they survive well outside during summer. There are reports of their occurrence in garbage dumps, unoccupied buildings, trees, mines, and under decaying matter (Cornwell 1968). In central Japan they even survive well during winter in unheated situations (Tsuji & Mizuno 1973). Like the oriental cockroach, they can become very abundant as an outdoor dweller and may overrun a given area (Nigam 1933).

3.3.4 *Periplaneta australasiae* (Fab.) - the Australian cockroach

Distribution - This *Periplaneta* species also apparently originated in tropical Africa. Its spread is less well documented than some of the other species already discussed, but is undoubtedly attributable to world commerce (Rehn 1945). It is presently well distributed in the tropical and subtropical regions of the world (Princis 1966). In general it requires warmer temperatures than *P. americana*. This probably accounts for its lack of success in the more temperate zones (Hebard 1917) although Ragge (1965) recorded it as being present in the British Isles. It has been reported from the Ryukyus Islands (Asahina 1961, 1971), China (Robinson & Bao 1988), Thailand (Asahina & Hasegawa 1981), Malaysia (Oothuman *et al.* 1984), the Philippines, Sri Lanka (Ceylon), India, Australia (Cornwell 1968), tropical Africa, tropical America (Brazil, Ecuador, Suriname, Panama and Costa Rica), the West Indies, and is present in the southern USA (Rehn 1945). Occasionally it is found farther north living in protected environments such as greenhouses.

Description - The Australian cockroach (Fig. 3e) is also a large insect measuring 27-33 mm in length. In general it is somewhat smaller than *P. americana* and is perhaps a little darker in colour. In the tropics somewhat larger specimens are often found. It has a design on its pronotum very similar to, but more distinct than, that of *P. americana*. It can be readily distinguished by the presence of a lateral pale-yellow stripe on each forewing which extends approximately one third the length of the forewing. The wings are fully developed in both sexes and extend slightly beyond the abdominal tip. Flight is possible in this species. The sexes can be separated by the stouter abdomen of the female, by the presence of a vertical keel at the tip of the female abdomen and by the presence of styli on the male abdominal tip. First instar nymphs are similar to those of *P. fuliginosa* but can be distinguished by the

presence of a pair of light-coloured spots on the metathorax (Powell & Robinson 1980). Larger nymphs are dark brown in colour but are distinctive because of the presence of yellowish spots on the lateral margins of their thoracic and abdominal segments. The bodies of adults are similarly marked but the markings are covered by the wings. The oothecae measure 10-11 mm in length and are nearly black in colour. Superficially they resemble egg cases of American cockroaches but are darker in colour and contain more eggs with better indications of egg location (Fig. 4f).

Biology and life cycle - Information here is quite limited. The adult life span is probably 4-6 months. Mating in adults occurs after a short maturation period reported as 5 days in males. The first egg case appears around 20 days after female maturation. A female may produce 20-30 egg cases at intervals of about 10-days. Oothecae are normally deposited shortly after they are formed. The incubation period is about 40 days but is obviously subject to temperature variations. Each ootheca contains 22-24 eggs which is quite distinct from the 16 of *P. americana*. Little is known about the nymphal developmental period but it is probably 6-12 months depending on conditions. Pope (1953a) found that it might be as short as 4 months. The number of molts is reported to be 9-12 (Willis *et al.* 1958).

Ecology - This species has a preference for warm humid environments. It seems quite dependent upon these conditions since it does not survive well outside the tropics and subtropics. It occupies habitats in dwellings and other premises similar to those of *P. americana*. It frequents greenhouses where it tends to feed on plants. It also occupies locations out-of-doors, which are quite varied and apparently are related primarily to the availability of food and minimum shelter. Its outdoor existence is limited to very warm climates. It is a general feeder and will accept a wide variety of substances as food (Cornwell 1968).

3.3.5 *Periplaneta brunnea* Burmeister - the large brown cockroach.

Distribution - This is another tropical species of *Periplaneta*. It is believed to have originated in tropical Africa and to have been spread by via world commerce (Rehn 1945). Its present distribution is sometimes confused because of its striking physical similarity to *P. americana*. Nevertheless, it is widely distributed in the tropical and subtropical regions of the world (Princis 1966). It appears to prefer warmer climates than does the American cockroach but is perhaps not quite so restricted by this factor as is *P. australasiae*. It is well established in the southern USA and is occasionally found in states much farther north (Hebard 1917). It has been reported from Costa Rica (Vargas & Fisk 1973), Brazil (Silva 1971), Chile, Guyana (Asahina 1961), and Suriname (Bruijning 1959). It is present in Japan (Asahina 1961, 1971), China (Robinson & Bao 1988), Thailand (Asahina & Hasegawa 1981), Malaysia (Jeffery *et al.* 1982, Oothuman *et al.* 1984) and Australia, where the name *P. ignota* Shaw is frequently used (Mackerras 1970). Sporadic reports of its collection in the more

temperate regions of the world are undoubtedly due to accidental introductions through shipping or through confusion with *P. americana*.

Description - As mentioned above, this insect (Fig. 3f) has a striking similarity to *P. americana*. In general, it is a stouter insect than the American cockroach, but this is not very helpful to the inexperienced eye. It is also slightly smaller, measuring 31-37 mm in length. The markings on the pronotum are very pale, being much less distinct than in *P. americana*. The wings are fully developed and cover the tip of the abdomen in both sexes. Gliding flight is possible. Perhaps the best character for separating adults of the two species is configuration of the cerci (Edmunds 1957). In *P. brunnea* they are short and stout with a more or less blunt tip (Fig. 5i). In *P. americana* the cerci are longer and are very tapered at the distal end, especially in males (Fig. 5h). Another diagnostic character is that adult males of *P. brunnea* have a small, inconspicuous supra-anal plate (epiproct), whereas in males of *P. americana* this structure is large, prominent, and deeply notched (Fig. 5i and h, respectively). Young nymphs of the two species are easily distinguished by the presence of white markings on the antennae, a clear medial area on the mesothorax, and cream-coloured abdominal tergites in first instar *P. brunnea* (Powell & Robinson 1980). In middle-sized nymphs the cream-coloured pattern occurs on some abdominal segments in *P. brunnea*, which is in marked contrast to the uniformly coloured *P. americana* nymphs. Oothecae are quite distinct, being up to twice as long (12-16 mm) as in *P. americana* (Fig. 4h).

Biology and life cycle - A study by Wright (1973) has provided considerable information on this species. At 27° C the egg incubation period is 35-59 days. This agrees well with an earlier estimate of 40 days (Willis *et al.* 1958). Oothecae average 24 eggs each with about 20 nymphs emerging per egg case. The average interval between pairing and first egg case appearance is 14 days. The egg case is only carried for one day, with a second one being produced about 6 days later. In laboratory culture an adult female may produce 30 or more oothecae but many eggs are inviable. Whether this is true in nature is not known. The nymphal development period averages 182 days and 192 days for females and males, respectively. Average adult longevity for mated pairs is 244 days for males and 219 days for females. Obviously these time periods are subject to temperature-induced variations.

Ecology The ecological requirements of this species are similar to those of the American cockroach (Cornwell 1968). It prefers warm, humid situations. As shown by its distribution, it is much more limited by this factor than is the American cockroach but somewhat less limited than the Australian cockroach. Typically it is found in food-storage areas, grocery stores, homes, city dumps, outhouses, sewers, etc. It is a general feeder and accepts a wide variety of organic matters as food. In Suriname it is said to be sometimes as common as the *P. americana* and *P. australasiae* and to be found in homes (Bruijning 1959).

3.3.6 *Periplaneta fuliginosa* (Serville) - the smoky-brown cockroach

Distribution - The origin of this species is unclear but it is apparently quite different from the other members of this genus thus far described. It was originally described as being subtropical (Cornwell 1968) and Princis (1966) indicated a quite limited distribution. More recent information has shown it to be widespread in the Far East where it occurs in China (Robinson & Bao 1988), Russia, Korea, Japan and some of the Islands north of Australia (Asahina 1961, Appel & Rust 1987). It is found in many southern states of the USA where it may become almost as important as the German cockroach in some localities (Haines & Palmer 1955, Appel & Rust 1987). It has become established in several localities in California (Appel *et al.* 1990). It has been reported from South America, Hong Kong, and Taiwan (Asahina 1961). A few scattered reports of its existence elsewhere have appeared (Appel & Rust 1987) but apparently it is not a significant pest species in other parts of the world.

Description - As its common name indicates, this is a uniformly dark-coloured cockroach (Fig. 3g). It is almost as dark as *B. orientalis*. It is 31-35 mm long, similar in size to *P. brunnea*. The wings are fully developed in both sexes. The sexes can be separated by the stoutness of the female abdomen and the presence of styli in males. Large nymphs are uniformly very dark and can be separated from similar species by this feature. Young nymphs resemble those of *P. brunnea* and *P. australasiae* but they can be distinguished. In *P. fuliginosa* nearly the entire dorsum of the mesonotum is whitish as are the dorso-lateral margins of the second abdominal segment. In *P. australasiae* there is also a pair of cream-coloured spots on the anterior margin of the metathorax. In *P. brunnea* the medial portion of the mesonotum is translucent, and the first and second abdominal margins are cream coloured (Powell & Robinson 1980). Additionally, the white banding on the antennae is different. In *P. fuliginosa* the basal segments tend to be dark and an intermediate region of white banding may be present. In *P. brunnea* the basal segments are always white. Antennal tips in both species, as well as in *P. australasiae*, are white. Oothecae vary in size from 10-13 mm and have a good external indication of egg position although distinct indentations are lacking (Fig. 4g).

Biology and life cycle - Paired males and females lived in the laboratory an average of 215 and 218 days, respectively (Wright 1979). Adults mate soon after maturation and the first ootheca appears 15-20 days later. Average incubation period is 100 days at 20° C (Tsuji & Mizuno 1972), 70 days at 23° C, 56 days at 25.5° C, and 37 days at 30° C (Gould 1941). A female may produce a total of 15-20 oothecae (average of 19) at about 6-day intervals at 26.7°C (Wright 1979). Oothecae have from 20-26 eggs with 24 being the most common number. Females deposit their egg cases after about 1 day. The nymphal development period is 274-439 days at room temperature and 179-191 days at 30-36° C, but Wright (1979) reported the period to be 320-388 days at 26.7°C. Under cooler conditions a normal two-year life cycle has been

suggested (Tsuji & Mizuno 1972), and cold-acclimatized nymphs can withstand prolonged periods of exposure to cold (Tsuji 1975). Nymphs reared individually at 30-36° C matured in 474-586 days, a phenomenon which has also been noted in other cockroaches. There are 9-12 molts (Willis *et al.* 1958). Young nymphs exhibit a very characteristic behavior pattern. They run about with their abdomens held high in the air in a fashion similar to rove beetles (fam. Staphilinidae). This is a very active species that scurries about rapidly and can fly.

Ecology - The smoky-brown cockroach is primarily an outdoor species. It is often found around garages, woodpiles, crawl spaces, unoccupied buildings, outhouses and is sometimes attracted to light at night (Cornwell 1968). It is perhaps this outdoor tendency which keeps it from moving farther into the temperate zones. However, Tsuji & Mizuno (1972, 1973) found it to be quite cold hardy and suggested that it can overwinter outdoors in central Japan. It's feeding habits have been observed in the field (Appel & Rust 1986). Adult males and small nymphs emerged from harbourages shortly after sunset. Soon, all other stages followed and foraging took place. It appears to feed well on plant materials. When feeding was complete, most stages returned to the harbourages. Adult males, calling females and some large nymphs remained abroad. Presumably mating occurred at this time. As a domiciliary pest it can become very abundant and sometimes occupies a habitat similar to that of the German cockroach (Haines & Palmer 1955). Where it is found in northern states of the USA it is usually in warm environments such as greenhouses (Mallis 1969).

3.3.7 *Periplaneta japonica* Karny - the Japanese cockroach

Distribution - This fifth member of the genus *Periplaneta* appears to be a native Japanese species. For many years it was obscure, being misidentified or confused with *B. orientalis* which it superficially resembles (Asahina 1961). As far as is known it is limited to Japan, parts of China (Princis 1966, Robinson & Bao 1988) and the Vladivostok area of Russia (Bey-Bienko 1950).

Description - Little information on this species has been published. However, it is a rather small *Periplaneta* with adult males measuring 23-25 mm and adult females 21-23 mm in body length (Fig. 3h,i). In colour it resembles *P. fuliginosa.* The pronotum is uniformly dark and is rather short in males. Wings are fully developed in males and extend beyond the tip of the abdomen, giving adult males an overall length of about 30 mm. Viewed from above, the male is rather slender in appearance. The adult female has wings that are abbreviated, covering about half of the abdomen (Bey-Bienko 1950, Asahina 1961). This fact, together with its dark colour, probably accounts for the misidentification of these cockroaches as *B. orientalis.* Small nymphs are uniformly dark coloured (Powell & Robinson 1980). Large nymphs are also quite dark but have a lighter-coloured area on the postero-lateral margins of the pronotum. Oothecae are similar to those of *P. americana* (Roth 1968) (Fig. 4i).

Biology, life cycle and ecology - Published information in these categories is scarce. However, it can be presumed that the biology and life cycle of *P. japonica* are generally similar to other members of this genus. It appears that in Japan this species has a normal two year life cycle under field conditions (Tsuji & Mizuno 1972, 1973, Tsuji & Tabaru 1974). Indeed, these authors have shown that it is usually second and last instar nymphs that overwinter under outdoor conditions. *P. japonica* is one of four serious domiciliary pests in Japan (Asahina 1961, Tsuji & Tarbaru 1974), the other three being *P. americana, P. fuliginosa* and *B. germanica.*

3.3.8 *Supella longipalpa* (F.) - the brown-banded cockroach

Distribution - The brown-banded cockroach, known previously as *S. supellectilium* (Serv.) (Gurney 1970, Ragge 1973), is a nearly cosmopolitan cockroach. It probably originated in Africa from whence it has been widely dispersed (Rehn 1945). It is now generally distributed in the tropical and subtropical regions of the world (Princis 1969). It is particularly abundant in Africa. Much of its spread into the temperate zone has occurred during the twentieth century. The USA presents an excellent example of this point. It was introduced into Florida about 1900. By 1967 it had been reported from 47 of the 48 contiguous states (Cornwell 1968). In some states there are indications that it may compete well with the German cockroach (Mallis 1969). It is interesting to speculate that this insect's rather late dispersal into the temperate zones is related in some way to the tremendously increased personal mobility of people that has also occurred in the twentieth century. The other cosmopolitan species apparently did not need this added factor for their dispersal. *S. longipalpa* has been reported from Japan (Asahina 1973a) and only reached the British Isles by the 1960s (Ragge 1965).

Description - This is a small cockroach measuring 10-14 mm in length (Fig. 3j). On the basis of size and colour of adult males it could be confused with the German cockroach. However, there are many distinguishing features. The pronotum is rather uniformly dark with lighter lateral edges and definitely lacks the two parallel stripes of *B. germanica*. The adult male appears to be very slender with its wings extending beyond the tip of the abdomen. Adult females have short wings which expose a considerable portion of their very stout abdomen. The common name derives from the presence of two dark-coloured transverse stripes or bands on the mesonotal and abdominal tergites. These tend to be obscured by the wings in adults. The forewings have both brown and black pigments, with those of the female being considerably darker. Nymphs and adults are cream coloured ventrally. In nymphs the dorsal light-coloured areas are very prominent. Also, the abdominal tergites are a light-brown colour with the anterior ones having black margins. Considerable colour variation exists in this species, making it rather attractive in appearance. Both nymphs and adults have long palps in accordance with the specific name. The oothecae measure 4-5 mm in length and are crescent shaped (Fig. 4b). They vary in

colour from light to reddish brown, have prominent teeth on the keel, and are indented showing the location of the eggs.

Biology and life cycle - The life cycle of this species is comparatively short. The adults live 90-115 days at 30° C. They mate within 5-10 days after maturity and produce an egg case about 10 days later. Females may produce a total of 10-20 egg cases at about 7-10 day intervals (Willis *et al.* 1958). The incubation period is 74 days at 25° C, 43 day at 27.5° and 37 days at 30° C (Gould 1941). Oothecae contain an average of 16 eggs of which about 14 hatch. Neither egg-case size nor the percentage of viable eggs decline with female age (Willis *et al.* 1958). The female normally deposits the egg case in an inconspicuous place and often glues it to some surface. Nymphs undergo 6-8 molts in the course of about 55 days at 30° C. Nymphal periods of 95-276 days have been recorded, but obviously are for cooler temperatures. Adults are reported to fly readily when disturbed (Gould & Deay 1940).

Ecology - The brown-banded cockroach is found in locations similar to those where the German cockroach exists. Unlike *B. germanica*, however, it is not confined to the kitchen area but wanders over the entire dwelling. It is often seen in bedrooms where it will hide in bureau and desk drawers and in other furniture. It hides behind pictures, books on shelves, under wallpaper and in other similar places (Cornwell 1968). These habits, including that of gluing its ootheca on the inside of furniture and placing them high on walls (Benson & Huber 1989), make it extremely difficult to control and unquestionably aid in its dispersal (Mallis 1969). They also account for an additional common name, the furniture cockroach. It is fond of starchy foods such as the sizing of books and the paste under wallpaper. This tendency may account for the success of the brown-banded cockroach as an invader of institutional buildings where cooking is not a major function. In warmer parts of its distribution range it is an outdoor species. It may also be found in almost any type of building.

3.3.9 *Blatta (Shelfordella) lateralis* (Walker) - the Turkistan cockroach

Distribution - This is essentially a desert species occurring in North Africa from Libya eastward into central Asia. It is widely distributed in Central Asia, including Kashmir, Iran, Afghanistan, Iraq and probably other central Asian countries that were part of the former Soviet Union. It often occurs in mountainous areas (Bey-Bienko 1950). Elsewhere, it has been reported from Egypt, Saudi Arabia, the Sudan, Israel and Libya. It does not seem to be present in other parts of the world (Princis 1966) except that it was introduced into California, USA, during the late 1970's (Spencer *et al.* 1979). It has since been reported from Texas and Arizona as well (Olson 1985, Gulmahamad 1993, 1995). Synonomy is a particular problem with this species, but the most appropriate name is that shown above (Princis 1966). This usage places *Shelfordella* in the status of a subgenus indicating that it differs from typical *Blatta*. Other names used are *B. tartara* and especially *Shelfordella tartara* Sauss. (Kapanadze 1971).

Description - This is a moderate-sized cockroach with males measuring 19-23 mm and females 22-25 mm (Fig. 3k,l). The wings are fully developed in males and extend beyond the end of the abdomen. They are straw-yellow in colour except that the outer margins of the forewings, near their base, are lighter coloured, being rather translucent (Asahina 1966, Bey-Bienko 1950, Gulmahamad 1993). In females the wings are greatly reduced; the forewings are triangular in shape. Each forewing bears a short cream-coloured line near the lateral margin. Females are dark brown with some cream-coloured markings on the abdomen. Nymphs are bicoloured with the thorax being light chocolate brown while the abdomen is very dark brown. Oothecae are also dark brown, are about 10 mm in length and closely resemble those of *P. americana* (Fig. 4e).

Biology, life cycle and ecology - Exact information in these categories is limited. Mating has been observed in the field and appears to follow the typical cockroach-mating pattern (Gulmahamad 1993). Kapanadze (1971) found that nymphs develop in 118-137 days at 30-35° C. Adult longevity varied from 30-300 days. Optimum embryonic development temperature was 30° C. This species occurs in cultivated and mountainous areas where it frequently breeds in manure (Artyukhina & Sukhova 1972). It also occurs in desert or semi-desert locations. It is believed to have originated in the southern Palearctic under semi-desert conditions. It is commonly found in human habitations characteristic of the regions in which it occurs (Bey-Bienko 1950). Indeed it is one of the more important domestic species within its normal range. It was introduced into California with military supplies being returned from the Middle East. It was originally discovered in warehouses and steam tunnels on an army base. Subsequently, it has spread into urban areas where it finds harbourage in and under various kinds of ground-cover vegetation and virtually any other object that in lying on the ground (Gulmahamad 1993). It is active primarily at night and is frequently found climbing on brick or concrete-block walls. It has been observed feeding on hibiscus flowers. It appears to have become well established in Southern California and in Arizona. It is likely to spread to other parts of the Southwestern USA.

3.3.10 *Polyphaga aegytiaca* (L.) - no common name

Distribution - This important species is known to occur in most of the countries surrounding the Mediterranean Sea and eastward as far as Iran and the Caspian Sea. Specifically, it has been reported from Algeria, Tunisia, Libya, Egypt, Israel, Syria, Iraq, Iran, Turkey, Greece, Crete, Cyprus, the former Yugoslavia, southern Italy and Sicily (Princis 1962). In the former Soviet Union it is known from the Caucasus, Transcaucasus and European Steppes. There are indications it may be extending its range into south-central Asia where it has been found living under rather harsh conditions (Bey-Bienko 1950). The origin of this species is unknown.

Description - *P. aegyptiaca* (Fig. 3m,n) is a large cockroach with males measuring 25-32 mm including the wings. Females are wingless, nymph-like and measure 25-34 mm. The body is robust and strongly convex dorsally. The female is a uniform dark colour while the male gives the appearance of being smoky brown primarily because of the presence of wings which tend to be lighter coloured and have prominent veins. The wings are rather broadly rounded at their distal end. The antennae are usually shorter than the body. The pronotum has a light-coloured anterior margin in both sexes. Cerci are very short and are unsegmented in females (Bey-Bienko 1950). Oothecae measure about 12 mm, are pointed at one end and have a row of 12-14 distinct teeth along the keel (Fig. 4j). Each contains 7-13 eggs (Roth 1968).

Biology, life cycle and ecology - Little exact information is available in these categories. Apparently 2-3 years or longer may be required for completion of the life cycle. This cockroach lives under rather harsh conditions of desert or semi-desert nature. It is adapted to loamy soil as well as to sand, which appears to account for its distribution. In the countries along the African coast of the Mediterranean Sea it is one of the commonest cockroaches associated with humans. It appears to do well in the abodes of desert-dwelling people and is well adapted to life in arid countries (Bey-Bienko 1950).

3.3.11 *Polyphaga saussurei* (Dohrn) - no common name

Distribution - *P. saussurei* has been reported repeatedly in the southern part of the former Soviet Union from west of the Caspian Sea eastward through at least the city of Tashkent. It occurs in Kazakhstan, Uzbekhstan, Tadzhikistan, and Azerbaidjan. It also occurs in Iran, Afghanistan, India, (the Karakoram region of Kashmir) and may occur in other south-central Asian countries as well (Bey-Bienko 1950, Princis 1962). It does not appear to have spread to other parts of the world. Its point of origin is unknown but undoubtedly is within the region it now inhabits.

Description - This *Polyphaga* (Fig. 3o) is a large insect with a strongly convex body dorsally. Males measure 32-37 mm and females 35-44 mm in total length. In males the wings are fully developed, extend beyond the tip of the abdomen and are broadly rounded at the distal end. Antennae and cerci are very short. This insect is uniformly quite dark in colour but the forewings of males are lighter (Asahina 1966, Chopard 1929). Females are wingless and nymph-like as are the females in *P. aegyptiaca*. The oothecae vary in size from 12-20 mm and have a variable number of eggs (Bey-Bienko 1950, Roth 1968). In general appearance they are similar to the oothecae of *P. aegyptiaca* (Fig. 4j) but are somewhat larger (Bey-Bienko 1950).

Biology, life cycle and ecology - It has been reported that under the conditions which prevail in the range of this species 3.5-4 years may be required to complete its life cycle. While this may seem rather long, it must be remembered that this is a large insect and weather conditions in that region can be rather

harsh. This species is adapted to live in loamy or clay soils. Because of this fact, it thrives in housing with clay floors and walls. It is reported to be capable of parthenogenesis and is an important domiciliary species in south-central Asia (Bey-Bienko 1950).

3.3.12 *Rhyparobia* (*Leucophea*) *maderae* (Fabricius) - the Madeira cockroach

Distribution - Until recently, this species has been known as *Leucophea maderae* (Fabricius) (Kevan 1980). Because this name is so familiar it has been placed in parenthesis above. This does not indicate sub-genus status, as was the case with *Shelfordella*. It is circumtropical in its distribution (Princis 1965). It is believed to have originated in West Africa near the equator. This very likely accounts for its preference for the tropics. It probably spread directly from West Africa to tropical South America and the West Indies. It has become broadly distributed in that part of the world. It is present in Florida, and has been found living in sheltered areas in New York City (Gurney 1953, Cornwell 1968). The Madeira cockroach has also spread northward along the west coast of Africa and is now established in Morocco, Spain and the island of Corsica. It has been reported from the Philippines, parts of Indonesia and Hawaii. Its spread into other Asian countries such as India and Australia can be anticipated (Rehn 1945). There is also the possibility of its becoming a pest species in the temperate zones where well-heated buildings provide adequate shelter (Gurney 1953).

Description - This is a large cockroach measuring 40-50 mm in length (Fig. 3p). Its wings are fully developed and usually cover the tip of abdomen in both sexes. It has a speckled or mottled appearance particularly on the posterior part of the forewings. The pronotum is nearly clear as are the forewing margins. A dark line occurs on the basal area of each forewing. This insect has been described as having a tawny-olive colour (Cornwell 1968). Nymphs are a darker olive colour and have small but prominent yellowish spots on the posterior-lateral margins of the abdominal tergites. The ootheca is carried internally by the female. It is usually only seen after the female has dropped it following nymphal hatch. It measures 16-19 mm in length, is a fairly bright-yellow colour and has obvious indentations indicating egg position (Fig. 4q). What appear to be malformed oothecae sometimes occur but this may simply indicate the shape of the brood chamber in which they are held.

Biology and life cycle - Precise data on adult longevity are not available, but this is undoubtedly a long-lived insect. Following maturation, mating occurs in 10-14 days and an ootheca appears in about 20 days. It is retracted and is held internally during the incubation period of about 60 days (Roth & Willis 1954). Each oothecae contains 34-36 eggs. There are reports that the number of nymphs actually hatching is much reduced (Willis *et al.* 1958) but under natural conditions this may not be true. Nymphs mature rather slowly, requiring 121-150 days and 7-8 molts at 30-36° C. Under cooler conditions they are reported to require 7-18 months to reach maturity (Scharrer 1951). If this is correct, a life

cycle of 2-3 years is quite possible. In spite of its size, this is an agile insect which can actively fly. As with certain other cockroaches, it produces a distinctive and repulsive odour when disturbed.

Ecology - In its native habitat the Madeira cockroach tends to be an outdoor species. Its natural foods are plants and plant parts. It is especially fond of fruits such as bananas and grapes. It is also found on many other types of plants. Frequently large colonies develop. In its association with humans it is often found in fruit stores, grocery stores, greenhouses and at ports of entry (Cornwell 1968). Its pest status in home dwellings is uncertain but presumably occurs, particularly in the tropics (Gurney 1953).

3.3.13 *Nauphoeta cinerea* (Olivier) - the lobster cockroach

Distribution - This species is sometimes also referred to as the cinereous cockroach. It is believed to have originated in East Africa below the equator (Rehn 1945). Therefore, it is not surprising to find its present distribution is world-wide but limited mainly to the tropics and subtropics (circumtropical) (Princis 1965). It probably spread originally from East Africa to the Malagasy Republic (Madagascar), Mauritius, Indonesia, Singapore, the Philippines, and other areas of the Far East via shipping (Rehn 1945). It now occurs in much of that part of the world including Australia (Mackarras 1970), Thailand (Asahina & Hasegawa 1981), Malaysia (Oothuman *et al.* 1984, Yap *et al.* 1991, Lee *et al.* 1993), the Ryukyus Islands, but not Japan (Asahina 1971). In Africa it has spread over most of the eastern part of the continent and as far north as Egypt. It is present in Hawaii. In the New World it was introduced into Brazil from Africa and into Mexico from the Philippines (Rehn 1945). It has spread into parts of the West Indies, is present in Florida (Anon. 1952, Gurney 1953), and in other states of the southern and southwestern USA. It is present on the Galapagos Islands. In the temperate zones it has been reported from England and Germany where it lives in protected environments (Cornwell 1968). Thus, it appears to have established itself outside of tropical climates to only a limited extent.

Description - The lobster cockroach gets its name from the design on its pronotum (Fig. 3q). It is intermediate in size, measuring 25-29 mm in length. It is described as having an ashy colour. Its wings are rather short and do not cover the abdomen. They show a speckled or mottled appearance. Nymphs also bear the pronotal design and have markings on the antero-lateral margins of the abdominal tergites (Cornwell 1968). Oothecae measure 15-18 mm in length and have clear indentations showing the position of the eggs (Fig. 4q). They are held internally as with other blabarid cockroaches, are light coloured and often are curved or crescent shaped (Roth 1968, Roth & Willis 1954).

Biology and life cycle - Adults of this species live about one year under laboratory conditions. Mating occurs after about six days of adulthood. Females exhibit mate selection, preferring males that have achieved social dominance

(Moore *et al.* 1988, Moore 1989). Male produced pheromones and male and female behavior apparently mediate the mate-selection process (Moore 1990). The first ootheca appears about one week after mating. As with other blabarids, the egg case is extended, rotated and then retracted into the brood chamber of the female. The incubation period is about 35 days. One female may produce up to 20 oothecae but usually the number is much smaller. About 40-45 days elapse between the emergence of successive broods of nymphs and the period becomes longer as the female ages. Oothecae average 33 eggs each, but vary from 26-40 eggs. Hatch is usually excellent. Nymphs undergo 7-8 molts in the course of 87-94 days at 30-36° C. Newly hatched nymphs exhibit the behavior pattern of crawling on and under the female. They remain in this association for about one hour as if this long a time is required for them to become adapted to a free-living existence (Willis *et al.* 1958, Roth & Willis 1954).

Ecology - As a tropical insect *N. cinerea* apparently is an outdoor species that feeds on plant materials. In its association with humans it has been a frequent intruder at ports of entry. It is often found around out buildings rather than in houses although there are reports of its occurrence in the latter (Pope 1953a). It has a fondness for animal foods, particularly if they contain fish oils, and is a frequent invader of milling plants, food storage sheds, etc. (Illingworth 1942). It may become very common locally in such situations (Gurney 1953). It has been reported from a hospital in Australia (Mackerras & Mackerras 1948), and is a regular dweller in native huts in the Sudan. One would expect that greenhouses would be an ideal type of dwelling for it in the temperate zones. It is also reported to be predaceous, feeding on at least one other species of cockroach (Cornwell 1968).

3.3.14 *Neostylopyga rhombifolia* (Stoll) - the harlequin cockroach

Distribution - This strikingly-coloured cockroach (Fig. 3r) apparently originated in the tropical Far East, probably in the Indo-Malayan region. It is now quite abundant in the Philippines and nearby island areas (Rehn 1945) including the Ryukyus Islands but not Japan (Asahina 1971). It occurs in Thailand (Asahina & Hasegawa 1981), Malaysia (Oothuman *et al.* 1984) and China (Robinson & Bao 1988). It has also been spread via shipping to other parts of the world. It is abundant in the Malagasy Republic (Madagascar), Mauritius, the Seychelles, and Madeira. On mainland Africa colonies are established along the east coast. From the Philippines *N. rhombifolia* has been imported into Hawaii and the New World prominently at Acapulco, Mexico. From there it has spread northward in Mexico to Baja California and Sonora where colonies reportedly live at or near the Sonora-Arizona (USA) border. It occurs in Costa Rica and probably other Central American countries. It has been reported from Venezuela, Argentina, and Brazil. The source of these latter introductions is not clear, but they occurred early, presumably also via shipping (Rehn 1945). Princis (1966) considered it to be circumtropical.

Description - The common name for this cockroach comes from its brightly coloured exterior (Fig 3r). It is a shining blackish brown with stripes and patches of various shades of yellow intermingled over its body, but particularly on its thoracic tergites. It is a medium-sized cockroach measuring 20-25 mm in length. Males are slightly smaller than females. Forewings are vestigial and hindwings are absent in both sexes. Nymphs resemble adults except in size (Cornwell 1968). Egg cases are carried externally and measure 12-15 mm in length (Roth 1968) (Fig. 4k).

Biology, life cycle and ecology - Only limited information is available for this species. Adult females lived 156 days at 24° C. Adult males are said to be found less frequently than females. Parthenogenesis occurs occasionally but is not well developed, as the nymphs frequently die (Cornwell 1968). Following mating, an ootheca is produced and dropped by the female. There is an average of 22 nymphs per egg case. Nymphs required 286-302 days to develop at 27° C (Willis *et al.* 1958). The domiciliary habits of this species are not well documented. Presumably, it is an outdoor species in its tropical home but tends to become associated with people in much the same way as *N. cinerea* and *R. maderae*.

3.3.15 *Pycnoscelus spp.* - the Suriname cockroach and others

Distribution - There are several species belonging to this genus and locally in the tropics of the Old World more than one of them may occasionally be domiciliary pests. However, on a world-wide basis it is only the Suriname cockroach, *P. surinamensis* (Linneaus) that has reached real prominence. This species apparently arose on the islands of the Malay Archipelago. It has been spread via shipping and is now virtually cosmopolitan in the tropical regions of the world (Rehn 1945, Princis 1964, Asahina & Hasegawa 1981). In the New World there are indications that it is invading the subtropics. It has become established at least in Florida, Louisiana and Texas (Hebard 1917). It is also troublesome occasionally in protected areas in Germany, England, Scotland and in certain northern states of the USA (Cornwell 1968). It has been reported from China (Robinson & Bao 1988).

Another interesting problem exists with regard to this cockroach. It has been known for many years that males are extremely rare in some parts of the world and that parthenogenesis is a regular means of reproduction. This problem has been clarified somewhat by the discovery that two well-defined groups exist, sometimes side-by-side, one being bisexual and the other parthenogenetic. The bisexual group has now been separated as a different species and designated as *P. indicus* (Fabricius). It is restricted in its distribution mainly to the Indo-Malayan region and perhaps Hawaii. The name *P. surinamensis* has been reserved for the parthenogenetic group and it is this form that is virtually cosmopolitan in the tropics of the world (Roth 1967). Among the races or clones of this species, it is known that variations in

chromosome number occur. This fact, together with parthenogenetic reproduction, make this genus of considerable evolutionary interest.

Description - *P. surinamensis* is a medium-sized insect measuring 18-24 mm in length (Fig. 3s). It is dark brown to black in colour as is particularly evident in the nymphs. In adults the pronotum retains this colour but the forewings are lighter providing a rather marked contrast. This has given rise to an additional common name, the bicoloured cockroach. In most individuals the anterior margin of the pronotum is pale. The wings are fully developed in adults (this is true for both sexes of *P. indicus*). The basal margins of the forewings are pale and just medial of this area a dark stripe occurs on both sides. Nymphs are uniformly dark and both nymphs and adults give the appearance of being stout. Oothecae are held internally by the female. They measure 12-15 mm in length and are rather fragile. Clear indentations indicate the position of the eggs (Fig. 4o). Egg cases are light coloured and crescent shaped (Roth & Willis 1954, Roth 1968). *P. indicus* is very similar in appearance to *P. surinamensis*. Males in *P. indicus* are slightly smaller than females but otherwise look the same.

Biology and life cycle - Most of the data available here is on *P. surinamensis*. Adult females live an average of 307 days. Mating is not a factor and egg development proceeds rapidly. The first ootheca appears about a week after adulthood. The incubation period is 35 days at 18-24° C and the nymphs are born in the manner of other viviparous cockroaches. The intervals between broods varies from 48-82 days, lengthening as the female ages. A given female may produce 1-5 broods with 3 being average. Egg cases contain an average of 26 eggs but the range is quite large. They are produced, extended, rotated and retracted similarly to other viviparous cockroaches. Nymphs undergo 8-10 molts over the course of 127-184 days at the above temperature range (Willis *et al.* 1958). Roth (1974) has studied reproductive potential in both species. Among other findings he reported that *P. indicus* is a better reproducer than are the clones of *P. surinamensis*. Presumably other information on *P. indicus* would not differ greatly from that on *P. surinamensis*.

Ecology - Like many other tropical cockroaches, *Pycnoscelus* tends to be an outdoor species. Its natural environment appears to be under stones, burrowing in top soil or dense humus, under loose litter, etc. It is a plant feeder and is actually involved in causing damage to plants of economic importance in certain parts of the world. In addition it does become a household pest and has been reported in this status in many places. Its occurrence in the temperate zones is limited to colonies living in greenhouses and other protected habitats (Cornwell 1968). A report has also appeared concerning an unidentified species of *Pycnoscelus* which produced a small sand mound and damaged oil palm and ground cover in Malaysia (Seng 1974).

3.3.16 *Blaberus spp.*

Distribution - Cockroaches of this genus are noted especially for their very large size. They are confined almost exclusively to the American tropics where they

are occasionally household pests. Infrequently they are found in temperate South America. *B. craniifer* Burm. is perhaps the best known of these species. It has become established in southern Florida. Other well-known species include *B. giganteus* L., *B. discoidalis* Serv., and *B. atropos* Stoll. Specimens collected in other parts of the world are almost always accidental introductions (Princis 1963, Cornwell 1968). Roth (1969b) has clarified the identification of nearly a dozen species of this genus based on male genitalia.

Description - *B. craniifer* is a very large insect measuring 50-60 mm in length (Fig. 3t). The wings are fully developed in both sexes and usually extend slightly beyond the tip of the abdomen. The forewings are very dark, being almost black, except for a small pale region just behind the pronotum. The pronotum is rather large and has a wide pale margin. Its center is very dark, except for some yellowish-orange markings. Nymphs also have a large pronotal shield and are marked with yellowish-orange spots on both the thoracic and abdominal tergites. Large nymphs are very heavy bodied and tend to be sluggish. Small nymphs resemble certain crustaceans in general form. Oothecae are large, measuring about 20 mm in length. They are quite dark and have a clear indication of egg position. The keel region is usually lacking, giving the ootheca an incomplete appearance (Fig. 4p). *B. giganteus* is an even larger insect measuring 70-80 mm in length (Fig. 3u). It is an attractive species with most of its forewings being a pale-cream colour and nearly translucent.

Biology, life cycle and ecology - These are long-lived insects. Adults of *B. craniifer* may live 425-475 days. Little information is available on reproduction but mating of young adults has been observed in the laboratory. Oothecae are formed similarly to other blabarid cockroaches and are held internally. A long incubation period is presumed and young are born viviparously. Oothecae average 34 eggs, but viability is not good in those strains studied. Nymphs undergo 9-11 molts in 257-277 days at 30-36° C (Willis *et al.* 1958). In their native habitat these cockroaches are outdoor species where they are often found under rotting logs. *B. giganteus* has been reported from bat caves where they may feed on bat guano. They also feed readily on plant materials. Occasionally they infest eating places, fruit stores and homes. There are reports of *B. craniifer* being an abundant household pest in Cuba (Cornwell 1968). *B. giganteus* is sometimes attracted to lights in Brazil (Silva 1971), Costa Rica and probably elsewhere.

3.3.17 *Eurycotis spp.*

Distribution - There are a number of species of this genus found in the West Indies and tropical America. Of these *E. floridana* (Walker) is perhaps the most important. It is recorded as being restricted to the USA, where it is reported from Florida, Georgia, Alabama and Mississippi. The genus has apparently remained confined to the New World (Princis 1966). In Costa Rica *E. biolleyi* Rehn has been reported invading houses (Vargas & Fisk 1973).

Description - *E. floridana* is a large, heavy-bodied cockroach measuring 30-40 mm in length (Fig. 3v). It is dark brown to black in colour but newly molted individuals are often present that are a reddish-brown colour. Forewings are very short in both sexes extending just beyond the mesonotum. Hindwings are absent. Thus, nymphs and adults are very similar in appearance except for size. Medium to large nymphs have a yellowish-lateral margin on the meso- and meta-thorax. Egg cases measure 14-16 mm in length, are very dark and have a slight indication of egg position visible externally (Fig 4l).

Biology, life cycle and ecology - This is a long-lived insect but apparently no exact data are available on adult lifespan. Mating occurs about 18 days after maturation. Parthenogenesis can occur. The first ootheca appears at about 55 days. Subsequently, oothecae are produced at about 8 day intervals. They are dropped by the female shortly after formation and are often glued to the substrate. In nature they would probably be buried in a hole. The incubation period is about 50 days at 30-36° C. Egg cases contain on the average 21-23 eggs. Nymphs develop over a period of about 100 days at 30-36° C, undergoing 6-8 molts (Roth & Willis 1954, Willis *et al.* 1958, Cornwell 1968). This species produces an extremely vile secretion which it emits when disturbed. If placed in a closed container it may actually be killed by its own secretion. This cockroach is also an outdoor species. In Florida it has been found living under the bark of dead trees, in woodpiles, under loose litter, in stumps, etc. It has sometimes been called a woods cockroach. Occasionally it gets into homes and may survive there at least for short periods. Since it does not fly, it obviously has to crawl or be transported into dwellings (Cornwell 1968, Mallis 1969).

3.3.18 *Blattella spp.* - the field cockroach, the Asian cockroach, and others.

Distribution - This is a large genus (Roth 1985), and in various parts of the world there are species other than *B. germanica* that sometimes become domiciliary pests (Woo & Guo 1984). Most of them are outdoor species and their intrusions are usually minor and/or accidental. However, *B. lituricollis* (Walker), *B. vaga* Hebard, and especially *B. asahinai* Mizukubo have achieved enough prominence to be specifically mentioned. The origin of these species is unclear but is probably Asiatic (Hebard 1935, Roth 1985). *B. lituricollis* has been recorded from Burma, China, the Philippines, Taiwan, Okinawa, Japan and Hawaii (Princis 1969). Asahina (1964) indicated a still broader distribution in Asia. Subsequently, it has been reported from Thailand (Asahina & Hasegawa 1981) and China (Robinson & Bao 1988). The other two species probably occupy about the same distribution range, but *B. asahinai* has also been found in India. In addition, *B. asahinai* was introduced into Central Florida from Okinawa probably in the early- to mid-1980s (Brenner *et al.* 1986, Roth 1986). The further spread of this species in the USA is of great concern because it is very active and is a strong flier. *B. vaga* has been introduced into the southwestern USA where it occurs at least in Arizona, California and Texas (Hebard 1935, Flock 1941, Riherd 1953).

Description - The similarity in physical appearance between these three species and *B. germanica* is striking. However, close examination allows them to be distinguished. All three are slightly smaller than the German cockroach. *B. lituricollis* has distinctive male genitalia (Zimmerman 1948). *B. vaga* (Fig. 3w) has a dark brown to black region on its face between its eyes and extending towards the mouth (Flock 1941). It also tends to be more silvery in colour. *B. asahinai* can be distinguished from *B. germanica* by the shape of both the medial-longitudinal groove on the eighth abdominal tergite and the tergal gland (Brenner *et al.* 1986). It's wings are longer than those of the German cockroach, extending beyond the tip of the abdomen. Other features, including male genitalia (Buxton & Freeman 1968, Mizukubo 1981), can be used (Flock 1941, Riherd 1953, Ross 1990) and it has been shown that gas chromatographic analysis of cuticular hydrocarbons is an effective tool for separating various stages of three *Blattella* species (*B. germanica, B. asahinai, & B. vaga*) (Carlson & Brenner 1988). Nymphs of *B. vaga* are a yellowish-cream colour overall except for dark cerci. As they grow the nymphs assume more dark pigmentation, but even as large nymphs they still show more yellowish-orange colouration than do nymphs of *B. germanica.* The egg cases of *B. vaga* are small, measuring only 5-6 mm in length. They are light coloured and have clear indentations showing egg position (Fig. 4c).

Biology and life cycle - The information in this section pertains mainly to *B. vaga* and *B. asahinai.* With the former, adult life span varies from 100-150 days. Mating occurs at 3-5 days after maturation and an ootheca appears 2-3 days later. Females of both species carry the egg case externally after rotating it 90° to the right. It takes about 20 days for the eggs to hatch. One female may produce a total of 1-8 egg cases with 5 being average for *B. vaga.* About 25-day intervals occur between them. The first 3 oothecae average 28 eggs each but the number drops markedly in later ones. Nymphs undergo 5-7 molts in 45-56 days at 30-36° C. *B. vaga* small nymphs are sometimes seen crawling over the female as if feeding on her grease layer. They are rather sluggish, and stick tenaciously to any surface (Roth & Willis 1954, Willis *et al.* 1958). *B. asahinai* females produce an ootheca that is smaller than that of *B. germanica* (Ross & Mullins 1988). The number of eggs in each is about the same but those of *B. asahinai* are smaller. The resulting nymphs are also smaller than those of *B. germanica*, but they are very active and mature in about 6-7 weeks under normal laboratory conditions (Brenner *et al.* 1986, Atkinson *et al.* 1991).

Ecology - In the USA, *B. vaga* is an outdoor species as its common name implies (Flock 1941). It is frequently seen in irrigated fields in southern Arizona and California. It feeds on decomposing vegetation. One instance of it attacking strawberries has been reported (Buxton & Freeman 1968). It is often found under stones or other objects. It sometimes occurs in desert locations. However, during drier parts of the year it tends to go into houses. It is not as secretive as is *B. germanica* and will wander about the house in the daytime or when the lights are on. It is sometimes attracted to lights at night. The presence of decaying plant material, such as mulches around houses, encourages these

cockroaches to enter (Cornwell 1968, Mallis 1969). *B. asahinai* is also an outdoor cockroach. In Florida it builds up to enormous numbers in heavily vegetated areas. From there adults fly to dwellings and are attracted to lights. They frequently enter those dwellings and can become a serious domiciliary pest, especially because of their large numbers (Brenner *et al.* 1986, 1988). *B. lituricollis* is reported to be common and widespread in Hawaiian fields but is rarely present in buildings (Zimmerman 1948). Asahina (1964) found it to be present throughout the year in Japan where it occurred near houses, hiding under debris. Asahina (1964) indicated that it may invade kitchens in tropical countries.

3.3.19 *Parcoblatta pennsylvanica* (Degeer) - the Pennsylvania wood cockroach

Distribution - As its common name implies, this is an outdoor cockroach. However, it has reached enough prominence to be included in this compilation. This species is limited to continental North America where it is widely distributed in the eastern, southern and midwestern states of the USA. It is also found in eastern and perhaps central Canada (Princis 1969). In addition, nearly a dozen other species of *Parcoblatta* are known, including *P. fulvescens* (Saussure and Zehntner). Most are primarily from the eastern half of the USA, but a few are indigenous in the western states. Occasionally, one or another of these species may be found in or near houses. This is probably also the case for another member of this genus, *P. kyotensis* Asahina, from China (Woo 1987).

Description - For simplicity only the characteristics of *P. pennsylvanica* are described here. It is a small to medium-sized cockroach but is the largest species of this genus found in the USA (Fig. 3x). Males are somewhat larger than females (22-30 mm vs. 13-20 mm). They are described as being a chestnut-brown colour with the thorax and forewings being edged in white in both sexes (Mallis 1969). Some colour variation exists and males are often somewhat lighter in colour. Wings are fully developed in males but are of variable length in females, where they may be either somewhat or greatly reduced. Nymphs are quite dark in colour. Egg cases measure 10-12 mm in length, have clear indentations for each egg, and are yellowish-brown in colour (Fig. 4m).

Biology and life cycle - In nature, adults are rather short-lived. They usually mature in the early spring (March-May), reproduce and die in the fall (October-November). One female may produce up to 30 oothecae during her life. Five to nine days elapse from dropping one egg case until the next one appears. The female deposits the ootheca after having carried it for 1-3 days. Incubation requires 30-36 days at room temperature. Oothecae have 32-36 eggs (Cochran 1986). Nymphs hatch in summer, undergo a few molts and overwinter in protected areas. They remain active all winter. There are 5-7 molts with the nymphs maturing in the next spring. Under unfavourable conditions of food or other factors, nymphs may require an extra season to mature (Gould & Deay 1940). In the warmer parts of its distribution range, there may be two generations per year (Cochran 1986). Males, but not females, are capable of

sustained flight. Little or no offensive odour is produced by this species (Mallis 1969).

Ecology - *P. pennsylvanica* is definitely a woods cockroach and it is often found in or near decaying logs, under loose bark and in wood piles (Rau 1940). Males are strongly attracted to light. Usually it is in connection with light attraction that people see them. During spring and early summer, sizable numbers of males plus occasional females occur around houses near wooded areas. Females are sometimes brought into houses on fire wood. Infestations in houses are normally accidental, but this cockroach has been found living under a wooden storage shed in Virginia, USA (Amos 1970).

3.3.20 *Ectobius spp.*

Distribution -The cockroaches of this genus are outdoor species and only occasionally become domiciliary pests. There are three species that may be of importance: *E. lapponicus* (L.), the dusky cockroach; *E. pallidus* (Olivier), the tawny cockroach (also called the Mediterranean cockroach); and *E. panzeri* Stephens, the lesser cockroach. All are found in England and on the European continent. *E. pallidus* is known to occur in England, Germany, the Netherlands, Belgium, France, Switzerland, Italy, Portugal, Spain and in Africa (Algeria, and Tunisia) (Princis 1971). It has been introduced into Massachusetts, USA, from Europe and appears to be established there (Gurney 1953). More recently it has also been reported from Michigan, USA (Gurney 1968).

Description - These cockroaches are shorter in overall length than the German cockroach. *E. panzeri* is only 5.0-7.8 mm long. Because *E. pallidus* may be spreading, it will be described in more detail. The wings are fully developed in both sexes. It measures 8.0-9.3 mm and is a uniform pale-yellow colour. Forewings are rather wide giving the insect a robust appearance. In all of these species there is a triangular area at the tip of the hindwings that is clear of veins and crossveins. Females of *E. lapponicus* and *E. panzeri* have, respectively, short and very short wings (Ragge 1965). Egg cases are 3-4 mm long and are dark brown in these species (Roth 1968) (Fig. 4n). Brown (1973a) has described the nymphs of these three species in detail, and has provided keys for their identification.

Biology, life cycle and ecology - Adults are usually short-lived. They mature in the summer, reproduce, and die in the fall. Egg cases are carried by the female for 1-2 days, but are then dropped. Eggs usually overwinter and hatch the next spring (Brown 1973a). Nymphs may either mature that summer (*E. panzeri*) or overwinter as large nymphs, maturing the following spring. There are 5-6 nymphal stages (Gurney 1968, Brown 1973b). Those species and sexes that have fully developed wings can fly. *Ectobius* as a group are outdoor species where they live under loose lichens and bark, or on the forest floor among various plants and plant debris (Roth & Willis 1957c). *E. panzeri* tends to be a coastal species (Ragge 1965). They are all active at night and are occasionally attracted to lights and enter houses. They are more nuisance than real

domiciliary pests (Gurney 1953, 1968, Smith & Chao 1956, Roth & Willis 1957c).

3.3.21 *Panchlora spp.*

Distribution - The *Panchlora* group occurs in the neotropics, South America, and Africa (Princis 1964). One species, *P. nivea* (L.), the pale green Cuban cockroach, is of sufficient importance as a domiciliary pest to be mentioned specifically. It occurs in the New World tropics and has been reported from Mexico, Cuba, Puerto Rico and Trinidad. It is widely distributed in Central America and northern South America (Roth & Willis 1957b). It is also established in the gulf states of the USA, notably Texas (Hebard 1943). Gurney (1955) has clarified the taxonomic status of this species.

Description - *P. nivea* is a small cockroach measuring 15-20 mm in the adult stage. It is described as having a delicate body that is distinctly flattened. It is light greenish or yellowish in colour with a translucent integument. After death, the colour fades rapidly and is no longer a useful identifying feature. The wings are fully developed in both sexes and extend well beyond the tip of the abdomen. Cerci are short and broad. Nymphs are dark brown, resembling those of *Pycnoscelus*. Oothecae are held internally by the female. They measure 3-4 mm in length, are crescent shaped, have a distinct external indication of egg compartments and are light coloured (Fig. 4r). The oothecal membranes are delicate and do not fully cover developing embryos in the brood sac. Oothecae are difficult to collect because females void them only after the nymphs have emerged (Roth & Willis 1957c).

Biology and life cycle - Little is known about the biology of this species. The information that is available is based upon laboratory rearing of a small number of females accidentally introduced into the USA, plus information derived from their progeny. One adult female lived 153 days at 24° C. Male nymphs matured in 144 days whereas 181 days were required for female nymphs. The number of nymphal instars is unknown. The mean number of nymphs hatching from egg cases was about 46 based on 14 oothecae. Eggs per egg case averaged about 55 but one egg case had 70 eggs. Approximately 48 days were required for embryonic development at 24° C. The interval between the first and second oothecal hatch was 63 days. In *P. nivea* the male does not exhibit the typical cockroach precopulatory-behavior pattern. Rather, he simply backs up to the female, makes connection and transfers a spermatophore (Roth & Willis 1957c).

Ecology - This small, attractive cockroach is essentially an outdoor species. It is found on rotting trunks of palm and coconut trees. Occasionally it occurs in and around human dwellings and may get inside. It is attracted to lights, but has little tendency to adapt itself to artificial surroundings. Because it readily feeds on bananas, it is often accidentally transported to other parts of the world on banana hands (Roth & Willis 1957c, Hebard 1917).

3.3.22 *Shawella couloniana* (Saussure) - no common name

Distribution - This insect is among those cockroach species with a limited geographical distribution. It is apparently restricted to Australia and New Zealand (Princis 1969) and presumably is a native of that part of the world.

Description - This is a small to medium-sized cockroach with adult males measuring 15-18 mm and adult females measuring 20-22 mm in length (Fig. 3z). Individuals, both nymphs and adults, are a uniform shining chccolate-brown colour which is quite reminiscent of the colour exhibited by American cockroaches. The wings of both sexes are short. In adult males they cover about half of the abdomen, whereas in adult females they cover only two or three abdominal segments. Oothecae are quite small, measuring 6-8 mm in length, and give the appearance of being short and stout. The female rotates the egg case (McKittrick 1964) and may carry it for an undetermined time before depositing it. When first formed an egg case is whitish in colour and gradually darkens with age, eventually becoming a rich-dark brown colour. Externally, there is a good indication of individual egg position (Roth 1968).

Biology, life cycle and ecology - Precise information in most of these categories is not available. From its size and appearance it may be assumed it has a moderately long life cycle, perhaps intermediate between such species as the German and American cockroaches. Presumably 6-8 nymphal instars exist in this species. Oothecae have about 20 egg compartments The insect seems to be rather sluggish in its movements. It is essentially an outdoor species but occasionally will enter houses. There are some indications that it may adapt to indoor life so that its associations with people may be something more than that of an occasional or accidental home invader (Mackerras 1970). In New Zealand it has been reported as occupying a timber yard, which may be another form of association with humans (Johns 1966).

3.3.23 *Lupparia spp.*

Distribution - In the Far East there exists a small group of arboreal cockroaches that deserve mention. Until recently they have been referred to as belonging to the genus *Onychostylus*. Indeed, Asahina (1973b) still recognizes this genus, but Princis (1969) puts some of them in the genus *Lupparia*. Of the species involved, *L. vilis* (Brunner) and *L. notulata* Stall are of interest for this compilation. *L. vilis* has been reported from Iwo Jima, China, Thailand, Malaysia, and Indonesia (Princis 1969). *L. notulata* occurs in Malaysia (Jeffery *et al.* 1984, Oothuman *et al.* 1984) and presumably elsewhere in the region. Indeed, this pattern of distribution suggests that the genus *Lupparia* may be much more widespread in the countries and islands to the north of Australia than has been documented in published reports.

Description, biology, life cycle and ecology - In none of these categories is information plentiful. *L. vilis* is a rather small insect (10-12 mm) with a very flattened body in both nymphal and adult stages. It is semi-transparent and

probably is a brownish colour. The oothecae are also very flat (Asahina 1965), This insect is of interest here primarily because it has been reported as a household pest on Iwo Jima (Anon. 1958). An infestation there was reported as being "light", but with at least the possibility of the species adapting to a domiciliary environment. It was reported to be easily bred in the laboratory under conditions similar to those required for the German cockroach (Asahina 1965). In Malaysia, where *L. notulata* is referred to as the batik cockroach (Oothuman *et al.* 1984), it was collected from houses (Jeffery *et al.* 1984). It is 13-17 mm in length, light brown in colour, and has lateral-transparent stripes on it's pronotum. The abdomen is dark brown with white markings laterally. Wing venation is prominent. Oothecae are bean shaped and dark brown. Presumably, cockroaches in this genus represent another case where essentially outdoor species can become household pests under certain conditions.

3.4 Miscellaneous species of general interest

There are a number of other cockroach species that probably are significant domiciliary pests. For example, Woo (1981, 1987) mentioned species belonging to the genera *Eupolyphaga* and *Polyphaga* from China and Tibet in this context, but little information is available about them. Also, on a world-wide basis a fairly sizable number of cockroaches that normally live outdoors are occasionally or accidentally found associated with people. Several of the species already discussed fall quite readily into this category. However, they have been singled out for individual treatment because they have either reached significant prominence, or there is something unusual about them. In addition to those species, a few other examples of outdoor cockroaches will be briefly mentioned here.

In Australia several species of the genus *Methana* Stal exist (Pope 1953a, 1953b). They normally live under the bark of trees or logs. Occasionally *M. marginalis* (Saussure) has entered houses (Cornwell 1968). The South African species, *Deropeltis erythrocephala* (F.), is likewise a woods cockroach that is sometimes attracted to houses by light (Hesse 1971). Similarly, the little gem cockroach, *Euthlastoblatta gemma* Hebard, was found invading a house in Georgia, USA (Gorham *et al.* 1971). In the neotropics there are about 20 species of the genus *Pelmatosilpha* Dohrn recorded by Princis (1966). Again, these are outdoor species that occasionally may be associated with humans (Rehn 1930, Hebard 1926). In Costa Rica the outdoor species *Archimandrita tessellata* Rehn (Fig. 3aa), *Ischnoptera vulpina* Hebard, and *Eudromiella sp.* sometimes invade houses (Vargas & Fisk 1973). None of them is thought to cause real damage and they are primarily nuisance pests.

In addition to the Asian cockroach, an alarming number of cockroach species have been recently introduced into Peninsular Florida. Among them are *Epilampra maya* Rehn (Nickle & Sibson 1984) and *Ischnoptera bergrothi* (Griffini) from Central America (Atkinson *et al.* 1990), *Neoblattella detersa* (Walker) and *Symplose morsei* (Hebard) from the West Indies (Peck &

Beninger 1989), *Ischnoptera bilunata* Saussure from South America and *Ischnoptera nox* Hebard from Panama (Atkinson *et al.* 1992). It is perhaps too early to know if any of them will become domiciliary pests, but the potential is present.

In recent years various species of cockroaches, other than the well-known domiciliary species, have been reared in biological laboratories and zoos for experimental and exhibit purposes. Among them the genus *Gromphadorhina* Brunner is prominent because of its large size and the hissing sound made by these cockroaches, especially when they are disturbed. *Gromphadorhina* is restricted to the Malagasy Republic (Madagascar) where 7 species have been recorded (Princis 1965, 1971). *G. portentosa* has an unusual mating pattern in that the female chooses a male to mate with based on the male's age and social status (Leibensperger *et al.* 1985). In addition, the selected male simply backs up to the receptive female and achieves coupling without the usual stylized cockroach-mating ritual (Barth 1968), as is also true with *P. nivea*.

No species of the family Cryptocercidae is of domiciliary importance. Members of this family live in decaying logs and are thought to be the most primitive of all extant cockroaches. Princis (1965) documented only 3 species belonging to this family. One is found in China, one in the Russian Far East and one from the USA. The latter, *Cryptocercus punctulatus* Scudder, is of special biological interest because of the large number of intestinal protozoa it harbours in an elaborate symbiotic relationship (Cleveland *et al.* 1934, Roth & Willis 1960). The Maritime Territory relic cockroach, *C. relictus* Bey-Bienko, also has been studied for similar reasons (Gromov & Mamkaeva 1980). In addition, *C. punctulatus* has two disjunct populations, one occurring in the Cascade mountains and the other in the Appalachian mountains of the USA. Nalepa *et al.* (1997) have presented evidence for the distinctness of these two populations and have erected a new species designation, *C. clevelandi* Byers, for the western population. The name *C. punctulatus* has been retained for the eastern population.

An interesting example of convergent evolution exists involving *Cryptocercus* and the Australian cockroach *Panesthia cribrata* Saussure (Rugg & Rose 1990). The latter closely resembles *Cryptocercus* in gross morphology and habits. However, it is a member of the most advanced cockroach family, the Blabaridae, as is readily evident from it's reproductive biology (Rugg & Rose 1984). The fact that it has behavioral characteristics resembling those of *Cryptocercus* more closely than those of other blabarids (O'Neill *et al.* 1987) is probably due to the similar environments in which they both evolved.

4. The Classification of Cockroaches with a Key to the most Important Domiciliary Species

Classification. The classification of cockroaches has been of interest to taxonomists since the time of Linnaeus. The principal systems currently in use are those of Rehn (1951), Princis (1960), and McKittrick (1964). These systems are based on different sets of characteristics and vary greatly in their details. Since classification of cockroaches is not intended to be a major part of this document, the scheme of McKittrick has been followed because of its relative simplicity. According to this scheme, cockroaches are placed in the Order Dictyoptera, Suborder Blattaria. Below these designations are two superfamilies, five families and a large number of subfamilies. For the present purposes only the families will be used. They are Cryptocercidae, Blattidae, Blabaridae, Blattellidae, and Polyphagidae. The cockroach species discussed in this document are listed below according to their family placement.

Family Cryptocercidae (No species of domiciliary importance)

Cryptocercus punctulatus Scudder
C. relictus Bey-Bienko
C. clevelandi Byers

Family Blattidae

Periplaneta americana (L.)
P. australasiae (F.)
P. brunnea Burm.
P. fuliginosa (Serv.)
P. japonica Karny
Blatta orientalis L.
B. (Shelfordella) lateralis (Walker)
Neostyolpyga rhombifolia (Stoll)
Eurycotis floridana (Walker)
E. biolleyi (Rehn)
Methana marginalis (Saussure)
Deropeltis erythrocephala (F.)
Pelmatosilpha spp.

Family Blaberidae

Rhyparobia maderae (F.)
Nauphoeta cinerea (Olivier)
Pycnoscelus surinamensis (L.)
P. indicus (F.)
Panchlora nivea (L.)
Blaberus craniifer Burm.
Blaberus spp.

Gromphadorhina spp.
Archimandrita tessellata Rehn

Family Blattellidae

Blattella germanica (L.)
B. lituricollis (Walker)
B. vaga Hebard
B. asahinai Mizukubo
Supella longipalpa (F.)
Lupparia spp.
Euthlastoblatta gemma Hebard
Ectobius spp.
Eudromiella spp.
Shawella couloniana (Saussure)
Parcoblatta spp.
Ischnoptera spp.

Family Polyphagidae

Polyphaga spp.
Eupolyphaga spp.

Key to adults of common domiciliary cockroaches[1]

1. Middle and hind femora with numerous strong spines along ventral margin
(Fig.5,a).....2

Middle and hind femora lacking strong spines along the ventral margin (Fig. 5,b).....14

2. Comparatively large species 20 mm or longer; subgenital plate of female divided longitudinally; male styli similar, slender, elongate, and straight (Fig. 5,d,f).....3

Species usually less than 20 mm; or if larger, antero-ventral margin of front femur with several large stout spines on basal portion, followed by a row of smaller spines; female subgenital plate single, not divided; male styli variable, frequently modified, asymmetrical or unequal in size (Fig. 5,c,e,g,j).....10

3. Wings of both sexes extending to or beyond tip of the abdomen.....4

[1] Adapted in part from Pratt & Stojanovich (1966). Also see Ragge (1973) for a simplified key to the most common pest species.

Wings of one or both sexes not extending to tip of the abdomen.....7

4. Uniformly dark blackish brown, shining species; 30-35 mm long (Far East, S. America, USA).....*Periplaneta fuliginosa*

Species with some yellowish markings on pronotum or forewings or both.....5

5. Forewings with yellowish stripes on antero-lateral margin; pronotum with yellowish margin and dark center sharply contrasting in colour; 27-33 mm long (circumtropical).....*Periplaneta australasiae*

Forewings completely brownish; pronotum with yellowish markings and darker areas less distinct 6

6. Styli long and slender, longer than space between their bases; cerci long and slender with terminal segment twice as long as wide; male supra-anal plate deeply notched (Fig. 5,h) 35-40 mm long (cosmopolitan).....*Periplaneta americana*

Styli shorter, not as long as space between their bases; cerci stouter with terminal segment about as long as wide; male supra-anal plate truncate Fig. 5,I); 31-36 mm long (circumtropical).....*Periplaneta brunnea*

7. Male wings covering two thirds or more of the abdomen; blackish or yellowish species measuring 20-30 mm in length.....8

Wings of both sexes greatly reduced; lighter in colour or with yellowish markings particularly on the thorax 9

8. Male wings covering two thirds of abdomen; female wings reduced to widely separated pads; very dark insects (cosmopolitan) .....*Blatta orientalis*

Male wings extending beyond tip of the abdomen; female wings triangular and pad-like, but broader and less widely separated; males straw coloured, with translucent margins anteriorly; females dark brown with a cream-coloured line on the lateral margin of each forewing (N. Africa, to Central Asia; W. USA).....*Blatta (Shelfordella) lateralis*

Male wings extending beyond tip of the abdomen; female wings reduced, but covering 1/2 to 2/3 of the abdomen; very dark (Japan).....*Periplaneta japonica*

9. Mahogany brown species, 30-40 mm long; wings of both sexes reduced to short pads, not widely separated; heavy-bodied species with strong odour (Southeastern USA).....*Eurycotis floridana*

Shining black brown colour marbled with yellow, especially on the thorax and first abdominal segments; 20-25 mm long; wings of both sexes reduced to small lobes (circumtropical) .....*Neostylopyga rhombifolia*

10. Pronotum with two conspicuous longitudinal dark bars on a pale background.....11

Pronotum variously marked, but without two dark longitudinal bars.....12

11. Face pale, male subgenital plate asymmetrical, styli very unequal, short and rounded (Fig.5,g); dorsum of last abdominal segment rounded in males; anal lobe of hindwings narrow with less than 20 veins (Fig. 5,m) (cosmopolitan).....*Blattella germanica*

Face pale, dorsum of last abdominal segment more pointed in males; anal lobe of hindwing wider with more than 20 veins (Fig. 5,m); strong flier (Far East, Florida) .....*Blattella asahinai*

Face dark; male subgenital plate almost symmetrical, styli somewhat elongate and subequal in size (Fig. 5,j) (Far East, Southwestern USA).....*Blattella vaga*

12. Pronotum with broad dark central stripe; forewings of both sexes appearing to have two transverse brownish bars; width of pronotum usually not exceeding 4-5 mm (cosmopolitan) .....*Supella longipalpa*

Pronotum and forewings marked otherwise, or if pronotum is so marked, total body length is 9 mm or less 13

13. Larger species; 13-25 mm or more in length; forewings without small dark spots; males fully winged, females with wings reduced or absent (Eastern N. America) .....*Parcoblatta spp.*

Small species, 9 mm or less; forewings sometimes with small dark spots (Africa, Europe, Massachusetts, Michigan) .....*Ectobius spp.*

14. Clypeus distinctly separated from main part of face between antennal sockets, usually much swollen at base and with a longitudinal dividing line and a transverse division into post-clypeus and ante-clypeus (Fig 5,k); ocelli of males especially prominent; hind wings of males with distinct anal lobes (Fig. 5,m); females wingless or nymph-like 15

Clypeus not distinctly separated from main part of face, not swollen nor with longitudinal groove nor transverse division (Fig. 4,l); ocelli usually not conspicuous; hind wings without distinct anal lobes (Fig, 5,n); females not wingless or nymph-like 16

15. Total length, males 25-32 mm, females 25-34 mm; male wings rounded at apeces (Fig. 5,o); (most countries adjacent to the Mediterranean Sea, and eastward to the Caspian Sea area and southward to Iran).....*Polyphaga aegyptiaca*

Total length, males 32-37 mm, females 37-44 mm; male wings broadly rounded at apices (Fig. 5,p) (southern former Soviet Republics, Afghanistan, Kashmir, and Iran; overlaps *P. aegyptiaca* south of the Black Sea).....*Polyphaga saussurei*

16. Top of eyes close together; general colour a nearly uniform pale greenish or yellowish; body flattened dorso-ventrically; posterior margin of pronotum somewhat angularly produced; small insect 15-20 mm (Neotropical, advantive on bananas) .....*Panchlora nivea*

Top of eyes otherwise, or very large insect; general colour various shades of brown, grey, and cream; body not markedly flattened; pronotum usually not angularly produced 17

17. Medium sized, 30 mm or less including wings.....18

Large sized, 40 mm or more including wings.....19

18. Pronotum uniformly blackish except a narrow yellowish band along the anterior and lateral margins (world tropics) .....*Pycnoscelus surinamensis*

Pronotum pale with a narrow dark longitudinal submarginal band on each side, and irregular brownish markings on the pronotum; forewings speckled (world tropics).....*Nauphoeta cinerea*

19. Pronotum with distinct shield-like design; very large insect measuring 55-70 mm or more in length; front femur with one or more stout spurs on underside (Fig. 5,q) (neotropical).....*Blaberus spp.*

Pronotum with indistinct shield; insects measuring 40-50 mm in length front femur with a line of stiff hairs on the antero-ventral margin (Fig. 5,r) (world tropics).....*Rhyparobia maderae*

5. Detecting and Monitoring Cockroach Infestations

5.1 General

In this section the question of how to deal with cockroaches when they become a problem will be initiated. It is clear that the first indication of a problem is when people detect the presence of cockroaches in locations where they are not wanted. Most commonly this is in living quarters, but it can be

anywhere food is prepared or stored, or in other locations where the presence of cockroaches impinges on human activities in undesirable ways. However, there are many situations, as discussed above, in which one or a few outdoor cockroaches accidentally invade a home. These cases do not normally constitute an infestation. Whether an individual chooses to consider it so depends on a number of factors. Among them are where the home is located, past experience with cockroaches, the ability to recognize the common pest species, and individual sensibilities. In most of these cases, the physical removal of the few insects involved would resolve the issue.

Whereas the accidental or nuisance presence of cockroaches may be less than desirable there is a significant problem when an important pest species becomes established in a residence or other location. In most parts of the world this means cockroaches belonging the genera *Blattella, Periplaneta, Blatta, Supella* and a few others. As stated previously, populations of some of these species can build up to enormous numbers. When this occurs, control efforts of some kind need to be undertaken because of the potential health hazard the cockroaches pose. It is in these situations that knowledge of where the cockroaches are located within a structure becomes important. This is often difficult to ascertain because most of the common pest species are active mainly at night when people are asleep. Thus, aggressive methods of detection are needed to determine where the cockroaches are hiding so that control efforts can be appropriately directed. In addition, as control procedures are undertaken the populations must be monitored to determine whether the control effort is being successful. These methods will be discussed below.

5.2 Methods for Detecting and Monitoring Cockroach Infestations.

There is a considerable body of literature dealing with these topics (Owens 1995). It is aimed mainly at research workers and professional pest control operators. Much of it relates to an evaluation of various traps and sampling techniques used against the German cockroach (Artyukhina 1972, Ballard & Gold 1982, 1983, 1984, Moore & Granovsky 1983, Owens & Bennett 1983, Reierson & Rust 1977, Ross 1981). This emphasis is appropriate because the German cockroach is the most important pest species on a worldwide basis. In addition, the methods used can usually be modified so they may be applied against other pest species. The individual home owner can also benefit from an understanding of these methods.

Owens (1995) has stressed that consistency in the application of the methods used is extremely important so that they are applied with equal intensity. This is necessary for there to be equal catchability of the available insects at each sampling interval (Barcay *et al.* 1990, Owens & Bennett 1982). For example, even seemingly small variations in the placement of traps can lead to large differences in the number in cockroaches caught. This could result in false conclusions with respect to a monitoring programme. The situation is further complicated by the fact that treatment with an insecticide may cause the insects to move. If this occurs, even competent monitoring techniques may lead

to erroneous conclusions. It is obvious that caution must be used in the application of these techniques, but they can be of great help in locating cockroach harbourages.

There are three main methods for sampling cockroach infestations (Owens 1995). They are visual counts, flush and count, and trapping. Regardless of method, the sampling effort should be concentrated where the cockroaches are expected to be found. For example, the German cockroach usually occurs in kitchens and bathrooms. The brown-banded cockroach may occur in any room in a residence. The oriental cockroach tends to occur in basements and crawl spaces. A knowledge of cockroach biology is vital to successful sampling.

Visual counts are usually done with the aid of a flashlight and a flexible mechanics' mirror, but is time consuming. Obviously, any harbourages that are missed will not receive treatment. This method does not usually cause the cockroaches to move and, hence, is not disruptive for planned control operations (Reierson & Rust 1977, Wright & Hillman 1973). However, complete records must be kept so that all known harbourages can be treated. In monitoring programmes, special care must be taken to look for new harbourages after each treatment (Barcay *et al.* 1990).

The flush and count method involves the use of a flushing agent like natural pyrethrins (Owens 1995). It is often used to detect low population numbers. The insecticide produces movement by the cockroaches, and may or may not result in their displacement to unknown locations (Barcay 1988, 1990, Barcay *et al.* 1990, Owens & Bennett 1982). This complicates monitoring as does the fact that the flushing agent itself may produce some mortality (Reierson & Rust 1977). It also means that thoroughness in searching for hidden harbourages is essential. To ensure consistency, a standard time interval should be established between application of the flushing agent and the beginning of counts (Reierson & Rust 1977). Record keeping is also important here.

There are two kinds of trapping that are in current use (Owens 1995). They are live- and destructive-trapping. Live trapping has been used for many years. It consists of placing traps at specific locations usually along walls or in corners. The traps may be glass jars or metal cans. Jars are greased on the inner lip to prevent escape of trapped insects. They are baited with some attractive material, such as bread wetted with beer. The outside of each jar is covered with cardboard, toweling, or some other material to aid the cockroaches climb to the top of the jar. Cans are usually fitted with a battery-powered device that shocks the cockroaches if they try to leave the trap (Ballard & Gold 1983, 1984, Burgess *et al.* 1974). The evidence is conflicting as to whether baiting the can traps increases their effectiveness (Owens & Bennett 1983, Ballard & Gold 1983). Consistency in placement of the traps is essential in monitoring programmes. Live trapping is especially useful in mark-release-

recapture studies designed to estimate the total size of a cockroach population (Barcay *et al.* 1990, Ross 1981).

Destructive trapping involves the use of traps in which the bottom surface is coated with a sticky material (Owens 1995, Rust & Reierson 1981). Cockroaches that walk on it become entangled. Hence, the name sticky traps or glue boards. They are said to be destructive because the trapped insects can not escape and soon die. With large populations these traps may become so full of cockroaches that no further trapping occurs. Obviously, this will place an upper limit on the number of insects trapped and may result in under-estimates of population size (Owens 1995). Sticky traps of various sizes and shapes are commercially available in certain countries (Ballard & Gold 1984).

A disadvantage in the use of any trap is that a return visit is necessary to record trap catch. This should occur at a specified time interval after trap placement. The latter must be done with precision and consistency to ensure the collection of usable information (Owens 1995). The number of traps used can be variable but 10-15 for a typical apartment has been suggested (Owens & Bennett 1983). An advantage of trap use is that a complete inventory of the trapped insects by sex and stage is possible. The available evidence indicates that traps provide better estimates of population size than do visual counts or flushing (Barak *et al.* 1977, Owens & Bennett 1983). However, trapping by itself will not bring about control of an infestation.

5.3 Inferences from Detection Methods

In addition to detecting, locating and estimating the size of infestations, other inferences can sometimes be drawn from such data. Some examples will be mentioned here. First, in monitoring programmes changes in the numbers counted or trapped at each interval would be expected to indicate whether a treatment is reducing an infestation (Owens 1995). Of course, care must be exercised against the possibility that the cockroaches were not killed, but have simply moved. Where low numbers remain, signs, such as newly cast skins or fresh fecal deposits, may be the best indication of a residual population.

Second, the stages and sex of the cockroaches recorded in counts or trap catches can be informative. Normally, growing populations would be expected to have a nymph:adult ratio of about 4:1 (Keil 1981, Ross 1981, Owens & Bennett 1983). If mostly adults are seen or caught, it may mean that a population is in decline. However, traps catches are often biased in favor of adults (Moore & Granovsky 1983), and in making flashlight counts nymphs, especially younger ones, are sometimes difficult to see. These limitations must be borne in mind while interpreting information of this kind.

Third, sticky trap catches sometimes show a prevailing direction of cockroach movement (Owens 1995). If this occurs, it may be possible to find and eliminate a food source or locate a harbourage, depending on which direction the cockroaches are moving. This is an example of the kind of

information that can be gained from careful observation and interpretation of findings.

Lastly, it is difficult to infer from monitoring data when an infestation has been eliminated (Owens 1995). A single gravid female in a deeply recessed harbourage may escape even the application of a flushing insecticide. Such a female may remain largely hidden for up to one month (Cochran 1983). Newly-hatched nymphs do not normally leave the harbourage immediately. A period of some months could pass before cockroaches are again detected. Thus, monitoring programmes should be continued beyond the period when cockroaches are last seen.

6. Cockroach Prevention and Control

6.1 General

In this section, the question of how to deal with unwanted infestations of cockroaches will be addressed. The coverage necessarily will be general because this document is intended to be of worldwide applicability. Specifically, regulations dealing with insecticide availability, use and other related topics vary from country to country and the details of those considerations are beyond the scope of this document. What will be presented is an overview of the various aspects of cockroach control. People involved in this work are expected to be familiar with local conditions, including at least the important pest species, health considerations of cockroach infestations, pertinent government regulations, safety concerns and insecticide application techniques.

There are three main topics that will be discussed here. They are prevention and sanitation and non-chemical and chemical control methods. Prevention and Sanitation go hand-in-hand because they minimize cockroach entry into buildings and discourage infestations by promoting cleanliness.

6.2 Prevention and Sanitation

Cockroaches may attempt to enter homes or other buildings from outdoor habitats in cold weather or they may move from adjoining homes or apartments (Akers & Robinson 1981). To prevent this from happening, it is necessary to close all openings through floors, walls, door frames, windows, spaces behind baseboards, etc. that would permit their passage (Moore 1973). Special attention should be given to water and steam pipes or other similar utility lines. Carpentry work may be necessary if the openings are large, but putty, caulk, plastic wood, or other fillers are usually satisfactory for smaller openings. Thoroughness in completing these tasks must be emphasized because cockroaches can pass through very small spaces.

Another important means of entry for cockroaches into premises is in infested containers of food, laundry, luggage, or other packages. Some common examples are soft drink cartons, egg crates, bags of potatoes, onions, or other loose food, and laundry or luggage containing soiled clothing (Mallis *et al.* 1961, Mallis 1969). All packages of this kind should be carefully inspected before being brought into a building, especially if cockroaches are known to be present at points of origin of these items.

If cockroach infestations are to be prevented, or even satisfactorily controlled, conditions within premises must be made unsatisfactory for them, i.e., denying them access to harbourage areas, food and water. Examples of harbourages include empty boxes or other unnecessary items and spaces behind loose baseboards, all of which can be either disposed of or repaired. Thorough inspections may be necessary to find all such items and locations. It is also important to keep basements and crawl spaces under buildings dry. Food should be kept in tight containers or refrigerators and all areas must be kept thoroughly clean so that no food particles or other organic debris remains exposed. Garbage cans must be securely covered and they should be emptied on a regular basis. Sources of water must be carefully controlled to reduce its accessibility to the cockroaches.

The importance of cleanliness, minimizing cockroach harbourages and preventing their entry into homes and other buildings cannot be overemphasized (Schal 1988). However, fulfillment of these requirements probably will not be enough to eliminate an established infestation. What these factors can be expected to do is to place such a population under stress and thereby facilitate its control by other means.

Success in long-term prevention of cockroach infestations may depend on suppression or elimination of reservoir populations. It is well known that cockroaches often find desirable breeding sites in refuse dumps, sewer systems, sewage treatment plants, warehouses, wharves, ships, or other locations where food or suitable organic matter is available (Cornwell 1968). It is not unusual for large populations to develop in situations of this kind. Particularly in warmer areas of the world, cockroaches can live and reproduce outdoors throughout the year. Even in temperate climates, there are many situations in which adequate heat and shelter are provided to sustain breeding with little interruption. It is evident that any long-term plan to eliminate cockroaches from homes, apartments and other buildings will be difficult unless reservoir populations in an area are greatly suppressed. Efforts of this kind should be organized on a community-wide scale.

6.3 Non-chemical Control

Non-chemical control has achieved considerable importance in recent years. The most common non-chemical methods include vacuuming, trapping and the use of heat, cold, or a non-toxic gas. These methods are usually carried out by professional pest control operators because of special equipment

requirements. For example, high-powered commercial vacuum cleaners are needed for best results in physically removing large numbers of cockroaches from a premise. Also, flushing agents are sometimes used in conjunction with vacuuming. Heating or cooling involves raising or lowering the temperature of an entire structure to the point that cockroaches are killed by overheating or freezing. To achieve this goal, the high or low temperature must be maintained in the entire structure for many hours. The use of a gas, such as carbon dioxide or nitrogen, requires making the structure leak proof. These methods can dramatically reduce the size of an infestation, but are expensive to employ and may not eliminate an infestation.

The use of traps was discussed in the Section 5 in connection with detection and monitoring. If large numbers of traps are used and replaced frequently, they can also reduce the number of cockroaches in a premise. Home owners could use this method, but it probably would not be effective against large populations if no other control method were employed.

6.4 Chemical Control

Chemical control remains the single most effective method for the control of established infestations. It is an ever changing scene because new insecticides continue to be developed and placed on the market, while older ones are being lost due to resistance and/or government regulations. Current practice is to use products belonging to several different classes of chemicals to delay the build up of resistance. The most prominent classes are pyrethroids and organophosphates (Fisher, 1990). In addition, single chemicals in other classes that are used include avermectin, fipronil, hydramethylnon, and boric acid. Several insect growth regulators (IGRs) are also available (Bennett & Reid 1995) but have not proven to be highly effective by themselves. However, they can be used in combination with a residual insecticide which may result in a highly effective treatment.

Emphasis in using these chemicals is often placed on controlling the German cockroach but the same materials can also be used for control of other cockroach species. The accompanying table contains a list of the insecticides most commonly mentioned for use as cockroach control agents.

Insecticides Commonly Employed in Cockroach Control

Chemical class[1]	Insecticide	Formulation	Action
Pyrethroid	Allethrin Cyfluthrin Cypermethrin Cyphenothrin Deltamehtrin Fenvalerate Permethrin Phenothrin Pyrethrins	Spray, dust, aerosol	Nerve poison (Na^+ channel disrupter)
Organo-phosphate	Acephate Chlorpyrifos Diazinon Fenitrothion Isophenphos Jodfenphos Malathion Pirimiphos methyl Propetamphos	Spray, dust, aerosol	Nerve poison (Acetylcholine esterase inhibitor)
Carbamate	Bendiocarb Dioxacarb Propoxur	Spray, dust, aerosol, bait	Nerve poison (Acetylcholine esterase inhibitor)
Amidino-hydrazone	Hydramethylnon	Bait	Respiratory poison (Electron transport inhibitor)
Macrocyclic lactone glycoside	Avermectin	Bait	Nerve poison (Cl^- channel disrupter)
Phenyl pyrazoles	Fipronil	Bait	Nerve poison (Nerve signal transmission inhibitor)

Benzoyl phenyl urea (IGR)	Flufenoxuron	Spray, bait	Metabolic system (Chitin synthesis inhibitor)
Various chemicals (IGR)	Fenoxycarb Hydroprene Pyriproxyfen	Spray, bait	Metabolic system (Hormone function disrupter)
Inorganic	Boric acid	Dust, bait	Tissue poison (Cellular disrupter)

[1] The concentrations at which insecticides are used varies considerably from class to class. Users should refer to locally approved concentrations. As a general guideline, dosages by class are as follows: Pyrethroids, 0.015-0.25%; Organo-phosphates, 0.5-3.0%; Carbamates, 0.25-2.0%, Amidinohydrazone, 1.0-2.0%; Macrocyclic lactone glycoside, 1.0-5.0%; Phenyl pyrazoles, 1.0-5.0%; Insect growth regulators, 0.001-0.05%; Inorganic, 5.0-33%.

6.4.1 Insecticide Formulations

Insecticides used in cockroach control are available in different formulations. Users must ascertain what is available locally from their suppliers as well as be aware that various formulations may result in a residual or a non-residual application. Factors determining which is the case include the chemical stability of the insecticide molecule, the type of formulation used and the conditions under which a treatment is applied. With the latter, heat and moisture often result in the rapid breakdown of the insecticide. Because some formulations may stain fabrics, wallpaper, floor tiles, or other household materials, the user should obtain information on this subject before making treatments.

Several formulations are designed to transform water insoluble chemicals into products that can be mixed with water for dispersal as sprays (Koehler *et al.* 1995). Among them are wettable powders and emulsifiable concentrates. Many insecticides are available in one or both of these forms. Prior to use, they are diluted with an appropriate volume of water so that the recommended concentration is achieved.

Dusts are another type of formulation used in cockroach control (Koehler *et al.* 1995). They consist of the active ingredient mixed with some inert carrier such as talcum powder (Rozendaal 1997). The dust formulations that are available commercially are normally sold at the recommended concentration so that no further preparation is needed.

The greatest change that has occurred recently in efforts to control the German cockroach is the advent of highly effective bait formulations (Appel 1990, Koehler *et al.* 1995, Ogg & Gold 1993). They consist of the active ingredient mixed with a bait base that is attractive to the cockroaches. A block

of the solid bait was originally placed in sealed bait stations. A later development consisted of making the bait into a gel that could be disbursed from a syringe or gun type of applicator. Baits are also sold at the recommended concentration.

Two other formulations that are used in cockroach control are microencapsulation and aerosols (Koehler *et al.* 1995). Microencapsulated insecticides are trapped inside microscopic spheres that slowly release the chemical. They are designed to provide long residual activity. They must be mixed with water for spraying. Aerosols, however, are more of a delivery system than a formulation. Commercial products are sold in pressurized cans and are ready to use. The main advantage of aerosols is that they can be directed into cracks and crevices (Reierson 1973).

There are many other types of formulations that do not find use in cockroach control. Granular insecticides are an example. They are designed for other uses and should not be employed in cockroach control.

6.4.2 Methods of Application of Insecticides

The traditional method of applying insecticides for cockroach control involves the use of a compressed air sprayer. Usually, the spray is applied as course particles, rather than as a mist. However, concern for over application of insecticides has resulted in adaptation of this method so that the spray is applied with a pinstream nozzle in a crack and crevice type of application. This greatly reduces the amount of insecticide applied. Wettable powder and emulsifiable concentrate formulations are used for this type of application, as are microencapsulated preparations. Where appropriate equipment is not available, a paint brush can be used to apply the properly diluted insecticide.

Dusts can be applied with a puff duster of the bulb, plunger, or bellows type. They should be applied to make a light and uniform film on the treated surface. Heavy dust deposits may be repellent to cockroaches and may cause them to move to untreated or more inaccessible locations. When used in connection with residual sprays, dusts should be applied after the spray residues are dry (Gupta *et al.* 1973).

Bait stations are ready to use from the supplier. They should be placed at locations where cockroaches are known or suspected to harbour. The usual recommendation is to place 12 bait stations in the kitchen and bathroom of an apartment or home. They should be carefully placed in a manner similar to that described earlier for traps. It must be remembered that in heavy infestations the cockroaches may deplete the baits quickly. Here, rebaiting is essential to achieve satisfactory control. Gel baits can be disbursed as small globs or streaks at many locations within the kitchen, bathroom, and elsewhere in a premise. This should make the bait more readily accessible and thereby increase the chances that cockroaches will encounter and eat the bait.

Aerosols are often used for spot treatments or in areas that are difficult to reach by other means. In some countries they are available as over-the-counter purchases, and as such are often used by individual home owners. In the hands of untrained individuals, they can result in the over application of insecticide.

6.4.3 Frequency of Treatment

It is recognized that retreatment may be required to achieve complete control of an infestation. The main factor involved is how long the deposits of insecticide remain effective. This depends on a number of factors, some of which were described above. In addition, surfaces vary tremendously in the amount of insecticide they absorb and, thereby, remove from availability. The insecticidal deposit may also be reduced by frequent washing of a surface, or it may be made relatively ineffective through becoming covered with dust, grease, or other material. In addition, the necessity for retreatment may depend on the thoroughness of the original application and the extent, if any, to which reinfestation has occurred. One treatment rarely results in total elimination. For most cockroach species, retreatments are necessary and should be made at appropriate intervals to kill any cockroaches remaining in the premises, as well as to prevent reinfestation. Practical experience at the local level is extremely valuable in deciding when to retreat.

6.4.4 Precautions

The toxicity of the insecticides used in cockroach control varies considerably. All users are urged to carefully read the label information and observe all cautionary warnings and directions for use. Insecticides should never be used at dosages exceeding the recommended levels. Care should be taken to avoid contamination of food or placing the insecticide where children or pets may come in contact with the materials or their residues. Special situations, such as in hospitals, zoos, pet shops, etc., may preclude the use of residual sprays or dusts. Here, it may be feasible to employ limited, carefully-controlled insecticide applications, or resort to the use of non-chemical methods.

No chemical insecticide should be used in cockroach control unless it has been officially approved for that purpose. Registration and approval to use specific insecticides may vary from country to country. All local regulations should be followed.

6.4.5 Resistance to Insecticides

The development of resistance to insecticides in cockroaches is confined primarily to the German cockroach, *Blattella germanica*. This is probably attributable to its shorter life-cycle, prominent pest status, and consequently more intensive exposure to chemical insecticides, as compared to other cockroach species.

There is a long history of resistance to insecticides in the German cockroach, including resistance to chlordane (Heal *et al.* 1953, Fisk & Isert 1953), pyrethrins (Keller *et al.* 1956), organophosphates (Grayson 1961, 1965, Bennett & Spink 1968) and carbamates (Barson & McCheyne 1978, Cochran 1982). Currently, resistance to pyrethroids has become widespread in field populations (Cochran 1989, 1995a, Dong *et al.* 1998). At present there is no evidence that resistance to avermectin, hydramethylnon, fipronil, IGRs or boric acid has occurred. That situation could change in the future, especially if these materials are used intensively. Resistance to boric acid is perhaps the least likely to develop because its action is physical. It destroys the cellular lining of the foregut (Cochran 1995b).

Some populations of German cockroaches are resistant to as many as 8-12 different insecticides (Cochran 1994). Obviously, controlling them with chemicals is difficult. However, it appears that such populations are not common. Thus, most populations can be satisfactorily controlled with insecticides. It is fortunate that a wide variety of insecticides from several chemical classes are available as cockroach-control agents. It is recommended that an insecticide rotation scheme, based on different classes of insecticides, be implemented to prevent or delay the development of resistance (Cochran 1990).

6.5 Cockroach Control in the Future

The passage of time will inevitably bring about many changes in the way people try to control cockroaches. Nevertheless, it appears that chemical control will continue to play a leading role in that arena. To assure that this will happen, new chemicals with new modes of action will be needed (Moffat 1993, Salgado 1997). It is likely that the nature of some of these new chemicals will require modification of the ways in which control is achieved, just as baits have brought about such changes in the recent past.

The other area in which major changes in control practices will probably occur is non-chemical control. It is difficult to predict what form these changes may take. From past experience, we know that the use of nematodes, fungi, diseases, parasites and predators has been suggested (Archbold *et al.* 1987, Fleet & Frankie 1975, Slater *et al.* 1980, Strange 1978). While breakthroughs in one or more of these categories could occur, it remains to be seen if any of them can have a major impact on cockroach control. It is perhaps in the more physical aspects of non-chemical control that significant improvements will occur.

Finally, implementation of the concept of integrated pest management (IPM) in cockroach control should be mentioned. This concept envisions a multi-pronged approach. Some of the tools needed for such a programme are already available. For example, use of sanitation, vacuuming, flushing, chemicals, and continued monitoring could be considered an IPM programme. Among the difficulties in the use of a programme like this are making it feasible

in a highly competitive commercial pest control market, and convincing a home owner that the entire programme is necessary. Nevertheless, improvements in the way cockroach control is achieved will almost certainly occur in the future.

7. Glossary

Active ingredient - the insecticide component of a formulated product.

Arolium - a pad found between the tarsal claws of most cockroach species that enables them to climb smooth vertical surfaces. The oriental cockroach lacks these pads.

Blabarid - any cockroach belonging to the family Blabaridae.

Catchability - the likelihood that an individual cockroach will be captured or counted in a particular monitoring episode.

Circumtropical - the entire tropical and subtropical areas of the world.

Flushing - the action of certain insecticides, notably pyrethrins, in causing cockroaches to move out of their harbourages.

Formulations - preparations in which the active ingredient, the water-insoluble insecticide, is combined with other materials to transform it into a usable product.

Incomplete metamorphosis - the situation in which an insect changes from an immature form to an adult without passing through a pupal stage. Cockroaches have this type of metamorphosis.

Mesonotum - the dorsal portion of the insect meso (middle)-thoracic segment.

Omnivorous - the condition in which an insect will feed on a wide variety of possible food sources.

Ootheca - the structure in which female cockroaches place their eggs and encase them with a more or less complete hard covering. This structure is also referred to as an egg case.

Oviparous - the situation in which female cockroaches deposit an ootheca from which the young hatch.

Parthenogenesis - the phenomenon in which female cockroaches of some species are able to reproduce without mating.

Pheromones - chemicals produced by insects that are used as a means of communication among members of the same species for various purposes.

Predation (predaceous) - feeding by one individual or members of one species upon members of another species.

Pronotum - the dorsal portion (shield) of the pro (first)-thoracic segment which is characterized by distinct markings in many cockroach species.

Residual - refers here to an insecticide treatment that persists for a significant period of time as opposed to a treatment that degrades quickly (non-residual).

Resistance - the situation in which an insect species is able to withstand the effects of an insecticide that formerly was effective in killing it.

Synonomy - the naming of a given species with different scientific manes by different authorities resulting in confusion as to the actual identity of the species in question.

Tergites - the dorsal portion of insect body segments.

Viviparous - the situation in which an ootheca is held internally by the female cockroach until the nymphs emerge as live young. This means of reproduction is utilized by members of the family Blabaridae.

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Legend for figures

Figure 1. Photograph of a fossil cockroach reported to be 250 million years old, but easily recognizable as a cockroach.

Figure 2a. The cockroach life cycle - egg, nymph, and adult.

Figure 2b. Cockroach morphology showing some of the structures used in the identification key.

Figure 3. Photographs of common domiciliary cockroach adults. a, *Blattella germanica* - female (l), male (r), 2.0X; b, *Blatta orientalis* - female with egg case, 2.0X; c, same - male, 2.0X; d, *Periplaneta americana* - male, 1.7X; e, *P. australasiae* - female, 1.8X; f, *P. Brunnea* - female, 1.7X; g, *P. fuliginosa* - female, 2.0X: h, *P. japonica* - female, 2.0X; i, same - male, 2.0X; j, *Supella longipalpa* - female (l), male (r), 2.0X; k, *Blatta (S.) lateralis - female,* 2.0X; l, same, male, 2.1X; m, *Polyphaga aegyptiaca* - male, 2.0X; n, same - female, 1.8X; o, *P. Saussurei* - female, 1.5X; p, *Rhyparobia maderae* - female, 1.5X; q, *Nauphoeta cinerea* -female, 1.9X; r, *Neostylopyga rhombifolia* - female, 2.1X; s, *Pycnoscelus surinamensis* - female, 1.7X; t, *Blaberus craniifer* - female, 1.2X; u, *B. giganteus* -female, 1.0X; v, *Eurycotis floridana* -female, 1.5X; w, *Blattella vaga* - female (l), male (r), 2.0X; x, *Parcoblatta pennsylvanica* - male 1.7X; y, *Panchlora nivea* - female 2.0X; z, *Shawella couloniana* - female with egg case, 2.0X; aa, *Archimandrita tessellata* - female, 0.9X. m-o and r were photographed from pinned specimens on loan from the US National Museum.

Figure 4. Drawings designed to show the general shape and size of oothecae from numerous cockroach species. Adapted from Roth (1968).

Figure 5. Anatomical characters used in the identification key. Arrows point to the morphological features of interest. a, middle femur with spines on ventral margin; b, same without spines; c, front femur with variable spines; d, ventral view of female subgenital plate divided longitudinally; e, female subgenital plate simple; f, male styli similar, slender, and elongate; g, male styli variable, often modified, and unequal in size; h, cerci long and slender, male supra-anal plate deeply notched; i, cerci stouter and more conical, male supra-anal plate abbreviated and not deeply notched; j male styli rather elongate and subequal in size; k, frontal view with clypeus distinctly separated from face, ocelli prominent; l, same with clypeus and ocelli indistinct; m, hindwing with prominent anal lobe; n, same with anal lobe less distinct; o, apices of wings more narrowly rounded than in p; q, front femur with stout spurs on underside; r, same with line of hairs on antroventral margin. a through j, q, and r as modified from Pratt and Stojanovich (1966); k, m, o, and p as modified from Chopard (1929).

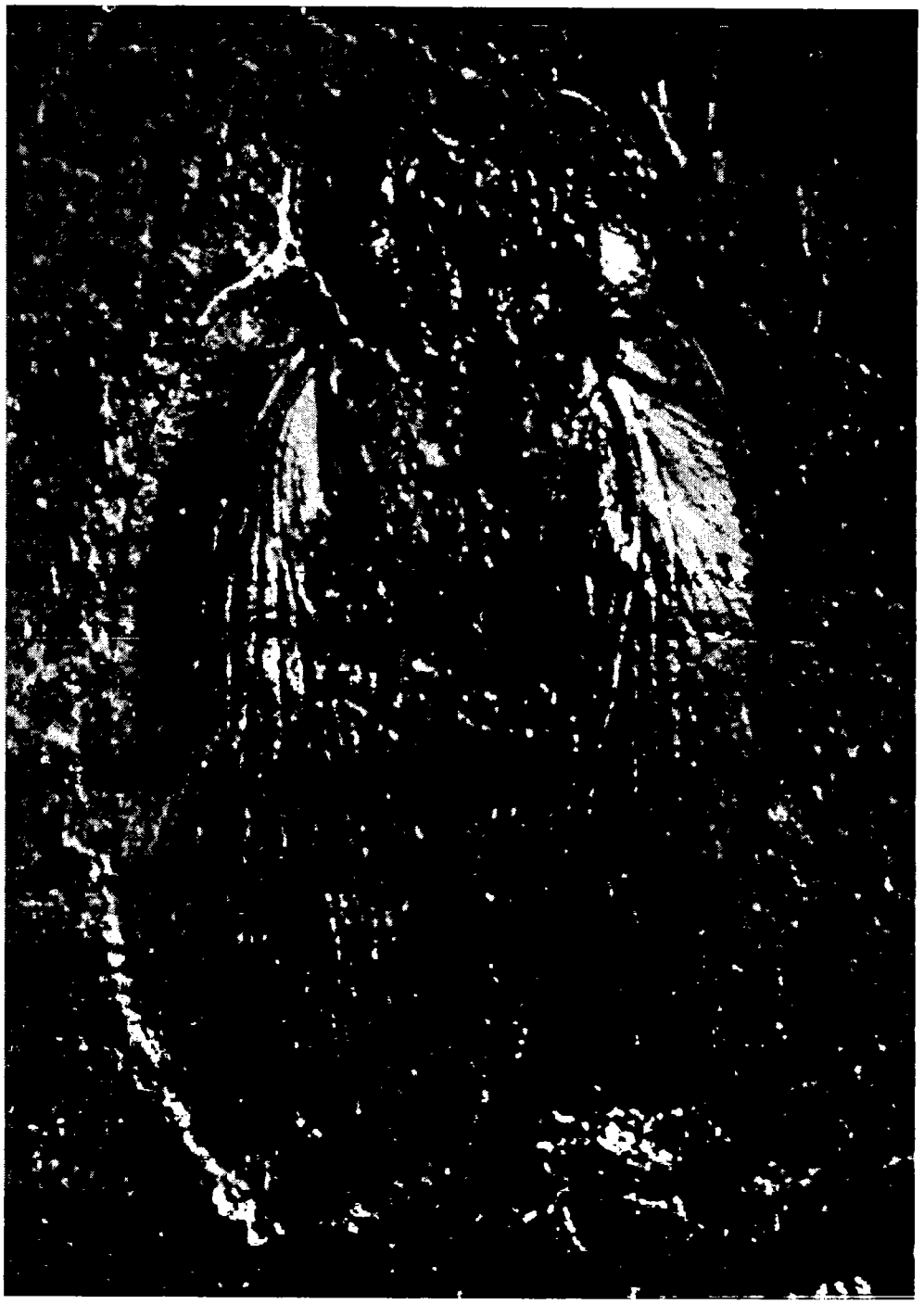


Figure 1

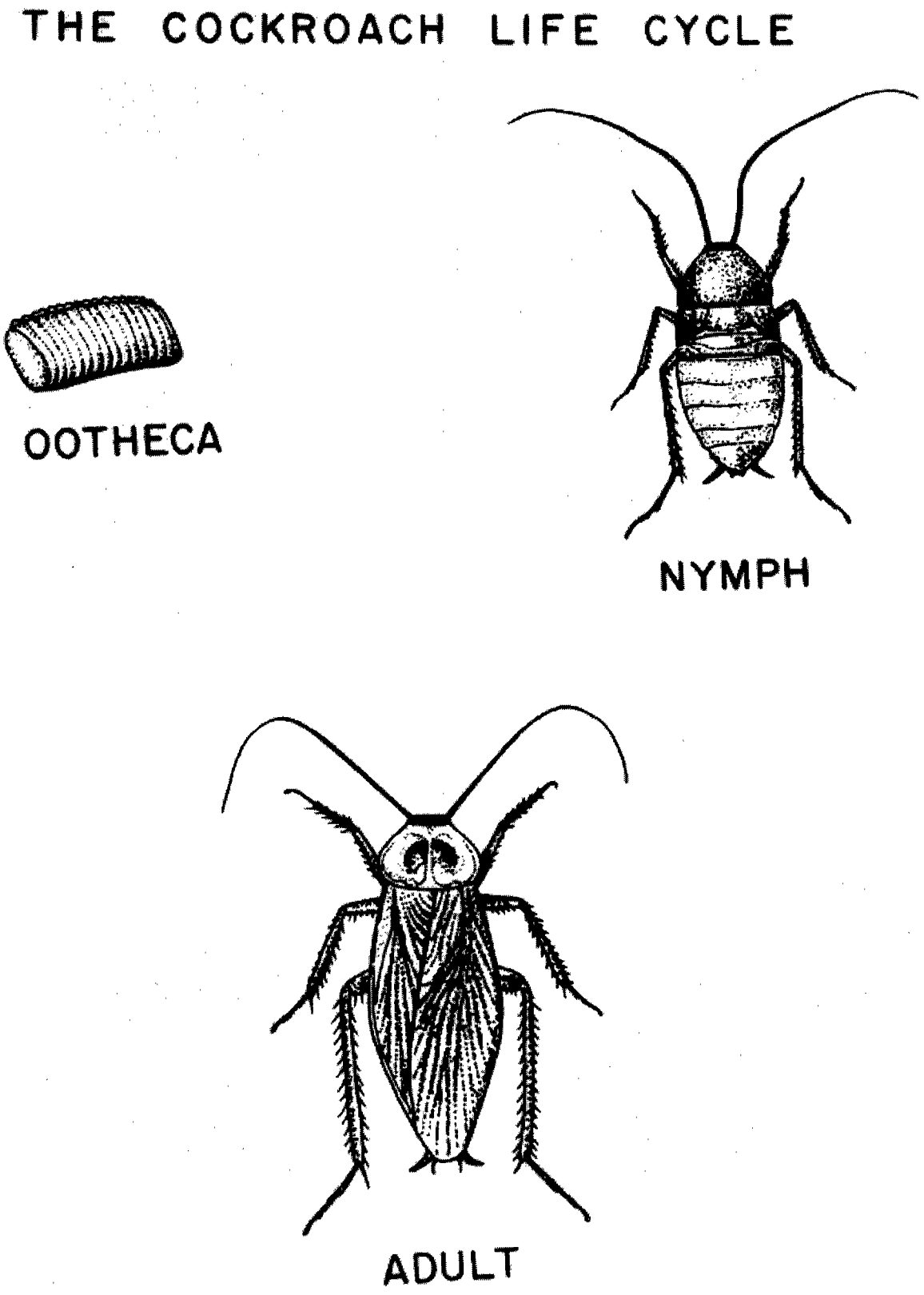


Figure 2a

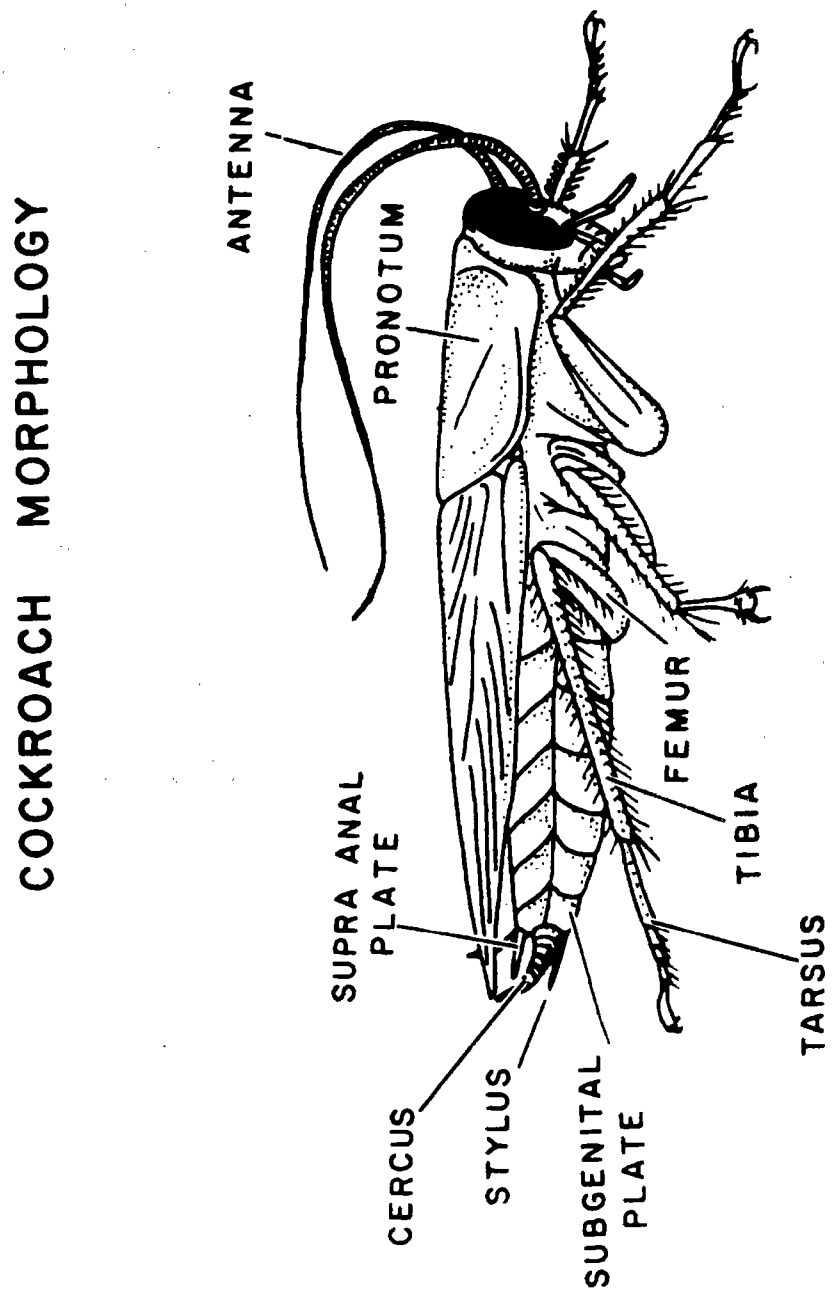

COCKROACH MORPHOLOGY
ANTENNA
PRONOTUM
FEMUR
TIBIA
TARSUS
SUPRA ANAL PLATE
CERCUS
STYLUS
SUBGENITAL PLATE

Figure 2b

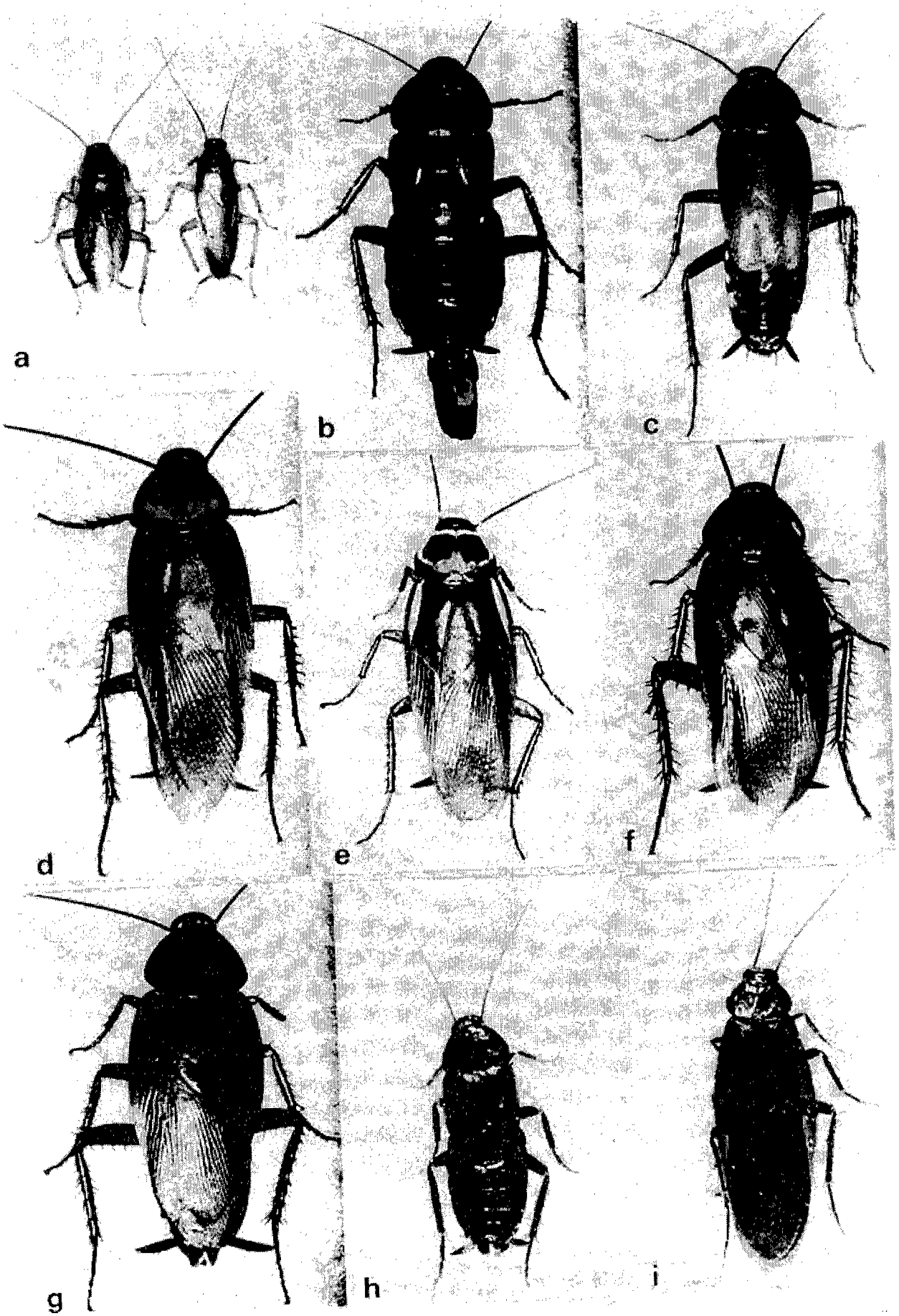


Figure 3

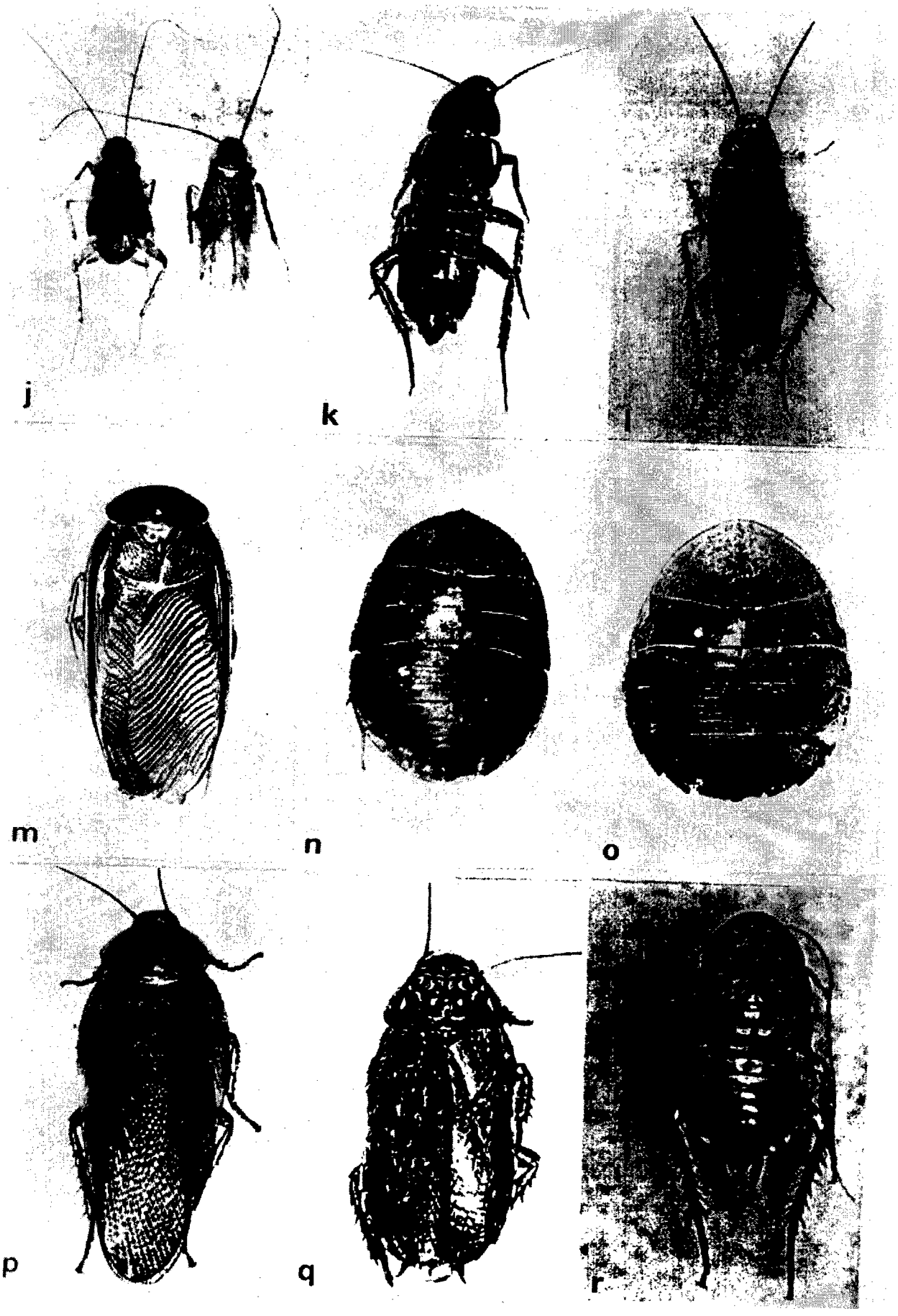


Figure 3, continued

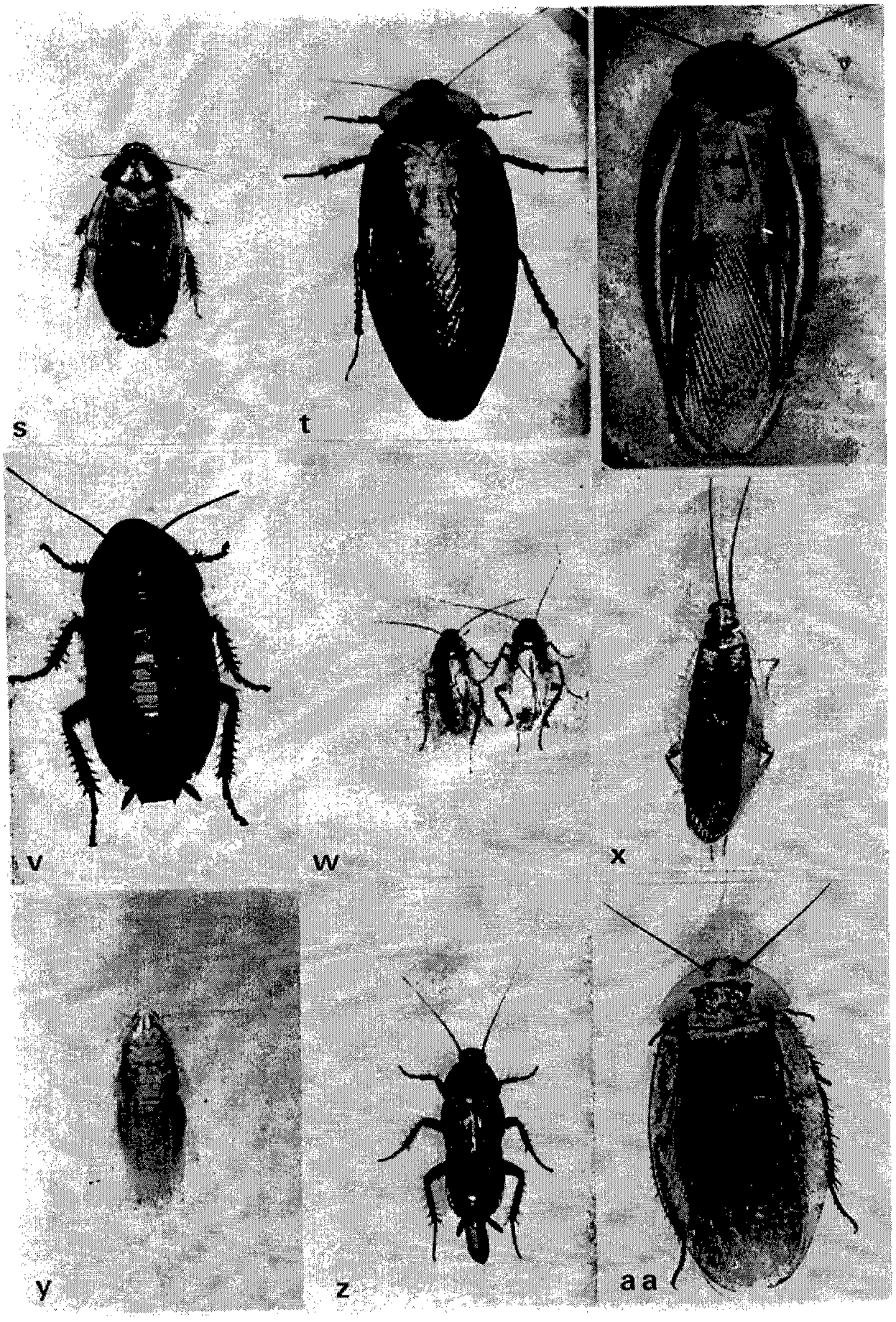


Figure 3, continued

B. germanica (3X)

a

S. longipalpa (3X)

b

B. vaga (3X)

c

B. orientalis (3X)

d

P. americana (4X)

e

P. australasiae (4X)

f

P. fuliginosa (3X)

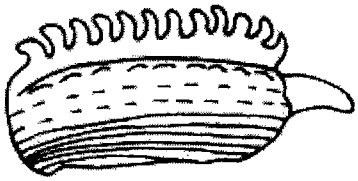
g

P. brunnea (3X)

h

P. japonica (3X)

i

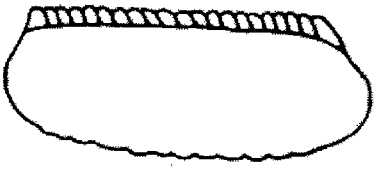


P. aegyptiaca (4X)

j

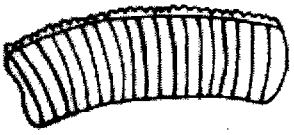
N. rhombifolia (3X)

k



E. floridana (3X)

l



P. pennsylvanica (3X)

m

E. pallidus (5X)

n

P. surinamensis (3X)

o

B. cranifer (1X)

p

R. madarae
N. cinerea (1.5X)

q

P. nivea (3X)

r

Figure 4

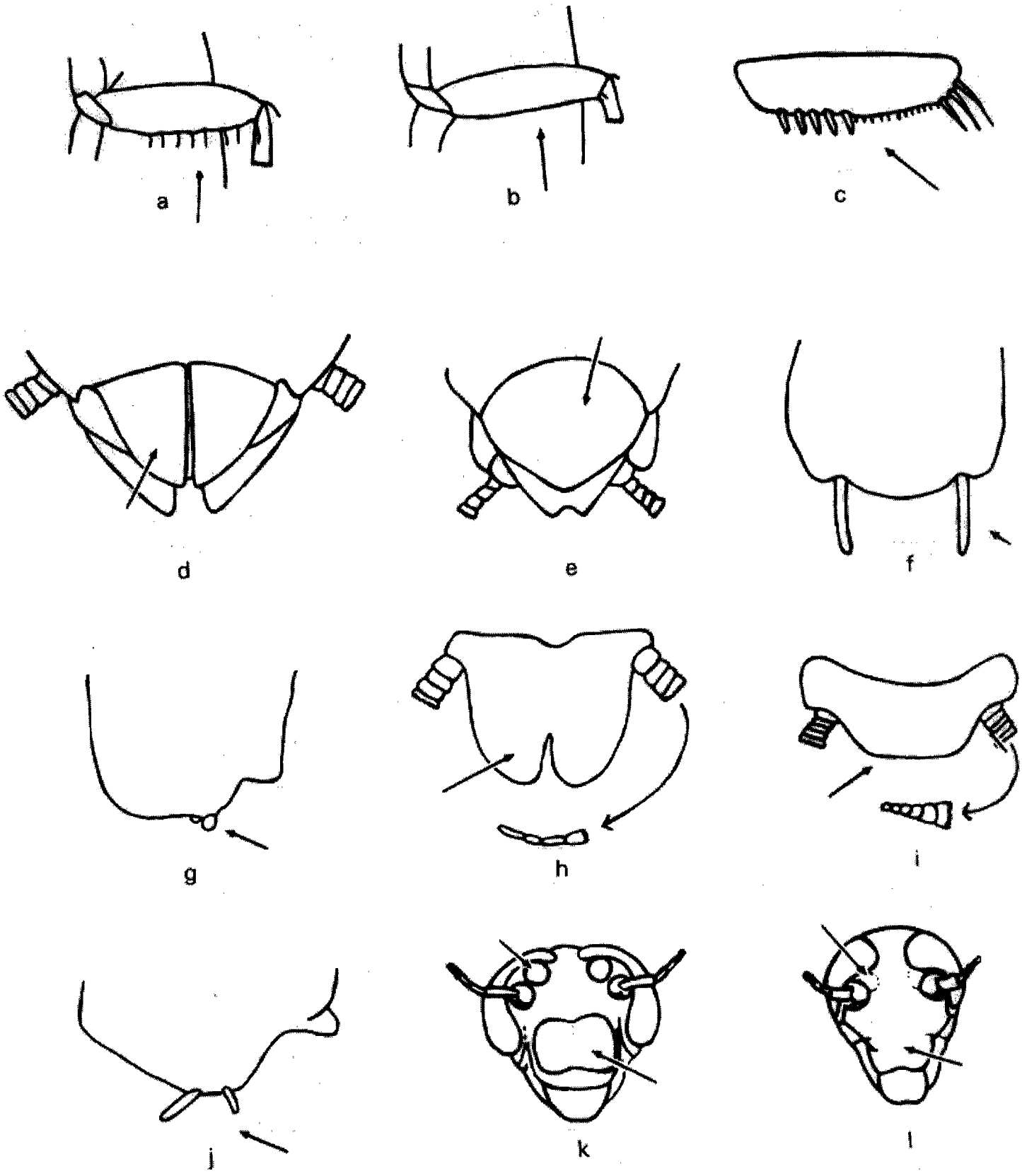


Figure 5

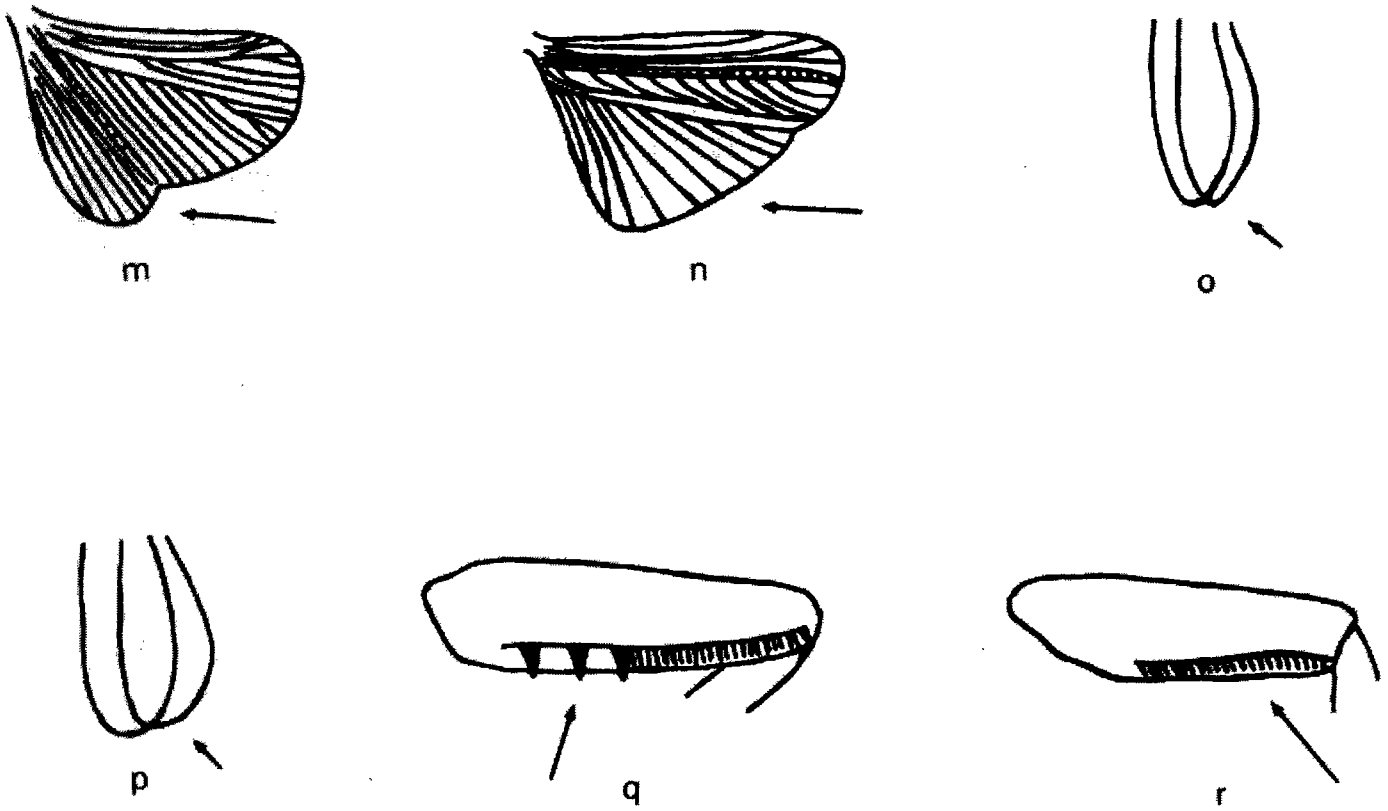


Figure 5, continued