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The Vector Biology and Control Division of WHO has been preparing, with the assistance of a number of collaborators outside the Organization, a series of papers on vector control. The Expert Committee on Insecticides held in October 1974 (Technical Report Series No. 561) recommended that these documents should be continued and revised from time to time to provide workers with up-to-date, practical information on the particular subject. It was also recommended that there should be a feedback to the Organization: readers are therefore requested to write to Vector Biology and Control giving comments on their experience of the subject reviewed. The following is the first revision of the paper on bed bugs (document WHO/VBC/75.536).[1]

VI. BED BUGS

INTRODUCTION

Bed bugs belong to a small specialized group within a large order of insects, the Hemiptera, most of which feed by piercing vegetation and sucking sap. The bed bug family Cimicidae also includes the bat bugs, chicken bugs, swallow bugs, pigeon bugs and others. Usinger (1966) cites 74 species arranged in 22 genera and six subfamilies and notes that 12 of the genera are associated exclusively with bats and nine with birds. Only the genus Cimex has some species that are attached to bats and others that occur on birds. He further points out that there are only three species of human bed bugs. Leptocimex boueti Brumpt occurs on bats and man locally in West Africa. Cimex hemipterus attacks man, chickens and rarely bats throughout the Old and New World Tropics. Cimex lectularius is associated with man, bats, chickens, and occasionally other domestic animals over most of the world.

It is generally assumed that the association between humans and bed bugs began when humans, bats and members of Cimicidae lived together in caves somewhere in the Middle East. The bugs followed humans during the processes of civilization, adapted to man-made dwellings and eventually spread throughout the world. Usinger (1966) and Mallis (1969) present interesting information on this group including taxonomy, historical references and evidence for the origins of the human species.

Only two of the three human bed bugs are closely associated with man; the ordinary bed bug, Cimex lectularius L. and the tropical bed bug, Cimex hemipterus Fabr. Both species are easy to rear and are ideal subjects for study, classroom demonstrations and research. The distribution of the two species is given in Fig. 1. Fig. 2 depicts the developmental stages of bed bugs. The two species can be distinguished by the shape of the pronotum (Fig. 3): in C. lectularius it is somewhat flattened toward the sides. The two species are distinct and cannot interbreed. However, they differ very little in biology or habits and both present similar pest and public health problems. C. hemipterus is more adapted to higher temperatures and does not thrive outside the tropics. C. lectularius is more adaptable and has extended its range throughout the world. Bed bugs can infest any type of habitation and do

[1] WHO is grateful to Dr D. E. Weidhaas of the United States Department of Agriculture, Gainesville, Florida; and Mr J. Keiding, Statens Skadedyrlaboratorium, Lyngby, Denmark, for their collaboration in the preparation of this revision.

not distinguish between the impoverished and wealthy. However, its presence is more evident in poorer quarters since conditions for survival are more favourable there. A "bed bug house" may be recognized by the distinctive bed bug odour, by the blood stains of squashed bugs and by the excretory spots of the bugs. The bed bug is distributed readily in laundry, clothing and baggage from infested locations. Dissemination is chiefly from house to house by stowing away in furniture or bedding or other articles.

APPEARANCE AND HABITS

Description

The bed bug is an oval-shaped insect (Fig. 2) whose body is flattened from top to bottom allowing easy access to narrow crevices. The adult is 4-6 mm long and reddish-brown in colour; it is blood-coloured after feeding and has a somewhat elongated appearance. After feeding the nymph resembles an animated drop of blood. The head of the adult has four-segmented antennae and beak-like mouth parts. The mouth parts consist of two pairs of stylets which pierce the skin of the host. The "parasitic" habit of the bed bug probably accounts for its loss of the power of flight; its wings are simple, functionless, oval structures. The adult male can be distinguished from the female by the tip of the abdomen which is more pointed than the female and carries a curved penis.

Bed bug eggs are approximately 1 mm in length and are elongated, reticulated, curved objects with a rim at one end which the insect pushes off in order to emerge. Eggs are white although they may often be soiled by the bug's excrement. Nymphs are pale straw coloured upon emergence from the egg and after moulting. In about an hour they turn amber coloured.

The habits of the nymphs and adults are similar in many ways. They are thigmotactic, i.e. they seek places where the body surface can make contact with a rough surface. They also react negatively to light, but may feed in daylight if hungry. Then they generally hide and congregate in cracks and crevices during the day and emerge to feed at night. Usually the majority are found in the bed frame or mattress. When populations are large they may be found in any crack or crevice. Searching for blood meals is generally considered as random movement for they do not seem able to detect a host beyond 5 or 10 cm. Their clawed feet give them a foothold on rough surfaces so that they can climb up walls or on ceilings. They cannot climb on clean glass or polished metal. The stimulus to leave the harbourage is not fully understood.

Biting behaviour

In all stages, feeding is accomplished by a type of proboscis, normally carried pointing backward under the body, but directed forward before feeding. The proboscis consists of two piercing stylets, the inner one of which forms a tube up which blood is sucked. Engorgement requires three minutes for first instar nymphs but 10-15 minutes for adults. The bug can imbibe from two-and-a-half to six times its own weight of blood and accomplishes this by enormous expansion of the abdomen. Soon afterwards, it begins to excrete much of the water content in the meal by depositing faecal drops. The faecal drops are usually discoloured and leave black or brown spots on furniture or walls which are a sign of infestation even when the bugs themselves are hidden.

LIFE HISTORY AND LIFE CYCLE

Stages

The bed bug has three stages in its life cycle: egg, nymph and adult. Nymphs resemble adults but are much smaller. Eggs are fastened by a quick drying cement exuded at the time of laying in cracks and crevices, on rough surfaces, behind woodwork, beneath wallpaper, in bedsteads and wherever the adults conceal themselves. The adult may deposit an average of one to five eggs per day over a period of two months until some 200 eggs are laid. Developmental times of all stages of bed bugs are dependent upon temperature and available food

supply. In warm weather eggs hatch in six to 10 days; however, in colder weather egg hatch may be delayed or inhibited. The nymph emerges from the egg by forcing off the rim, and there are five moults (nymphal instars). Ordinarily one meal is taken between moults. Wing pads appear with the last moult. The life cycle is subject to great variation and a complete cycle may require five to eight weeks even under favourable conditions. When food is not available to any stage, it may remain unchanged for an indefinite time.

Temperature and development

The lowest temperature at which bed bugs will complete their life cycle is 13°C (55.4°F); above this point, the speed of development increases in relation to the temperature. Table 1 gives the average incubation periods for the eggs and the times for complete life cycles at various temperatures, assuming regular opportunities for feeding. Bed bugs are killed at temperatures above 44°C in less than an hour, and development ceases at 37°C.

The length of adult life depends upon temperature. With frequent opportunities of feeding, they live from nine months to one-and-a-half years at normal room temperatures (18-20°C; 64-68°F), about 15 weeks at 27°C (80°F) and about 10 weeks at 34°C (93°F).

From the data in Table 1, it is evident that proliferation of bugs will be much more rapid under warm conditions; and, indeed, heavy infestations are much more liable to develop in tropical or subtropical countries. In cooler temperate climates, the temperature is distinctly unfavourable for bugs (at least, in unheated bedrooms) for a large part of the year. In such zones, heavy infestations are only likely to develop in the favourable warmth of bed-sitting rooms.

TABLE 1. EFFECTS OF TEMPERATURE ON SPEED OF DEVELOPMENT AND RESISTANCE TO STARVATION OF BED BUGS. THE FIGURES IN BRACKETS ARE MAXIMUM PERIODS OBSERVED (FROM BUSVINE, 1966, INSECTS AND HYGIENE)

Temperature		Average in days			
		Speed of development		Resistance to starvation	
°C	°F	Incubation	Complete cycle	Males	Females
28	82.4	5.5	34.2		
25	77.0	7.1	46.0		
23	73.4	9.2	61.6	85 (136)	69 (127)
18	64.4	20.2	125.2	152 (260)	143 (225)
15	59.0	34.0	236.7	-	-
13	55.4	48.7	Not completed	338 (470)	360 (565)
7	44.5	No hatch	-	220 (386)	286 (465)

Starvation

Bed bugs can tolerate long periods of starvation depending on the temperature and the stage:

	Longevity (mean days) after one feeding (at 70-75% RH)					
	Nymphal stages		Males		Females	
	C. lectularius	C. hemipterus	C. lectularius	C. hemipterus	C. lectularius	C. hemipterus
18 °C	114-235	68-264	176	134	277	154
27 °C	28-73	24-87	43	37	88	54
37 °C	16-37	11-26	29	17	32	23

The most resistant stages are females and fourth nymphal stage. The least resistant is first nymphal stage. The longevity of fasting bugs is greatest at low temperatures.

Humidity

Under normal conditions humidity has only a slight influence on the biology of the bug. However, the longevity of unfed small nymphs decreases under dry conditions and extreme wet conditions are not suitable for C. lectularius.

DISSEMINATION AND DISPERSAL

Where two bedrooms adjoin, it is quite possible that bugs may travel from one to another and cause a new infestation especially in poorly constructed houses. Bugs have been accused of spreading along a whole series of adjoining houses in this way, but there is very little definite evidence of the distances to which they will migrate. Generally in an infested house the bugs are almost exclusively confined to bedrooms which should cast doubt on the rumours of their colonizing powers. In rural areas of developing countries they may be found both in beds and in nearby cracks of mud walls.

Infestation of new houses is almost exclusively due to bugs being carried to them passively. Owing to the fact that they do not remain long on the host, they are not often carried on people's bodies or clothing. Occasionally, however, bugs are carried on outer clothing (overcoats in temperate areas, collars, hats, etc.) on to which they have presumably crawled when the article in question was hung against an infested wall. Movable articles such as suitcases and bundles of clothes are frequently infested. Under normal circumstances, the risk is greatest in hostels and lodging houses, due to the constant occupation by transient visitors who may bring bugs in with their luggage. Most frequently bugs are transferred from one house to another by infested furniture.

PUBLIC HEALTH IMPORTANCE OF BED BUGS

Usinger (1966) and Mallis (1969) reviewed the studies and views on the role of bed bugs in disease transmission. Although some bugs from infestations have been found harbouring many parasites and diseases, it is generally accepted that the bed bug plays an insignificant role in the transmission of disease to humans. However, the presence of the bed bug may lead to nervous and digestive disorders in sensitive people. It has been reported that children from bug-infested homes can be recognized by their pasty faces, listless appearance and general lack of energy, which may not result completely from malnutrition, dirt or other causes of physical inferiority.

Some people may be immune to the bites of bed bugs. Others may gain immunity. Some are always susceptible. Riley & Johannsen (1938) describe the bite of a bed bug as follows: "Usually the bite produces a small, hard swelling, or wheal, whitish in colour. It may even be accompanied by an edema and a disagreeable inflammation . . .". The cause of irritation is due to salivary secretion rather than puncture. The secretion contains an anticoagulant. Hardened wheals caused by these bites may lead to secondary infection when scratched.

Another objection to bugs is their characteristic and unpleasant smell. This may be partly due to the odour from a stink gland which the adults emit when disturbed. Also, the profuse excreta of bugs tends to smell disagreeably, especially in damp conditions.

Because of the above characteristics, bed bugs are universally disliked. Accordingly, when it was found that house spraying with residual insecticides destroyed the bugs, spray teams were welcomed in many tropical countries, even if their real objective was to control anopheline malaria vectors. Unfortunately, bugs have become resistant to organochlorine insecticides in many parts of the world and in many areas the inhabitants of sprayed houses no longer get relief from bugs as a result of DDT sprays. There have, on oaccasion, been vigorous objections to spraying operations because they no longer controlled bed bugs even though they were still effective against the mosquitos. This problem of public relations has been a serious difficulty in many antimalaria programmes in tropical countries.

CONTROL

Detection

Many of the habits and characteristics of the bed bug will indicate infestations. These include spots of excreta, bites, odour or the presence of clusters of eggs. An electric torch or flashlight is useful to inspect for harbourages and infestations. An aerosol of pyrethrum is useful for inspection either for active infestations or for the effectiveness of a treatment. When the aerosol penetrates the harbourages it irritates the bugs and drives them out.

Minor infestations

Small invasions of bed bugs can occur in any household, particularly on second-hand furniture or bedding. Household hygiene including thorough cleaning is important, particularly in the early discovery of bed bug infestations.

When a light infestation is discovered, the infested articles should be thoroughly cleaned and then sprayed with a good household insecticide. A household aerosol containing pyrethroids or dichlorvos should be adequate, if directed into all crevices likely to be infested. In case these measures have not completely eradicated the bugs, the room in question should be searched periodically for a few weeks, with further treatment as necessary.

Major infestations

Control of large bed bug infestations requires the use of a residual insecticide. The principal areas to be treated are the bedding, bed springs, slats, mattresses and cracks and crevices in the walls or flooring. In severe infestations the undersurfaces of windows and door casings, pictures and picture mouldings and, where present, wallpaper should be treated.

Certain precautions must be followed. If there are any questions, either the local health department or a private pest control company should be consulted or used. Infant bedding, including the crib should not be treated with residual insecticides. Treated mattresses should be aired and dried completely before being covered with sheets for re-use. Treatment should be undertaken early in the day so that it will be dry before the room is again used for sleeping. When diazinon is used it should not be sprayed on mattresses, chairs or clothing. Before use any spray should be tested for staining in an inconspicuous area.

Applications of residual insecticides should be made with hand sprays or compressed air sprayers that produce a coarse spray, usually defined as a wet spray. The treatment of mattresses and upholstery must be done with care to avoid soaking and staining. Particular care should be taken to treat the tufts and seams of mattresses. On walls, baseboards and floors, sprays should be applied to the point of run-off; approximately one litre per 25-50 m^2 (one gallon per 135-270 yd^2).

Except where resistance to DDT has been encountered, 5% DDT emulsion or kerosene solution is the insecticide of choice except against C. lectularius (see below). DDT suspensions (wettable powders) are effective but undesirable because of white powdery deposits or smears.

Resistance

High resistance to DDT and dieldrin/HCH is common in bed bug populations in many areas (Table 2), the resistance often being induced by insecticide treatments used in antimalaria campaigns. Under these conditions organochlorine insecticides are of no use and moderate to low toxicity organophorphorus compounds are recommended. The choice depends upon toxicity, cost and availability. Malathion is probably the first choice. It has a high degree of safety and is normally very effective with a satisfactory residual effect. Insecticides effective and safe for use include:

Insecticides	Percentage of concentration in spray
bromophos	0.5-1
DDT	5.0
diazinon	0.5
dichlorvos[1]	0.5
fenchlorphos (ronnel)	1.0
fenitrothion	0.5-1
HCH	0.5
jodfenphos	0.5-1
malathion	1.0-2
permethrin	?
pirimiphos methyl	1.0
synergized pyrethrins[1]	0.2

The addition of natural pyrethrins (0.1-0.2%) to the residual insecticide formulations will increase the effectiveness of the treatment by irritating the bed bugs and causing them to leave their hiding places, thereby increasing their contact with the fresh insecticide deposits. For bed bugs resistant to DDT and organophosphorus compounds, 1% carbaryl, dioxacarb or propoxur may be used. Deltamethrin as a spray or dust at 0.005% is effective for flushing out and killing bed bugs, or bendiocarb as a 0.24% spray or 1% dust may be used.

TABLE 2. INSECTICIDE RESISTANCE IN BED BUGS IN COUNTRIES OR AREAS (WHO, 1980)

Species	DDT	Dieldrin/HCH	Organo-phosphates	Other insecti-cides
C. hemipterus	China (Province of Taiwan), Gambia, India, Kenya, Madagascar, Malaysia, Singapore, Somalia, Sri Lanka, Thailand, Upper Volta	Benin, Gambia, India, Kenya, Madagascar, Malaysia, United Republic of Tanzania, Upper Volta	-	-
C. lectularius	Almost everywhere	Almost everywhere	Israel, USSR	-

Attention is drawn to the WHO "Instructions for determining the susceptibility or resistance of adult bed bugs" (unpublished document WHO/VBC/81.809) which supersedes information given in document WHO/VBC/75.586 Rev.1.

[1] Non-residual insecticides which require two or more treatments.

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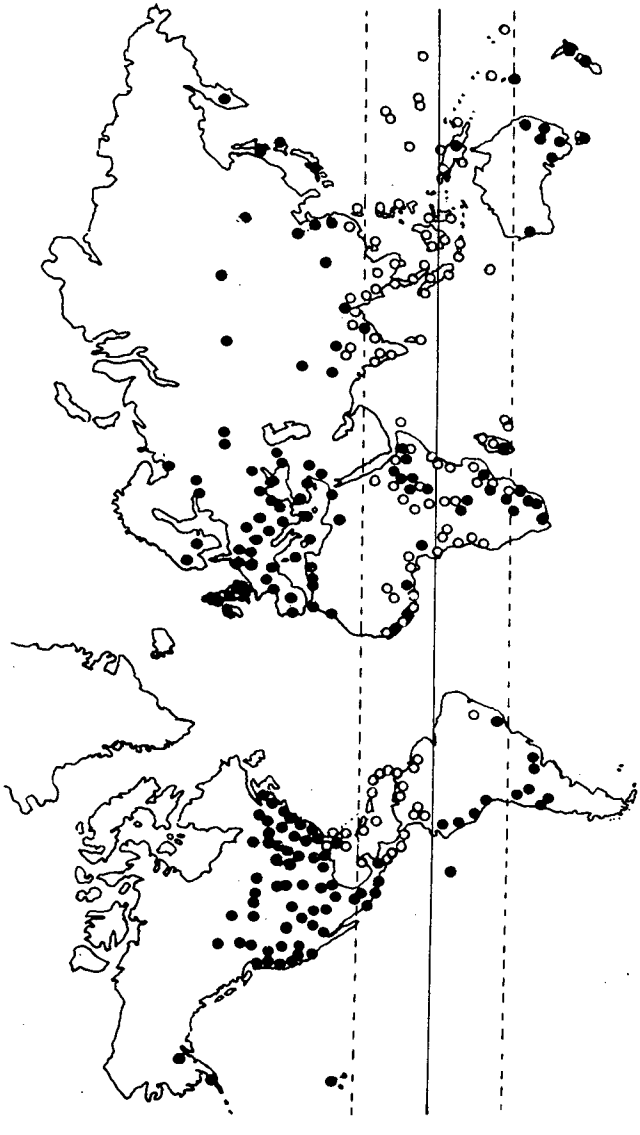


FIG. 1. WORLD DISTRIBUTION OF CIMEX LECTULARIUS (BLACK CIRCLES) AND C. HEMIPTERUS (OPEN CIRCLES)
(AFTER USINGER, 1966, MONOGRAPH OF CIMICIDAE, THOMAS SAY FOUNDATION)

FIG. 2. LEFT: ADULT MALE BED BUG (ORIGINAL),
RIGHT: AN EGG (ABOVE) AND FIRST INSTAR NYMPH
(AFTER SMART, 1948, INSECTS OF MEDICAL IMPORTANCE,
BRITISH MUSEUM OF NATURAL HISTORY, LONDON)

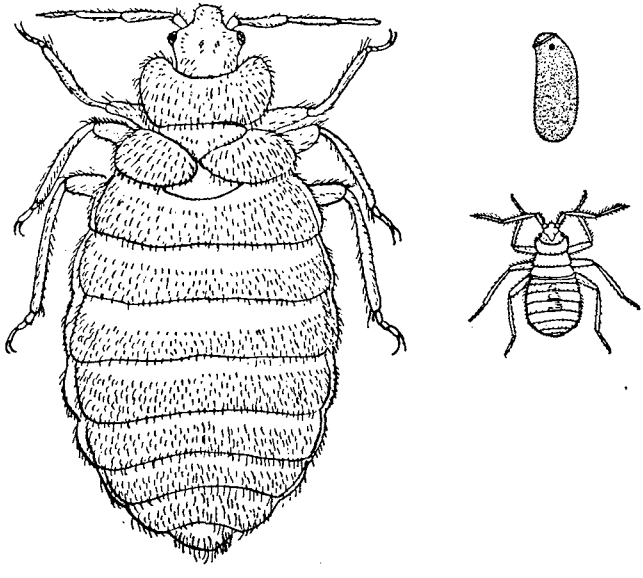
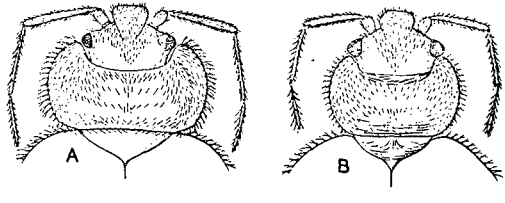


FIG. 3. HEAD AND PROTHORAX OF TWO SPECIES OF BED BUG
A: CIMEX LECTULARIUS; B: CIMEX HEMIPTERUS
(FROM SMART, 1948, LOC. CIT.)



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