VECTOR CONTROL
IN INTERNATIONAL
HEALTH

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PREFACE

The speed and frequency with which people travel and goods are transported between countries and continents has increased enormously during the last decade, and the trend is continuing. Accompanying this growth in international transportation, the risk of potentially harmful insects and rodents being carried from one area to another has also increased many times. The seriousness of the present situation and the possibility of even greater problems occurring in the future require that measures to prevent the dissemination of disease vectors should be intensified.

The control of vectors in international seaports and airports requires international action and cooperation. In this respect, the International Health Regulations adopted by the Twenty-second World Health Assembly in 1969 specify measures to ensure maximum security against the international spread of disease and vectors of disease. These measures, however, must be applied with a minimum of interference with traffic and the minimum discomfort to travellers.

That most important phase of vector control, but one that is unfortunately often neglected, is control in and around seaports and airports. This should include all cargo-handling installations as well as the cargo itself. For all practical purposes, infestations of ships and aircraft are most likely to originate from ground installations and cargoes that are not vector-free. Vector control at the source would do much to prevent the transportation of vectors of disease and to meet the requirements of the International Health Regulations.

To be most effective, control methods must be applied at the most vulnerable stage in the life cycle of the vector, and therefore accurate identifications and a good knowledge of the biology of the vector are needed. Surveillance and evaluation inspections must also be carried out to determine the action to be taken and to assess achievements and failures of control. The present manual on vector control in international health has been prepared in response to a recommendation of the Committee on International Quarantine meeting in March 1969.

It is not possible to refer to all disease vectors in a manual of this kind, nor to describe all the techniques and their many variations used in control operations; emphasis has therefore been placed on insects and rodents associated with diseases that are of major concern in international health. The descriptions of fundamental principles and details should, however, enable staff with a sound basic training to organize control programmes capable of dealing adequately with other important vectors more local in their occurrence. This manual should provide vector control officers and team leaders with all the necessary information for the development and operation of vector control programmes in ground installations and aboard ships and aircraft.

Since the manual covers a variety of highly specialized topics, experts in each field were invited to provide material for the different chapters. The names of the contributors appear on p. VI. Dr J. V. Smith, Center for Disease Control, US Public Health Service, and Dr R. Pal, Vector Biology and Control, WHO, Geneva, co-ordinated the various contributions and acted as technical editors.

Most of the figures in the manual have been reproduced from training guides of the Center for Disease Control (National Communicable Disease Center), US Public Health Service, but some of the photographs have been specially taken for the manual. The World Health Organization is indebted to all those who have given permission for their illustrations to be used and who have collaborated in various ways in the preparation of the text.
CHAPTER 1

VECTOR CONTROL IN PORTS AND AIRPORTS

GENERAL

Effective vector control measures are most important in and around airports and seaports. Ideally, the ground installations associated with international transportation should be in such excellent condition that they provide no suitable habitats for vectors. The attainment of this goal, although difficult, is possible if determined and well-organized efforts are made.

Both natural environments and man-made structures provide habitats for various vectors. Sometimes, structural design or details of construction permit rodents to enter a building or give mosquitoes access to cisterns, but the multiplication of vectors in ground installations more often occurs when port or airport authorities are unaware of what constitutes a suitable habitat, when there is a lack of proper maintenance, when sanitation arrangements are poor, and when there is indifference to proved control principles.

The immediate objective of a vector control programme is the reduction of vector populations in a given area; the long-term objective, whose importance cannot be overemphasized, is their permanent elimination from the area. Each actual or potential vector habitat should first be thoroughly examined to determine whether it is possible to render it permanently unsuitable for vectors. If it is not possible to make such changes immediately, temporary control measures must be used. Such measures are usually effective for only a relatively short time and must be repeated periodically. Both permanent and temporary control measures must be planned and undertaken as part of an overall vector control programme, and a detailed knowledge of the area involved and of the vectors found within it is required.

ORGANIZATION

The way in which a vector control programme is organized will depend on the nature and extent of the vector problem and on the financial support that is available. However, every control organization should have a well-trained, intelligent, and imaginative leader and well-trained assistants.

The basic organization should consist of four units responsible for administration, surveys, operations, and evaluation, the work of these units being co-ordinated by the leader. Such an arrangement will lead to an increase in the efficiency of the control organization if each unit is given a single major responsibility and objective.

The administration unit should have the duty of maintaining records. It is difficult to overemphasize the importance of proper record-keeping procedures and the great value of complete and uncomplicated records in planning and evaluating vector control operations. Data collected during all phases of the programme must be analysed, and the results filed and made available when needed. On the basis of such data, decisions are made regarding future activities. The duty of the surveys unit is essentially to discover the work that has to be done. This involves continual examination and re-examination of the area. Surveys will be more thorough if the unit is unencumbered by responsibility for control operations. Similarly, the operations unit will operate more efficiently and will be able to devote its activities fully to vector control when the work has been planned on the basis of previous surveys. The evaluation unit serves the overall programme by monitoring the effectiveness of administration, surveys, and operations, bringing problems to the attention of all concerned.

The leadership also has the important responsibility of developing good working relationships with other services. Within port areas, sanitation and maintenance have a direct effect on problems of vector control. The storage and disposal of refuse, the construction and repair of buildings, and the handling of cargo should all be carried out in such a way as to avoid producing vector habitats, and close relationship between the organizations responsible for these services and the vector-control organization is most desirable. Similar relationships should be developed with responsible persons and organizations in the adjacent areas. It is important that these areas should be subject to surveillance in order that reinfestation of the port or airport may be prevented or minimized.
The purpose of a survey is to collect and record information about vectors, their habitats, and conditions that favour their breeding within a given area. The results of surveys are used (1) in planning a control programme, (2) to guide control operations, and (3) to evaluate the effectiveness of the programme.

Potential mosquito breeding areas may be located by means of maps or aerial photographs, or they may be noted by an observer from a vehicle. However, there is no substitute for making a survey of the entire area on foot. In this way, actual and potential breeding areas can be examined and sampled, and signs of rodent activity can be observed. Samples of adult mosquitoes should be taken to identify the species present and to estimate numbers; this activity should be continued throughout the programme.

The initial survey

The initial survey is made before control operations begin, the objective being to define the nature and extent of the problem. The species of vector, characteristics of the habitat, and the size of the population are some of the factors that must be known in detail. Since the size and species composition of vector populations fluctuate during the year as a result of seasonal changes, climatic conditions, and the availability of breeding areas, no single survey will completely define the problem. Thus, in the initial survey actual breeding sites and those places that have the characteristics of breeding sites should be recorded, even if no vectors are found in the latter. A series of follow-up inspections should be made periodically, keeping breeding habitats and vector populations under continual surveillance. After the initial survey has been made, and the problems defined, the programmes can be properly organized and control operations, both interim and permanent, started.

The operations survey

Daily operations and the plans made for each week, month, and year are guided by continual surveys. For effective control, information is required from rapid complete surveys of the area since some vectors, such as mosquitoes, require a few days only in which to develop and become a problem. It is quite likely that routine inspections will not cover all possible vector-producing areas during the critical time and, for this reason, the pattern of routine surveys should be adjustable so that areas most likely to give rise to a vector problem are inspected every day. However, it is important that there should be complete coverage of the area in the shortest possible time. Areas that present an immediate potential problem are determined by correlating knowledge of the area, the vector populations and their biology, and the influence of environmental factors such as temperature, wind, and rainfall. The current status of vector populations and their origin provides the programme leader with the information needed to initiate control measures in order of priority.

The evaluation survey

The procedures and techniques of evaluation do not differ greatly, if at all, from operational surveys but the objectives are different. The personnel of operational and evaluation surveys should also be different so that persons do not evaluate their own work. Independent evaluation should result in control problems being corrected more quickly. Evaluation surveys indicate how well control procedures have been carried out, how effective they have been in eliminating vectors, and how much progress has been made. Ideally, the initial survey would report and define the problem, while the operation survey would report the progress of control measures, and the evaluation survey would report achievements and outstanding problems.

MAPS

Reasonably accurate and comprehensive maps are essential in vector control work. Maps should be prepared before control operations are started, and mapping should continue as a routine while control measures are being applied. Every effort must be made to keep maps up-to-date, revisions being made to show all improvements or changed conditions. Maps are used for purposes of orientation and for locating vector habitats and sampling stations in and around the installations. All information useful to vector control activities should be plotted and should include the following: (1) streets, roads, access routes to vector habitats, buildings and other structures, and boundaries; and (2) natural drainage flow, ponds, lakes, streams, marshland, and other areas of water. In particular, a map should show the location and characteristics of actual and potential habitats of the various vectors. All such features, as well as the sampling stations should be distinguished by symbols so that they are easily identified and readily located, and all
FIG. 1

MODEL MAP PREPARED FOR USE IN A VECTOR CONTROL OPERATION

LIMITS OF POPULATED AREA

CONTROL LIMITS

ADULT STATIONS

LARVAL STATIONS

LIGHT TRAPS

Kilometres
symbols should be clearly defined in a legend. Some types of information required for vector control work are illustrated in Fig. 1.

A large amount of detailed data can be incorporated into maps by means of symbols and a coding system. Once a system of symbols has been devised, a field worker may add data to the maps directly and without writing a descriptive report. It is also important that symbols and codes should be chosen for easy interpretation and the number of different symbols should be kept to a minimum. The symbols should be made no larger than clear legibility demands, and whenever possible they should be placed vertically on the map; all symbols and codes should be kept as simple and distinctive as possible (see Fig. 1). If pre-existing maps are not available, mapping can be carried out during the initial survey, special attention being given to the proportions and spatial relationships of various structures and to the physical features of the area. The scale selected for a map should allow all useful detail to be included. Scales may vary from 1:5,000 to 1:50,000 or more, but a suitable scale will be apparent when the intended use of the map is taken into consideration.

CLIMATOLOGICAL DATA

Climatological factors have a considerable influence on vectors and thus on their control. In order to survive, disease vectors must adapt to a given range of climatic conditions and the success of a species or population depends on a complex of environmental conditions, any one of which alone or in combination may act as a limiting factor; the optimum combination will support the largest population. Although a better understanding of the influence of these factors is needed, it is, nevertheless, possible to use simple climatological data as indicators of vector population size.

The data that are most often available, or rather easily obtainable, are those for light, temperature, humidity, rainfall, and wind; continuous records of these factors should be maintained in the form of graphs or charts. Vectors such as mosquitoes will show direct correlations with some of the factors while other vectors, such as rodents and fleas, may show less correlation, or even none. For example, the rate at which mosquito or fly larvae develop is closely related to temperature, and as it is generally accepted that early larval stages are more easily killed than late ones, the optimum time at which to apply control measures will be indicated by the temperature. Measurements of relative humidity indicate the evaporation rate of water from temporary ponds or containers; when the relative humidity is high, mosquito breeding in such places is prolonged. Many adult mosquitoes are most active at dusk—the time of mating, searching for food, and general movement. This activity is influenced by light, temperature, humidity, and wind. When conditions are generally good for activity, some species of mosquito move slowly up-wind and fly down-wind slightly faster. Wind speed measurements may thus be used to predict invasions of mosquitoes from outside the control area, necessitating applications of pesticide.

These examples show the potential value of climatological data in control activities; their actual value will depend on continuous recordings of climatic conditions being correlated with measurements of vector populations.

ENVIRONMENTAL IMPROVEMENT

The interests and activities of ports and airports are directed primarily towards the provision of services for the transportation industry. Included in these services are the maintenance of facilities, the continuous handling of cargo, and the disposal of waste material. As in most industrial complexes, the services are provided from within the organization, being essential for operational efficiency. It is particularly important, however, to recognize that these activities are directly related to vector problems. Frequently, those responsible for refuse disposal, maintenance, and cargo handling are not adequately informed about the requirements and techniques of vector control. Since the elimination or modification of habitats is a major concern in vector control work, the control programme must supply to the other services information on methods of preventing infestation, and encourage a constant awareness of vector problems.

The most important aspect of vector control is the elimination of sources of infestation through environmental improvement; all other control operations are only complementary to this work. The techniques employed in source reduction are fully compatible with proper maintenance and other port activities and they minimize the need for repeated applications of pesticides.
Food, shelter, and water are the main requirements of vectors. Each site where such factors are present should be examined first to assess the possibility of their complete elimination and then with a view to applying modifications that would render the site inaccessible to vectors. For example, waste organic material should ultimately be disposed of hygienically but while it remains in the port area, it should be stored in fly- and rodent-proof containers; the buildings and the storage facilities should also be rodent-proof. Areas of water should be drained or filled; cans, tires, and other objects holding water should be disposed of or stored under cover, and cisterns should be screened to exclude vectors. Control workers should locate all potential vector-producing areas and either deal with them or report them to the responsible service, suggesting ways to improve the situation.

The proper handling of refuse, the rat-proofing of buildings and enclosures, and the elimination of mosquito-breeding sites are of paramount concern in vector control programmes everywhere and further details are given in later sections.

CHEMICAL CONTROL

Chemical control methods are used to supplement environmental improvement techniques and to deal with emergency situations. Such measures, in combination with procedures to reduce the breeding potential of the vector, provide the highest level of vector control but, in the absence of practices to curb the breeding potential of vectors, chemical control alone is expensive and only partially effective. In emergencies, however, insecticide applications are the only means by which a rapid and effective reduction in vector population density can be achieved.

Vector populations that are repeatedly exposed to the same chemical treatment may develop resistance, leading to failure of control. Before control activities are initiated, the susceptibility of the vectors concerned should be established. Periodic checks upon the susceptibility levels should be made once the control programme is in operation. By relating the susceptibility of the vector to the level of control achieved, it is feasible to determine if, and when, a change in pesticide is warranted.

Equipment

Various types of hand- and power-operated equipment are available for dispensing insecticides. Hand-operated equipment includes common spray guns and aerosol dispensers for indoor use (Fig. 2), and the compressed-air sprayers (Fig. 3), knapsack sprayers (Fig. 4), dust blowers (Fig. 5), and granular applicators, such as the sling seeder or rotary type of grass seeder, for outdoor applications. Power-operated equipment (Figs. 6, 7, 8) includes hydraulic sprayers, mist blowers, pneumatic sprayers, aerosol generators, dust blowers, and ultra-low-volume mist blowers. When extensive coverage is required, power-operated equipment is desirable where the terrain is suitable. Hand-operated equipment is used to treat limited areas or sites in locations that are not accessible to power-operated units.

The selection of appropriate equipment must be governed not only by the points mentioned above but also by cost, availability of repair facilities, and the ability of the staff to handle the various types of equipment. In countries where mechanical aptitude and repair facilities are limited, hand-operated equipment can be used far more efficiently, and with a greater degree of effectiveness, than power-operated units. Even when power-operated equipment is the primary means of applying insecticide, adequate hand-operated

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* Test kits and instructions for measuring the susceptibility levels of insect vectors to various insecticides are available from Vector Biology and Control, World Health Organization, 1211 Geneva, Switzerland.
equipment should also be available for use in the less accessible sites.

Personnel engaged in spraying should be thoroughly trained in the proper care and maintenance of equipment to ensure its trouble-free operation. Adequate spare parts should always be available for all types of equipment to permit proper servicing to be carried out.

Pesticides for the control of rodents and certain insects are incorporated into baits that may be distributed by hand. In certain circumstances, insecticides incorporated into plastic-resin formulations are applied by suspending the device in the space to be treated.
Chemicals

The chemicals available for vector control purposes can be classed as petroleum, arsenicals, chlorinated hydrocarbons, organophosphorus compounds, carbamates, and synthetic pyrethroids. Most of these materials affect the insect by direct contact but the toxicity may be increased by the effect of the vapour. A few of the materials used in mosquito or fly control, produce their effects as stomach poisons.

Pesticides present various degrees of hazard to the user and they should therefore be handled in such a way that the possible harm to man and other animals, either by contamination of food or water, or by contact, is kept to a minimum. Any person who is responsible for handling or applying pesticides should be thoroughly trained in their use. The following eight rules for the handling of the pesticides should always be observed.

1. Store all pesticides in their original containers in a locked cupboard or closet where they are out of reach of children, pets, and livestock.

2. Keep all pesticides away from food or feeding stuffs.

3. Use pesticides only when necessary and use the correct material for the particular control operation.

4. Read the entire label on the pesticide container and follow the directions and precautions exactly.

5. Wear protective clothing as directed. Special care should be taken to prevent contamination of the skin when concentrates are handled, i.e., impermeable aprons and gloves should be worn and respirators should be used if necessary.

6. Avoid inhaling sprays or dusts when pesticides are being mixed or applied, and avoid spilling pesticides on the skin or clothing; if any material is spilled, wash it off at once with soap and water. Particles or drops of pesticides that accidentally enter the eyes should be flushed out immediately with large volumes of clean water.

7. Do not eat or smoke when working with pesticides. Wash the hands and face and change into clean clothes after handling pesticides. Wash contaminated clothing daily.

8. Discard any pesticide container without a label or with a damaged label. Do not guess at the contents.

Detailed instructions for the safe use of pesticides are given in Annex 3.

The selection of a pesticide is based on the type of vector to be controlled and the stage of its development. The first consideration is that the material should be highly effective against the vector but present no hazard to man or other animals when correctly applied. The cost, ease of application, odour, and persistence may also influence the choice of material; the importance placed on these characteristics will vary from one control problem to another and in most instances a compromise solution to the selection of a pesticide will be necessary. Persistent insecticides, such as DDT, may be cheaper and more effective than other pesticides in controlling the aquatic stages of certain vectors, but if their use is detrimental to valuable fish or wildlife resources, it may be necessary to choose a more expensive material that is less persistent. Before the control operation begins, the operator should contact other agencies or groups whose interests or functions might be detrimentally affected by the operation.

To obtain a high level of control, the supervisor of an operation should have a thorough knowledge of the biology and ecology of the vector concerned. He should have had adequate experience with the appropriate control techniques, and must know when, where, and how often the various measures should be applied.

Insecticides

Vectors are affected differently by the various pesticide materials. Data on toxicants that are of particular value in the control of mosquitoes, flies, fleas, and cockroaches are given in Annex 2, together with directions for preparing insecticide formulations from different types of concentrates, wettable powders, and dusts.

Larviciding

Larvicides are applied to eliminate the vector or to prevent its breeding, but such treatment should be employed only when breeding cannot be stopped by draining or filling breeding sites, improving the sanitation arrangements, or by destroying containers in
which breeding occurs. Larvicidal applications enable the vector source to be attacked whereas adulticides act on dispersed populations. However, larvicidal treatment may enhance the development of resistance to an insecticide in a vector species. Moreover, treating an aquatic environment with larvicide presents a considerable hazard to fish, crustaceans, and other forms of wildlife. Applications of larvicidal are the chief measures used to control mosquitoes breeding in artificial containers and in contaminated waters when source-reduction techniques cannot be applied.

The chemicals employed for this purpose are shown in Annex 2. Most of these materials are applied to destroy an existing infestation and their effectiveness is limited to periods of 24 hours or less. When an infestation involves vector species in containers, it is often possible to use higher rates of application and thus extend the effectiveness over a period of 2-4 weeks. Thus, compounds such as Abate or Durban can prevent the breeding of *Aedes* sp. and *Culex* sp. for approximately a month after the treatment is made. Whenever higher doses of the more toxic compounds such as Durban and fenthion are applied, care must be taken to ensure that valuable non-target organisms are not present, since such applications are lethal to fish and other aquatic animals.

Larvicides should be applied only when an inspection reveals the need for them. When the rate of application affords short-term control only, treatments must be repeated at intervals of 7-10 days in order to prevent the emergence of adults. Formulations include granular preparations, emulsifiable concentrates, and wettable powders and solutions, the choice of which depends entirely upon the conditions under which the treatment is made. Granular preparations are frequently used where the cover of vegetation is heavy, while emulsifiable concentrates are indicated when accessibility is limited and the charge for the application must be carried by hand. Ordinary fuel oil combined with a spreading agent can often be used effectively against the immature stages of mosquitoes.

**Adulticides**

Chemical measures against adult vectors can be applied in several ways. The application of a suitable insecticide to interior surfaces of houses or shelters leaves a deposit that is effective against mosquitoes for periods of 2-6 months (Fig. 9). Applications of this kind are effective only when the mosquitoes rest on a treated surface long enough to pick up a lethal dose. Residual treatments applied to scrub, trees, and grass require higher dosages that remain effective for periods of 1-2 months. Indoor residual treatments are applied by means of compressed-air sprayers or power-operated equipment. For outdoor spraying, power-operated equipment is generally used.

Space treatments are used both outdoors and indoors to provide an immediate reduction of the mosquito population. Such applications are effective only at the time of treatment and the insects are killed by droplets or particles of pesticide coming into contact with some part of their body. Aerosol dispensers may be used to treat the interior of houses or shelters, and some solid formulations of volatile compounds, such as dichlorvos, generate a vapour lethal to insects for a period of 2-4 months. For outdoor applications, aerosol generators, mist blowers, and dust blowers are employed. Hand-operated equipment of each type is available for treating limited areas; large power-operated units with capacities of 100-200 US gallons (375-750 litres) of pesticide are used when the area is extensive.

The selection of equipment and the type of treatment depends largely upon the situation and individual preferences. Applications of pesticide are strongly influenced by local weather conditions, particularly the wind velocity. The most effective results with fog generators are obtained when the wind velocity is within the range 2-6 miles per hour (0.9-2.7 metres per second). Mist blowers produce larger droplets than fogging equipment and can be operated effectively when the wind velocity is in excess of 6 miles per hour (2.7 metres per second). Since fog generators, mist blowers, and dusting equipment generally provide the same level of biological effectiveness, the choice of the method of application will be determined by other factors, such as cost and prevailing climatic conditions. The effect of a space application is temporary, and it may therefore be necessary to treat heavy infestations at frequent intervals, even daily. The cloud or fog of
insecticide may drift for a considerable distance and since such applications are usually made in areas occupied by man and other non-target organisms, care must be taken to use only those insecticides that have been specifically approved for the purpose. The fog produced by thermal aerosol equipment is often so dense as to prevent visibility; fogs should not, therefore, be applied near busy roads or in situations where a failure of visibility will constitute a hazard to traffic on the ground or in the air.

**Rodenticides**

In rodent control operations, applications of rodenticide should be considered only as supplementary to, and not as a substitute for, the proper disposal of garbage and storage of food, the elimination of rat colonies and habitats, and the rat-proofing of structures. Tables of the chemicals commonly employed as rodenticides and the doses used are given in Annex 3, and a full description is given in Chapter 3 of the techniques used to poison domestic rodents.

**BIOLICAL CONTROL**

At the present time, few natural agents appear promising for use in biological control. For many years, however, several species of mosquito-eating fish, mainly of tropical origin, have been used successfully in special situations. In some programmes, top minnows (such as *Gambusia*) are bred and distributed to control mosquitoes in cisterns, ornamental pools, and marshes where the water is relatively permanent. However, the success of this type of control operation depends on more than simply placing the fish in a body of water. Both mosquito larvae and fish occupy particular ecological niches which, even in a small body of water, may not be the same. Under those circumstances the use of fish would not provide effective control. Sometimes, success depends on the use of more than one species of fish in a given area, and even then it is necessary to maintain a constant surveillance to make sure that control is effective. There is little question, however, that fish can be successfully used, particularly in areas where mosquitoes lay eggs on the surface of the water. In some cases, larval mosquito populations have been reduced by as much as 50% by *Gambusia* alone.

**PUBLIC RELATIONS**

For maximum effectiveness, vector control work should be understood and supported by personnel employed in and around ground installations as well as by those operating ships and aircraft. Failure to obtain this support often occurs because the personnel concerned do not know what is expected of them and do not understand the vector control programme. The vector control team, and particularly the leader, has the responsibility of providing other service groups and personnel with detailed information about vector problems and instruction in the development of good habits, practices, and attitudes in relation to these problems. To be effective, members of the vector control team must be courteous, patient, and well informed. There are numerous ways in which information can be communicated and good public relations developed. Some methods are complicated and expensive while others, such as the use of posters and leaflets or direct verbal communication to groups and individuals, are simple and effective. Within ground installations, the simplest methods would probably be the most effective since the number of persons working there will be relatively small. In the areas outside ground installations it is most likely that the cooperation of leading citizens and local authorities will be needed and the use of communications media such as newspapers, radio, and, possibly, television will be necessary. All efforts made to inform the general public on vector problems are of value.

**SURVEILLANCE AND EVALUATION**

The elements of surveillance and programme evaluation have already been mentioned, and additional information will be found in subsequent chapters. However, as a major part of any vector control programme, these activities warrant further discussion. The evaluation of a vector problem should be used to guide all other control activities but methods for evaluating the effectiveness of a programme should be employed with a full awareness of both the merits and weaknesses of the method itself and of the way it is applied. For example, light traps are used to collect adult mosquitoes of certain species. Effective evaluation necessitates several traps being operated frequently during a long period. These results must then be
correlated with those obtained with other sampling methods and with the results of larval sampling. An analysis of this information will show trends that can be used to evaluate control operations.

In itself, the quantity of pesticide used in a programme does not indicate the effectiveness of vector control, and neither does the extent of rodent-proofing work nor the amount of garbage removed, unless appropriate follow-up surveys are made to determine the elimination, or reduction in numbers, of the various species of vector.

Evaluation must be based on the continuous surveillance of vector populations, as many techniques as are appropriate being used to measure the effectiveness of control. To determine the effectiveness requires a consistent series of pertinent records readily available and frequently analysed.

Each part of the control programme should be included, management, records, and control operations (including the maintenance of equipment) being subject to evaluation from time to time. In this way, losses of time and effort are avoided, and technical errors are noticed and corrected.

In the case of *Aedes aegypti* infestations, the following data on larvae may be obtained: the house index (the percentage of houses infested), the container index (the percentage of containers infested), and the Breteau index (the number of positive containers per 100 houses). A rapid method of determining the container and Breteau indices is the single-larva survey in which a single larva only is taken from each positive container for identification and counting. Where special efforts are being made to eradicate *Ae. aegypti*, a very sensitive method is needed to detect the final traces of breeding in an area; such a method is the use of ovitraps (see Chapter 2).

Although it has also been the practice to obtain a house index for adult *Ae. aegypti* by determining the proportion of houses in which resting mosquitoes of this species are found, it is more usual to assess adult infestations by determining the average population density in the houses in terms of the number of adults found per man-hour of searching on a village or urban area. A more precise method is to determine the catch in each house by means of an application of pyrethrum aerosol, the insects being collected on a ground sheet. An average for at least 10 houses should be obtained. These methods of adult assessment may be employed for both anopheline and culicine mosquito surveys.

Anopheline larvae, which are usually found in fairly open water, may be assessed by sampling pools where there is breeding, using a dipper of standard size, but it is difficult to express the results as an index. The culicine vectors of various types of encephalitis, which often develop among irrigated crops such as rice and in the waste water draining from these crops, may also be assessed by taking larval samples with a dipper. Catches of adult culicines, especially species of *Culex*, in light traps have been used as indices of infestation. Artificial shelters and traps have also been employed to estimate populations of both culicines and anophelines, although they have not been used extensively to obtain density indices.

The assessment of the flea vectors of plague is essentially a geographical study, because the wild rodents that serve as reservoirs of the infection are found in natural foci characterized by a particular biotope, usually where steppe-like conditions prevail. Thus the foci of sylvatic plague in the world are reasonably well known in outline but there is a need for detailed plotting of distribution patterns on large-scale maps. The principal surveillance method is still to trap rodents and to examine them for fleas; this yields a flea index, which is simply the average number of fleas per rodent. Since not all species of rodent flea are vectors, the index should be calculated for a single species at a time, *Xenopsylla cheopis* and *X. astia* being particularly important. Supporting information that may also be obtained is the proportion of individual rodents that are infested. Accurate identification of the species of flea is essential.

Surveillance of infestations of body lice hitherto has been largely restricted to occasions when outbreaks of epidemic typhus are feared and mass delousing campaigns are contemplated. Once again, the best index is the number of insects per host; in this case, the average number of body lice found on the clothing of each person examined. Opportunities for making such assessments are presented at centres, such as hospitals and jails, where people are normally required to undress on admittance. In countries and districts where pediculosis is known to be prevalent, medical orderlies and other attendants should be encouraged to make systematic examinations and to keep regular records of the numbers of lice that they find.

In all forms of vector surveillance, which deals with the distribution and density of a vector, the maximum information is obtained when these data are accompanied by epidemiological surveillance data indicating the proportion of infected vectors. An entomologist should collect groups ("pools") of 50–100 mosquitoes of a single species for assessment by a virologist. The sporozoite rate of anopheline mosquitoes should also be determined and flea indices should ultimately refer to the proportion of fleas infected with the plague bacillus. In the case of mosquito-borne arbovirus diseases that have natural reservoirs, antibody surveys

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of animal populations form an essential background for entomological surveillance.

It has now become necessary to make tests of the susceptibility levels of vector populations to DDT, and also to gamma-HCH, dieldrin, and other insecticides in use. The test methods have been standardized and test kits are available from the World Health Organization. Surveys of susceptibility levels, particularly in body lice and plague fleas, can conveniently be combined with surveillance surveys, and when the vector species are collected for testing the numbers and the intensity of infestation should also be recorded. Sampling techniques are described more fully in subsequent chapters.

CHAPTER 2

BIOLOGY AND CONTROL
OF IMPORTANT INSECT VECTORS OF DISEASE

GENERAL

In order to obtain the highest degree of vector control consistent with maximum safety and minimum costs, operators need a knowledge of both the biology of vector species and of the various control methods, techniques, and procedures. Despite very great advances in the development and use of pesticides, it is wrong to assume that procedures based solely on these materials are the principal techniques used in operational programmes. In any control programme, environmental improvement may be the key to successful control and should be given primary consideration. However, while pesticidal measures are secondary, maximum control usually cannot be achieved without the use of pesticides, either as a supplementary treatment or in emergencies. Although this is true for insect and rodent control, it does not apply to disease control which has been accomplished in some areas with pesticides alone, the classical example being the control of malaria. This has been achieved by applying insecticidal measures against the section of the vector population that enters dwellings.

In employing various control measures, it is important to recognize the limitations of individual applications. Although emphasis is placed on those methods that have proved successful in many different areas, some control measures may be associated with certain geographical areas having specific climatic conditions that affect the physiological and behavioural characteristics of a particular strain of vector. Thus, measures effective in one country may be of less value in another.

Obviously, vector control cannot be based simply on routine or mechanical application of well-tried methods. As much as possible should be known about the biology and ecology of vectors in general and in particular about the vectors in the areas where control measures are to be applied. It is very important that the most vulnerable time in the life cycle of a vector should be recognized and that population increases under known conditions are correctly forecast. This approach provides a sound basis for the planning of an effective and economical programme.

In this chapter, general information is given about the various groups of insect vectors, together with detailed information on some vectors of disease that are particularly important in international health.

MOSQUITOS

Mosquitos are the most important single group of insects with regard to public health. It is a remarkably adaptable and fully cosmopolitan group with over 3,000 species distributed throughout the world. Few, if any, areas where water is available for their larval development are free from these insects. Throughout human history, mosquitos have been a constant impediment to progress, causing great suffering on account of their blood-sucking habits and their ability to support and transmit disease-causing organisms. They are well known as vectors of malaria, yellow fever, dengue fever, filariasis, and most of the arthropod-borne viral types of encephalitis.

Despite natural forces and the extension of environmental changes produced by man, mosquitos continue to thrive wherever there are human populations. Since mosquitos live in close association with man, travelling with and feeding on him, but existing for the most part as free-living insects, they are particularly well adapted to harbour and transmit agents of disease. It is fortunate that a few species only are known to be natural vectors of disease, and that many species are associated mainly with other animals. It is quite possible, however, that new relationships will be found as our knowledge of vectors and diseases increases, or that the relationships between mosquitos and human disease will change in response to changing environmental conditions.

Mosquitos belong to the family Culicidae of the order Diptera (i.e., the two-winged flies). They are small, long-legged, two-winged insects; the adults differ from other flies in having the following two
Mosquitos have four distinct stages in their life cycle—namely, egg, larva, pupa, and adult (Fig. 10). The first three stages are passed in water but the adult is an active, flying insect that feeds on blood or plant juices.

**Eggs**

The eggs are white when first deposited but they darken within an hour or two. In general, there are three distinct types of mosquito egg: (1) those that are laid singly on the surface of the water; (2) those that are glued together to form rafts that float on the surface; and (3) those that are laid singly out of water. These differences are reflected in the structure of the egg.

Anopheine eggs are typical of those that are laid singly on the surface of water. These eggs are elongated, oval, usually pointed at one end, and provided with a pair of lateral floats (Fig. 10); the average length is about 1 mm. Hatching occurs in 2-3 days.

Several genera of mosquito lay their eggs side-by-side, forming a raft. The raft, which may contain 100 eggs or more, remains afloat on the surface of the water until, after a few days, the eggs hatch. Egg rafts are characteristic of the following genera: *Culex, Culiseta, Mansonia, Uranotaenia*.

Eggs that are laid out of water must either be deposited close enough to water for the newly hatched to larvae reach the water readily, or they must be able to survive long periods of drying until they are flooded. The eggs of *Orthopodomyia* and some species of *Aedes* are laid on the sides of tree holes, in leaf axils, or in rockpools or containers just above the water level; with a rise in the level of the water the eggs hatch. Other species of *Aedes* and all species of *Psorophora* lay their eggs on the ground where they remain until flooding occurs; the eggs of some mosquitos may survive for 3-4 years if they are not flooded. The eggs of some species hatch as soon as they are flooded and there may be several generations per year; the eggs of other species develop only after they have been subjected to freezing, and there is thus only one generation a year. If it is recognized that there are certain exceptions, some useful generalizations can be made that will be helpful in a control programme. The eggs of mosquitos that oviposit elsewhere are quite variable but generally go through a period of conditioning before they hatch; aquatic development may be completed in a week or less. These species may have one or more generations and overwinter in the egg stage.

**Larvae**

The larvae of all mosquitos live in water. Some larvae develop in permanent ponds and marshes, some in temporary flood waters or woodland pools, some in water contained in tree holes or the axils of leaves, and others in any type of artificial container that holds water. Mosquitos have become adapted to most kinds of aquatic situation; thus all bodies of water except the open water of large streams, lakes, and the sea should be considered as possible habitats. Although mosquito larvae obtain their food from the water, they must rise to the surface to breathe (but larvae of the genus *Mansonia* obtain air from the underwater portions of plants). During the larval period there are four developmental instars which together usually require at least 4-10 days for completion, but it should be remembered that this period depends on environmental factors—temperature, in particular—and is, therefore, quite variable. The time required for aquatic development is often longer in the early spring and autumn generations. At the end of each instar, the larva mouls; the fourth instar is the mature larva and with the fourth moult the pupa appears (Fig. 10).

Mosquito larvae move about mainly in two ways: by jerks of the body, and by propulsion with the mouth brushes. The movements of anopheine larvae at the surface of the water are generally of the first type while the “crawling” movements of larvae along the bottom and the slow movements at the surface are probably of the second type. Mosquito larvae assume characteristic positions in the water; anopheine larvae lie parallel to the surface while those of most other groups hang head-down with only the tip of the air tube penetrating the surface film. Certain non-wetted structures such as the air tube, the spiracular plate, and the palmate hairs serve to suspend the larva from the surface film. Larvae of all mosquitos dive rapidly to the bottom when a shadow passes over them or when the water surface is suddenly disturbed. This reaction is of particular importance when inspections are being made and samples collected.

The head of the larva is broad and somewhat flattened (Fig. 11) and the antennae are located on each side of the head towards the front; behind the antennae near the hind margin of the head are the eyes. The mouthparts are on the underside of the head near the front and in addition to the grinding and grasping structures they comprise a series of brushes. Thus, the larva is able to strain out small aquatic organisms and...
FIG. 10
CHARACTERISTIC APPEARANCE OF THE VARIOUS STAGES OF THREE GENERA OF MOSQUITO OF PUBLIC HEALTH IMPORTANCE *

ANOPHELES

AEDES

CULEX

* Prepared by K. S. Littig & C. J. Stoianovich, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
particles of plant and animal materials present in the water. The larvae of a few predaceous species have mouthparts adapted for grasping and swallowing the prey.

The thorax is broader than the head or abdomen and somewhat flattened. It has several groups of hairs that are useful in identifying the species, but there are no other special structures.

The abdomen is long and subcylindrical, consisting of 9 well-defined segments. The first 7 segments are similar, but the eighth and ninth are considerably modified. The eighth segment bears the respiratory apparatus, which in anophelines consists of paired spiracular openings while there is a prominent air tube in the other groups. The ninth segment is out of line with the other segments and bears 2–4 tapering membranous appendages commonly known as anal gills (Fig. 11). These gills seem to be associated with the regulation of osmotic pressure rather than with respiration.

**Pupae**

The mosquito pupa is also aquatic and is very active. It is a non-feeding stage but rises to the surface to breathe (except the pupae of the genus *Mansonia*). The pupa differs greatly from the larva in shape, the front part, consisting of the head and thorax, being considerably enlarged and enclosed in a sheath; on the upper surface is a pair of respiratory trumpets. The abdomen comprises 8 freely movable segments with a pair of paddles at the tip.

Mosquito pupae are undoubtedly the most active of all insect pupae. The pupae of most species are lighter than water, their buoyancy being due to an air space between the wing cases on the underside of the combined head and thorax. By means of vigorous movements
of the abdomen, the pupae move about with considerable speed and rise directly to the surface when movement stops.

The pupal stage lasts for a period that varies from a day to a few weeks; no species is known to overwinter as a pupa. At the end of the pupal stage, the pupal skin is broken and the adult works its way out, crawls on to the surface of the water, and is soon ready to fly.

Adults

The adult mosquito is a small fragile insect with a slender abdomen, a pair of narrow wings, and three pairs of long, slender legs. The length varies from slightly over 1/16 inch (1.6 mm) to about 1/2 inch (12.5 mm). The three regions of the body—head, thorax, and abdomen—are distinct.

The head of a mosquito, which is almost spherical and joined to the thorax by a narrow membranous connexion, bears a pair of large compound eyes, a pair of antennae, a pair of palpi, and the proboscis. The antennae arise on the front of the head between the eyes and are long, slender structures consisting of 15 segments, only 14 of which are usually visible. Each of the last segments bears a whorl of hairs that are short and sparse in the female, but long and bushy in the male. The antennae are believed to serve as organs of hearing and smell.

The palpi are 5-segmented structures originating at the lower front margin of the head near the proboscis. In female anophelines, the palpi are straight and about the same length as the proboscis. The palpi of male anopheline mosquitos differ from those of the female in being enlarged at the tip (Fig. 10). The palpi of female culicines are very short, while in the male they are usually long and densely haired, with the last two segments turned upwards.

The proboscis projects downwards and forwards from the lower front margin of the head and consists of a labium (a sheath-like structure) enclosing a group of 6 stylets. The labium serves as a protective sheath for the stylets but does not enter the wound when the mosquito is biting. The stylets serve to penetrate the skin of the host animal and also form a duct through which saliva is injected into the wound and through which liquid food is sucked. The mouthparts of the male are incapable of piercing the skin of a human or animal host.

The thorax, or middle region of the body, bears the wings and legs. The upper surface of the thorax (the mesonotum) is covered with coarse hairs or scales that are variously coloured; the colour pattern is often useful in identifying the species. The sides of the thorax may be covered with scales and bear several groups of hairs or bristles that are also used in identification. The long, slender legs arise from the lower sides of the thorax, each leg consisting of a short conical coxa, a small hinge-like trochanter, a long femur, a slender tibia, and a 5-segmented tarsus. The first segment of the tarsus is the longest and is often equal to the tibia in length, the fifth tarsal segment bears a pair of small claws. The legs are covered with scales of various colours, forming patterns that are often useful in the separation of species.

The wings are long and narrow with a characteristic arrangement of veins. These veins are covered with scales, often variously coloured, that may be distributed in definite patterns. The hind margin of the wing also bears a close-set row of long, slender, fringe scales. A pair of small knobbed structures, the halteres, is found behind and slightly below the wings. They vibrate rapidly when the mosquito is in flight and serve to maintain equilibrium.

The elongated abdomen is nearly cylindrical and consists of 10 segments, only 8 of which are readily visible. The ninth and tenth segments are greatly modified for sexual functions. In the culicines, the abdomen is covered with scales that often form characteristic markings. In Aedes and Psorophora, the abdomen of the female is tapered apically, the eighth segment being withdrawn into the seventh. In other genera, the abdomen is bluntly rounded at the apex (Fig. 12). The terminal segments of the male abdomen are greatly modified for copulation and the structures are often of value in identifying the species.

Habits of adult mosquitoes

Male and female adult mosquitos are usually present in about equal numbers. The males generally emerge first and remain near the breeding places, and mating takes place soon after the females emerge. Only the females bite and those of most (but not all) species
require a blood meal before they can lay fertile eggs. The females tend to travel greater distances and to live longer than the males.

Flight habits vary considerably; *Aedes aegypti*, probably the most highly domesticated mosquito, flies very short distances. Although the possible flight range of anopheline mosquitoes may vary considerably, depending on the species and circumstances, their effective flight range is generally uniformly limited to the area required to provide food and shelter and suitable conditions for the continuation of the species. Flight ranges of about 2–10 or more miles (3–16 km) have been reported for anopheline mosquitoes: *Anopheles albimanus* and *A. gambiae*, 3–4 miles (5–6.5 km); *A. quadrimaculatus*, 2–8 miles (3–13 km); *An. culicifacies*; 1½ miles (2.8 km); *An. punctipennis*, 10 miles (16 km). Thorough larvicidal measures applied within a 2-km zone around an installation are generally sufficient to protect the area from anopheline mosquitoes; however, other species such as *Ae. vexans* and *Ae. sollicitans* may fly 10–20 miles (16–32 km) or more.

Mosquitoes also show considerable variation in their host preferences; some species feed on cattle, horses, or other domestic animals, while others prefer to feed on man. A few species feed only on cold-blooded animals and some subsist entirely on nectar or plant juices. Some species are active during the day and others only at night.

The life span of adult mosquitoes is not well known. Some species apparently live 1 or 2 months during the summer, although under unfavourable conditions this period may be greatly reduced. Adults that hibernate may live for 6 months or more.

**Environmental influence**

All stages in the life cycle of a mosquito are dependent upon a number of environmental factors for their survival and development. Some of these factors are still unknown, especially as they interrelate in many combinations. However, appropriate combinations of factors occur widely, and many of the environmental conditions provide suitable habitats for one or other species of mosquito. Some common, and measurable, environmental factors, such as wind, light, temperature, rainfall, and humidity, have a known relationship to the survival of mosquitoes that can be used as the basis of an index for use in surveillance and control.

For present purposes, it can be assumed that oviposition takes place under favourable combinations of biological and environmental factors that influence the selection of an oviposition site. Similarly, viable and properly conditioned eggs will hatch in water when there is an appropriate combination of factors. Both long-term mosquito control operations and a large part of environmental improvement programmes are aimed directly at preventing oviposition or the hatching of eggs. These measures include, for example, drainage, filling, water-level management, the removal of containers providing a larval habitat, the screening of cisterns, etc. The seasonal pattern of mosquito population changes is related to the supply of water and rainfall and runoff help to provide a continuous supply of water, but other factors may also be important.

In general, long dry periods retard the expansion of some mosquito populations, but irrigation (where it is practised) is usually intensified at these times and provides an alternative source of water; some species thus thrive during dry periods. The storage of water in containers for mainly household purposes, especially during dry periods, is a practice that maintains small populations of *Ae. aegypti*. The population levels are of course lower than when rainfall provides water for the multitude of containers used by this species for oviposition. A slight rise in the level of water may cause an increase in mosquito production by re-establishing the less frequently inundated oviposition sites, and by increasing the number of temporary bodies of water. Excessively heavy rainfall and runoff during flood conditions has a flushing effect, and large numbers of mosquito larvae may be washed away and destroyed. Such a reduction in the larval mosquito population is of relatively short duration. Standing water remaining after floods have receded is often very extensive and some species of mosquito, such as *Culex tarsalis* in the western USA, have been known to increase tremendously under these conditions.

To apply a knowledge of such changes in water level usefully, control programme leaders must also consider the season of the year. In temperate areas, increases in water during the late autumn and winter are generally of little immediate concern except in the extent to which they influence mosquito production during the following year. On the other hand, flooding during the spring and summer is obviously important for mosquito production.

The success of adult mosquitoes in attaining their biological goals depends to a large extent on the environment. For control operations and population surveillance, a team leader should be able to recognize favourable and unfavourable combinations of light, temperature, wind, and humidity, all of which have an effect on the activity of adult mosquitoes. It is difficult, however, to do more than offer generalizations, and, even then, team leaders must take local conditions and species of mosquito into consideration. Many species are most active during the evening hours near sunset or in the early morning just before sunrise. It may be considered therefore that they tend to avoid
“extremes” of light and darkness, heat and cold, and low humidity, that are most often found during the day or during the night. When they are inactive, mosquitoes “rest” in shelters of some type that provide favourable conditions.

At appropriate times, mosquitoes fly in a breeze but sampling for adult mosquitoes on nights with a strong wind usually results in none being collected. Activity is also very limited during rainstorms, but both before and after may be greatly increased. Overcast humid days are often suitable for increased activity well into the daylight hours. Those species of mosquito normally active during the day are usually found in limited areas where light, wind, humidity, and temperature are favourable, generally reflecting, in fact, the conditions experienced in the morning and evening hours. Some species have been reported to show fluctuations in the numbers collected by light traps on a 4-week cycle correlated with the dark and bright phases of the moon, collections being at a maximum during the darker phases.

These generalizations should be useful in planning and interpreting routine mosquito surveillance and evaluation activities, which in turn guide the day-to-day work of control.

Sampling techniques

During many years’ experience, a variety of techniques and equipment has been developed for sampling mosquito populations. It must be understood however, that samples taken in the course of surveillance and evaluation for vector control have no direct relationship to the actual mosquito populations. Nevertheless, such sampling indicates which species of mosquitoes are present and by the number of specimens collected, whether or not the control operation is effective. With consistent sampling over long periods, interpretation of the results becomes more meaningful. Thus it is important to establish sampling stations in the early stages of a programme and to make regular collections; the limitations of each sampling method should be recognized and several methods should be used to evaluate control operations.

Adults

In general, samples of adult mosquitoes can be taken in the act of biting human volunteer “baits”, from resting shelters, and in light traps. Other methods of sampling have been developed but they are used mainly for research and perhaps have less value in control programmes based in port or airport areas than they would in much larger areas.

The collecting equipment is quite simple and generally inexpensive (Fig. 13); it consists of a collecting tube (aspirator), a killing tube, pill boxes, cages (if live collections are required), field record forms or notebook, a writing instrument, an electric torch, and a map. The killing bottle is made from a glass or plastic tube of convenient size; a large test tube about 1 inch (2.5 cm) in diameter and 7 inches (18 cm) in length is often preferred. The tube is filled to a depth of about 1 inch (2.5 cm) with finely chopped rubber bands, art gum, or other readily available form of rubber. A sufficient quantity of chloroform or ethyl acetate to saturate the rubber is then added. A disk of blotting paper is placed over the rubber, then a half-inch layer of cotton-wool, and finally two or three more disks of blotting paper slightly larger than the internal diameter of the tube are pressed down over the cotton-wool layer. The tube is closed with a cork (never rubber) stopper. Collecting tubes remain effective for several weeks and can be recharged with chloroform when necessary. Some workers wrap adhesive tape around the base of the collecting tube to lessen the risk
of breakage; an inverted paper cone is sometimes inserted inside the mouth of the tube to trap mosquitos more readily.

A simple aspirator is prepared from a section of plastic or glass tubing 12 inches (30 cm) long with an inside diameter of about 3/8 of an inch (1 cm). One end of the tube is covered with bobbinet or fine wire mesh; that end is then inserted into a piece of rubber tubing 2-3 feet (0.6-1 m) long.

Small pill boxes or salve boxes are convenient containers for unidentified mosquitos. A wisp of cotton-wool or, preferably, soft facial tissue in the box will prevent damage to the specimens during transportation.

Biting collections

Collecting mosquitos in the act of biting is a convenient method of sampling adult populations. The “bait” subject rolls up his shirt sleeves or trouser legs and sits quietly for 10-15 minutes, collecting the mosquitos that settle on the exposed skin. The mosquitos are collected with the killing tube or aspirator and collections are made at the time of maximum activity which, for most species, is generally during the 2-hour period starting at sunset. A series of 10- or 15-minute collections should be made during this period since the numbers and species of mosquitos will vary during the 2 hours. If collections are made after dark, an electric torch will be required to illuminate the mosquitos and it is desirable that the light intensity should be lowered by covering the lens with a piece of clear red plastic film.

Biting collections become more significant as an index of vector population size when they are carried out at regular intervals by the same person, some individuals being more attractive to mosquitos than others.

For species biting in daytime, the index may be based upon the number of mosquitos alighting upon the clothing of the volunteer bait in a given time (i.e., the landing rate). This is more convenient when populations are very large and is useful means of checking the abundance of mosquitos before and after control measures have been applied.

Resting station collections

Adults of many species are inactive during the day and may be found resting quietly in dark, cool, humid places. Not all such places are used and therefore a careful search is required to locate inhabited sites in which collections can be made frequently. A careful inspection of a daytime shelter will provide an index to the species and the population densities of the mosquitos using it. The mosquitos are captured with an aspirator or killing tube after they have been located, usually with the aid of an electric torch. Houses, stables, chicken houses, privies, culverts, bridges, caves, and hollow trees have all been used successfully as collecting stations for resting mosquitos. Although these are some types of shelter used by mosquitos, it is probable that not many such places are to be found in a port or airport area. It is therefore even more important that a careful search should be made for any kind of dark, cool, humid place.

Within resting shelters, all corners from ceiling to floor, should be examined, as well as the undersides of horizontal surfaces, behind boxes, cartons, equipment, etc., resting against the walls, and in the folds of clothing or other materials. A careful searcher will quickly learn where mosquitos are likely to be resting. If suitable collecting stations are difficult to find, shelters made of barrels, kegs, boxes, etc., can be placed in shady, humid situations. Good collections from resting shelters are very valuable indicators of the effectiveness of control measures.

Light-trap collections

A very useful tool in survey work is a mosquito light trap (Fig. 14). Many species are attracted to light and it is possible to take advantage of this response in sampling adult populations between dusk and dawn. Light traps have been used widely to obtain data on the abundance and species composition of mosquito populations in a control area.

Light from the trap attracts adults from a considerable area if it is located where it does not compete with other light sources. When the mosquitos approach the light they are sucked downwards through a screen funnel into a killing jar or mesh bag suspended below the trap. The light and fan are generally operated by electricity from the mains supply but batteries can be used in remote areas. A killing jar is made from a pint or quart (½ or 1 litre) glass jar or plastic container; a layer of sodium or potassium cyanide is placed in the bottom and is covered with a layer of plaster of Paris or cardboard. For reasons of safety, pieces of rubber saturated with chloroform may be used instead of cyanide, and some workers use paradichlorobenzene in the killing jar in a similar way.

Experiments have shown that carbon dioxide used in conjunction with the light trap increases the number of mosquitos and the range of species collected. About 1 or 2 pounds (½-1 kg) of dry ice (i.e., solid carbon dioxide) wrapped in a double layer of newspaper or aluminium foil and suspended alongside or slightly above the trap provides sufficient carbon dioxide for one night. This technique may be particularly useful in areas where mosquitos are scarce.

The light trap is mounted on a post or suspended from a tree, with the light about 6 feet (2 m) above the ground and preferably at least 30 feet (9 m) from buildings close to trees and shrubs; traps should not be
FIG. 14
TWO PATTERNS OF LIGHT TRAP FOR COLLECTING ADULT MOSQUITOS

A. CDC MINIATURE LIGHT TRAP

B. AMERICAN LIGHT TRAP
placed near other light sources or in situations exposed to strong winds. The traps are operated on a regular schedule for 1–7 nights each week; a reasonable compromise between too few collections and too great a demand on resources is 2 or 3 nights a week. The collections are removed each morning and placed in properly labelled boxes for subsequent sorting and identification of species.

There is considerable variation in the attractiveness of light traps to different species of mosquito. An evaluation of light-trap collections must, therefore, be made in conjunction with other sampling methods.

**Larvae**

Detailed inspections are required to find suitable breeding sites where larval sampling stations, which will be used continuously throughout programme activities, can be established. Larval surveys reveal the sites where mosquitoes are breeding; accurate records of the surveys provide an index of the species present and indicate variations in their relative abundance.

A white enamel dipper about 4 inches (10 cm) in diameter is generally used for collecting mosquito larvae (Fig. 13). The handle of the dipper may be extended by adding a length of cane or wood, etc.
White enamel pans about 14 inches long by 9 inches wide by 2 inches deep ($35 \times 23 \times 5$ cm) are sometimes used instead of dippers. The pan is used to sweep an area of water surface until it is half full of water, and it may then be floated on the surface of the water while the larvae are removed.

Inspection of small water containers or cisterns may require the use of an electric torch or a mirror to illuminate the breeding place. Large-bulb pipettes or siphons are sometimes used to remove water and larvae from small, rather inaccessible sites such as tree-holes to a white enamel pan in which the larvae are counted and collected. Wide-mouthed pipettes ("eye droppers") are used to transfer larvae from the dipper or pan to small vials, preferably with screw caps, in which the larvae are kept until they are either identified or mounted on glass slides. To preserve larvae, ethyl alcohol (ethanol) of 95% strength is very satisfactory but 70% ethanol is also in common use.

Many variations of the basic equipment exist, most of them having been developed as the result of field experience. The inspector would be wise, however, to start with the standard equipment described here and then to make such modifications as may appear desirable.

**Inspection procedures**

Mosquito larvae are usually found where there is vegetation or debris on the surface. Thus in large ponds, lakes, and reservoirs, larvae are confined to the marginal areas. In dipping for larvae, it is necessary to work slowly and carefully because a disturbance of the

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### FIG. 16

**MODEL FORMS FOR RECORDING MOSQUITO IDENTIFICATIONS**

<table>
<thead>
<tr>
<th>Locality</th>
<th>Date Received</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determined by</td>
<td>Date</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Date of Collection</th>
<th>Type of Collection</th>
<th>Mosquito Species</th>
<th>No. of Larvae</th>
<th>No. of Males</th>
<th>No. of Females</th>
</tr>
</thead>
</table>

(Reverse side)

### ANIMALS OTHER THAN MOSQUITOES

<table>
<thead>
<tr>
<th>Date of Collection</th>
<th>Collection Site</th>
<th>Locality</th>
<th>Host</th>
<th>Species of Animal</th>
<th>Total No. Collected</th>
</tr>
</thead>
</table>

(Reverse side)
water or a shadow cast on the surface usually causes the larvae to dive to the bottom.

Anopheles larvae are collected by a skimming movement of the dipper with one side held just below the surface. The stroke is ended just before the dipper is full since larvae will be lost if water spills over. Where clumps of erect vegetation are present, the dipper, with one edge depressed, should be pushed down into a clump so that the water flows from the vegetation into the dipper. To capture larvae that are likely to dive when the water is disturbed, a rapid sweep of the dipper is required.

An inspector should always record the number of dips made and the number of larvae captured. A convenient form for recording these data is illustrated on Fig. 15. The larvae are then transferred to small vials and preserved in ethanol for later identification. It is possible to estimate breeding rates by counting the number of larvae of each species in every dip. The number of dips taken will depend upon the size of the breeding area, but they should be made systematically throughout the site, and the total number should be a multiple of 10 for convenience in determining the number of larvae per dip. Inspections should be made at intervals of 1–2 weeks during the breeding season, because areas that are free from larvae at one inspection may be heavily infested soon after. Laboratory identifications of specimens should be maintained on a standard record form similar to that shown in Fig. 16.

**Oviposition traps**

Larvae of *Aedes aegypti* can also be detected by means of a sensitive device called an “ovitrap”. Although this particular device is new, essentially the same idea has been used in some countries for a number of years. The ovitrap described here was developed by the US Public Health Service and has been used extensively in the *Ae. aegypti* eradication programme in the USA.

The oviposition jar (Fig. 17) is made of flint glass with smooth tapered sides and has a capacity of about 1 pint (½ litre). The inside diameter at the top is about 3 inches (7.5 cm) and the overall height is about 5 inches (13 cm). The jar is coated on the outside only with glossy black, abrasive-resistant, ceramic paint, and water is poured into the jar to a depth of about 1 inch (2.5 cm). A “paddle”, which is a strip of compressed fibre-board about ¾ inch wide, 5 inches long, and 1/8 inch thick (2 × 13 × 0.3 cm) with at least one rough side is attached to the side of the jar in a vertical position by means of a clip. The prepared jar is then placed in the field. Female *Ae. aegypti* mosquitoes are attracted to the ovitrap and lay eggs on the paddle close to the waterline.

In the field, ovitraps should be placed on the ground in partial or total shade at intervals of 350–500 feet (107–152 m) and, if possible, close to other potential breeding containers or to adult mosquito resting places. The exposure of ovitraps to direct sunlight should be avoided. Once they have been set out, the traps can be left in place indefinitely but they should be inspected at weekly intervals. At each inspection the “exposed” paddle is removed, the jar cleaned, the water level adjusted, and a new paddle attached.

The exposed paddle is taken to the laboratory and either examined under a microscope for eggs or the eggs are hatched and the larvae identified. Identification is important since some other species in certain areas lay eggs in ovitraps. Each paddle and trap should be numbered so that positive findings can be used to locate control operations in that particular area.

The operation of ovitraps in port or airport areas for several weeks during the optimum period of oviposition for *Ae. aegypti* is a sensitive and accurate way of determining the presence of this species.

**Important vector species**

**Genus Aedes Mirgrn**

The genus *Aedes* contains more than 500 species that are distributed from the polar regions to the tropics. It is the dominant mosquito genus in temperate and

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1 For further details on the oviposition trap, the reader may refer to The CDC *Aedes aegypti* handbook, 1967, Atlanta, Ga., USA, National Communicable Disease Center.
cold areas and includes many major pest species and important disease vectors. In northern USA, as well as in Canada and Alaska, many species of *Aedes* occur, often in astronomical numbers.

All species of *Aedes* lay their eggs singly on the ground or at, or above, the waterline in tree holes or containers. The eggs contain fully developed embryos and, after a period of conditioning, they hatch when submerged in water. A fact of particular importance in the control of this genus is that the egg shell is impermeable to water and eggs can survive for long periods, even extending to several years, in dry conditions. Some species produce only one generation a year while others are intermittent breeders, having several generations each year, depending upon the occurrence of rain, floods, or irrigation overflows. All species of *Aedes* occurring in regions with cold winters survive this period in the egg stage.

*Aedes* breeding places are extremely variable; in general, eggs are laid in temporary pools where the water level rises and falls, causing the oviposition area to be flooded at various intervals. Some species breed in coastal salt marshes that are flooded at intervals by unusually high tides while others have become adapted to agricultural irrigation practices. A few species, such as *Ae. aegypti*, breed in tree holes, rock pools, and artificial containers. Practically all species of *Aedes* feed on blood; many are vicious and extremely irritating biters of great economic importance while others are quite passive. The time of biting is also quite variable, but attacks are most frequently made during the evening hours. Some species, however, bite only during the day and others will bite at any time. Light traps, biting collections, or landing rate counts are effective sampling methods for many species of *Aedes*. The flight range varies within the genus from less than ½ mile to 20 miles or more (0.8–32 km).

The high degree of variability noted in this and other groups of mosquitoes clearly indicates the need to know the biology of each species and to apply appropriate control measures.

**Medical importance**

Certain mosquitoes of the genus *Aedes* are known vectors of disease—notably, yellow fever, dengue, and various types of viral encephalitis. Most important of these diseases is urban yellow fever, especially when it is considered as an internationally quarantinable disease. The virus is transmitted from man to man by the yellow fever mosquito, *Ae. aegypti*, and generally requires an incubation period in the mosquito of 9–12 days before the insect becomes infective. Once the mosquito is infected it remains so as long as it lives. Although less well known, the life cycle of the dengue viruses is much the same, both *Ae. aegypti* and *Ae. albopictus* being vectors. Another epidemiological type of yellow fever is called jungle or sylvatic yellow fever; it is normally a disease of monkeys or even other animals. The life cycle involves *Ae. africanus*, *Ae. simpsoni*, and possibly other species of *Aedes*, as well as species of *Haemogogus* and perhaps *Sabethes* as vectors. Sylvatic yellow fever occasionally spills over into human populations when people living in tropical forests are bitten by infective mosquitoes. However, the virus is the same as that of urban yellow fever and one vaccine provides protection against both types of disease in man. Many species of *Aedes* are suspected of transmitting various encephalitis viruses in man.

**Control**

*Ae. aegypti, Ae. albopictus, Ae. simpsoni*, and related species may be controlled by the methods described for the control of *Ae. aegypti* (see p. 28), particular emphasis being given to locating and treating the specific breeding places of each species. The control of floodwater species of *Aedes* and *Psorophora*, however, requires a different approach because the breeding sites range from woodland pools to salt marshes, irrigated pastures, and cultivated land. Moreover, these mosquitoes are able to fly or migrate as adults for considerable distances.

After breeding areas have been identified by larval surveys, control measures consist of (1) the elimination of breeding areas or their modification by environmental improvement measures; (2) the application of selected chemicals, primarily as larvicides, when an inspection shows that they are required; (3) the application of adulticides to complement larvicidal treatments when the emergency control of invading adult mosquitoes is indicated. For this group of mosquitoes, prehatching larvicidal treatment is useful; the selected larvicide (see Annex 3) is applied 1–8 weeks before the eggs are flooded, usually in the late spring or early winter.

**Aedes aegypti** (Linnaeus)

**Distribution**

The yellow fever mosquito occurs in Asia, the Americas, and Africa. It is widely distributed in all tropical and subtropical ports of the world within the limits of 40°N. to 40°S. latitude. Because the species is closely associated with man, it is continually carried to places far outside its permanent range and is periodically reintroduced into areas of South and Central America where eradication had previously been certified.
Medical importance

*Ae. aegypti* is recognized as the vector of several viral diseases, including yellow fever, dengue and mosquito-borne haemorrhagic fever. Once widespread in most of the Western Hemisphere, yellow fever remains endemic to forested areas of tropical America and to West and Central Africa. The reason for the absence of yellow fever throughout most of the Orient, where *Ae. aegypti* is prevalent, is still unknown. Dengue is endemic to certain regions of the South-West Pacific, New Guinea, Indonesia, India, and countries bordering on the South China Sea and the Caribbean area. In South-West Asia and the Western Pacific area, epidemics of haemorrhagic fever and certain dengue-like diseases have occurred with alarming frequency since 1956.

Bionomics

The breeding habitat of *Ae. aegypti*, like that of several other species of the subgenus *Stegomyia*, was originally tree holes, but this mosquito has become more or less domesticated and has adopted water containers as breeding places. Oviposition, usually in artificial water receptacles in or near human habitations, begins on the sixth or seventh day after emergence and on the third or fourth day after a blood meal. Eggs are deposited on the wet sides of a container at, or just above, the surface of the water in batches of 300–750 eggs have been laid. Breeding habitats include old tires, jars, bottles, cans, jugs, urns, roof gutters, discarded automobiles or domestic or commercial appliances, neglected toys, drinking-water jars, water-plants, neglected flower vases, animal drinking pans, basement sumps, elevator pits, and other places where water is trapped. Occasionally, eggs or larvae are found in tree holes, axils of leaves, crab holes, and storm-sewer basins. The female does not lay eggs in pools or puddles with earth walls but seeks concealed sites which are easily overlooked during cursory inspections.

Embryonic development is completed in 72 hours in temperatures between 77°F and 86°F (25–30°C). The eggs require a moist substrate for 48 hours after their deposition in order to become resistant to subsequent drying. Properly conditioned eggs will hatch a few minutes after being submerged in a suitable medium (i.e., water with a reduced oxygen content resulting from bacterial action on organic material in the water). Some eggs may remain viable in the dry state for at least a year; not all eggs hatch on the first submersion and some may hatch only after several wettings. In the temperate climate of southeastern USA there is evidence of overwintering eggs with a delayed response to initial hatching stimuli. During the early summer when day-length is increasing, a high proportion of eggs hatch on first submersion. As the day-length decreases, there is a progressive fall in the proportion of eggs that hatch at the first soaking. In addition to resisting desiccation, eggs can survive extremes of temperature that would be fatal in other stages. Some eggs have survived a 5-minute exposure at a temperature of 118°F (48°C), a 25-hour exposure at 12°F (−11°C), and a 1-hour exposure at 2°F (−17°C).

The period of larval development depends on the temperature of the water, the population density, and the availability of food. Larvae that are not crowded and that have adequate food complete their development to pupation in 5–7 days when the water temperature is within the range 77–84°F (25–30°C); at 41–46°F (5–8°C) larvae survive only a short exposure period and continued exposure at 50°F (10°C) is fatal. Larvae are injured by water temperatures above 90°F (32°C) and fail to complete development at 97°F (36°C). Crowding of larvae leads to delayed development and increased mortality. Larvae have survived for 13 days on moist earth and although they are most frequently found in habitats containing clean water they can tolerate considerable concentrations of acid, alkali, or salt. When disturbed, even by a shadow, the larvae dive to the bottom of the container where they are easily overlooked; if the container is emptied, a large proportion of the larvae may remain in the small amount of water and debris left in the bottom, and some may survive. The container should therefore be inverted if possible.

The pupal stage is completed in a period of 1–5 days depending on the temperature of the water. At 80–90°F (27–32°C) males require an average of 1.9 days, and females 2.5 days. Some pupae survive a 5-minute exposure to 117°F (47°C) and an 82–100% survival has occurred after exposure at 40°F (4.5°C) for 24 hours. Pupae kept on wet filter-paper for 24 hours were able to develop into adults when they were replaced in water. Like larvae, pupae are easily alarmed and react by dropping to the bottom of the container but return to the surface more rapidly than larvae.

Just prior to the emergence of the adult, the pupal cuticle splits along the mid-dorsal line of the thorax. The new adult takes about 15 minutes to free itself from the pupal skin and then rests on the old skin and the water surface for about an hour while the wings expand and the exoskeleton hardens. The antennal hairs of the male become functional as hearing organs 15–24 hours after emergence; the terminal segment rotates through 180° during the first 1–2 days and copulation then becomes possible. Adults are killed by exposure at 43°F (6°C) for 24 hours and by
prolonged exposure at 45-48°F (7-9°C). At the upper temperature range, adults are killed by continuing exposure at 97°F (36°C) or short exposure at 105°F (40°C). Adult longevity varies with temperature, humidity, food, and reproductive activity. At 50°F (10°C) and 100% relative humidity unfed adults live about 30 days. The life span is less at higher temperatures and lower relative humidities. Longevity is increased if the mosquito feeds on honey, and females that have not had a blood meal are known to have survived for 102 days. When offered a host animal, normal females will feed on the second or third day after emergence. The average age of blood-fed females is about 62 days and for females that have not taken a blood meal, 82 days. Since the shorter life span of blood-fed females does not hold for virgin females, it appears that the shorter survival time may be related to oviposition.

A single mating, usually occurring within 2-3 days of emergence, ensures fertile eggs during the entire reproductive life of the female. Copulation normally takes place in flight, and lasts less than 1 minute. Blood meals are essential for egg development and oviposition.

Feeding occurs mainly during the daylight hours with maximum activity near dusk but there is a secondary peak in the early morning. Adults may fly up-wind when the wind speed is not more than 3-4 miles per hour (1.3-1.8 metres/second). At higher speeds they fail to make progress and generally seek shelter. The flight range is usually quite small, apparently by preference rather than an inability to fly farther. Adults avoid light and seek resting places that are sheltered from the sun and wind. In a room they are found in dark places, under furniture or behind pictures for example; in closets they prefer dark rather than light garments as resting sites.

Control

Since *Ae. aegypti* is a domesticated species, usually breeding in water in artificial containers near human dwellings, methods for its control are more easily stated than accomplished. The basic requirement is to find and eliminate habitats. The careful maintenance of yards and vacant lots will prevent the accumulation of discarded articles that may catch rain water and become breeding sites for many generations of mosquitoes. The first action should be to make a methodical and widespread search for water containers. Whenever possible, articles of value should be stored under shelter, or in such a way that water does not readily collect in them. When receptacles cannot be eliminated, or when the water is needed for some purpose, one or more of the following measures should be taken: (1) mechanically excluding adult mosquitoes by covering or sealing containers (for *Ae. aegypti* this entails stopping all openings larger than those of a BS 200 (750-μm) screen); (2) frequently emptying and scrubbing containers such as animal drinking pans, and flower vases; (3) stocking underground cisterns, wells, and concrete fish or lily ponds with mosquito-eating fish such as *Gambusia*; or (4) regularly treating the inside of any type of water container with safe and effective insecticides. Insecticide may also be applied to other surfaces around the containers being treated; this is known as perifocal or premises treatment. However, the value of extensive applications of insecticides that have little adulticidal activity, Abate for example, is questionable.

Larviciding

Various chlorinated hydrocarbons and organophosphorus insecticides have been used as laricides in suspensions, solutions, granules, and solid formulations. Suspensions and emulsions of DDT (1.25-5.0%), dieldrin (1.25%), aldrin (5%), dieldrin (2.5%), fenthion (1.25%), Gardona (2.5%), or Abate (1.75%) are suitable for treating non-potable water. Abate on sand granules is used to treat potable water, the low level of toxicity to mammals making this compound the insecticide of choice for the treatment of drinking water.

The general procedure is to treat the breeding container and adjacent surfaces thoroughly so that the residue will destroy existing and subsequent larval infestations; the residue should also destroy adults alighting on the treated surfaces. Thorough coverage and proper treatment of all sites is essential for eradication. Outdoor applications are made by means of a power-operated sprayer mounted on a truck, or by means of a hand-operated sprayer in areas not accessible to vehicles. To treat indoor sites, such as flower vases and ant traps, a syringe or pipette can be used for liquid formulations; granules or wettable powder can be dispensed with plastic spoons. The standard dosage for flower vases is 1 part per million (ppm) of active ingredient.

In treating potable water containers with Abate, a standard volume of 1% Abate-sand granules (equivalent to 18.5 g) in a plastic spoon is applied to water-storage drums (209-litre capacity). This application rate provides a concentration of 1.0 ppm of the toxicant in 190 litres of water.

The need to re-treat an area depends on the findings obtained from a very thorough inspection or an analysis of oviposition trap data if they are used. Reinfestations may occur not only as a result of the loss of insecticidal activity in treated containers but also from infestations in untreated containers that were overlooked by the sprayman or that have occurred since the area was treated.

The length of time that an insecticide remains effective in any particular container depends on the
active compound, the type of container, and the amount of subsequent dilution arising from rainfall or other sources. In indoor tests, malathion applied at a rate of 2 g/m² in tin cans and in rubber tires provides adequate residual activity for 4 weeks and 11 weeks, respectively; compounds such as Dursban, fenitrothion and Gardona at the same rate of application persisted effectively for 14–19 weeks in tin cans and for more than 19 weeks in tires. Comparative field tests of Gardona and Abate applied as premises treatments in Florida, USA, showed that each was superior to malathion as a larvicide. In 50-gallon (190-litre) storage drums, Abate at a concentration of 1.0 ppm effectively killed *Ae. aegypti* larvae for 15 weeks, whereas 10 ppm of Gardona were required to give a residual activity lasting 11 weeks.

When complete coverage of breeding sites is accomplished, the treatment cycle depends on the toxicant used and upon the rapidity with which untreated containers appear in the area. Elimination of all infestations in a limited area is preferable to the destruction of a high proportion of the infestations in an extensive area; however, vector control programmes at airports and seaport installations must cover the entire port area plus at least a 1/2-mile (1-km) belt of the surrounding area. When coverage is assumed to be complete, experience has shown that a treatment cycle of 2–3 months may be adopted.

**Adulticiding**

In addition to the adulticidal action obtained by perifocal or premises treatment, the undersides of dwellings or structures, which serve as resting places for adult mosquitos, should be treated. DDT (2.5%), dieldrin (1%), lindane (1%), malathion (2.5%), and fenithion (1%) can be used either as emulsions or as suspensions. Treatment should be sufficient to wet the surfaces thoroughly, normally beyond the point of runoff. On flat vertical surfaces, target dosages of 0.5–2 g/m² are feasible but impracticable on irregular surfaces.

The treatment cycle varies with the insecticide used, the nature of the surface, and its exposure to weathering. Residues on surfaces protected from weather persist for periods of 4–5 months, but when surfaces are exposed to sun and rain the residual activity may decay within 1–3 weeks.

Only dichlorvos has been used as a residual fumigant applied to water-storage containers, principally cisterns. The commercial preparation contains 20% of the toxicant in resin and each dispenser weighs 100 g. The dispenser is fastened securely by strong wire to the roof of the cistern, usually to the framework of the lid, to the hinge, or to some other support, and hangs 8–9 cm below the top of the cistern but above the water level. The dispenser should never be allowed to come into contact with the water.

The number of dispensers per cistern is one per 3–8 m³ and they should be replaced at intervals of about 6 weeks; their effective life is longer when the water is at, or above, the 50% capacity level.

**Resistance**

Physiological resistance to DDT and dieldrin has been observed in the Caribbean area and South America, West Africa, and South-East Asia. In areas where resistance to DDT has been confirmed, one of the other insecticides mentioned above may be used.

**Evaluation**

Mosquito control organizations often depend on light traps, larval surveys, landing-rate counts, and public complaints to evaluate their operations. *Ae. aegypti* is not attracted to light traps and the public is often unaware of its presence. The traditional methods for evaluating eradication campaigns include elaborate procedures that are not only expensive but require numerous well-trained personnel. The recently developed oviposition traps for evaluating *Ae. aegypti* control operations provide a more sensitive and efficient means of detecting the presence of this mosquito than do the traditional larval surveys.

**Genus CULEX LINNAEUS**

**General**

The genus *Culex* includes about 300 species, most of which occur in the tropical or subtropical regions of the world. Among the species of this group are those known as house mosquitos because of their close association with man. The group includes several important pest species and vectors of disease.

*Culex* mosquitos breed in quiet waters of almost all kinds from artificial containers and catchment basins of drainage systems to large bodies of permanent water. Water in which there is much organic material, including sewage, is often favoured. The eggs are deposited on the surface of the water in rafts, each of which may contain 100 or more eggs. The rafts remain afloat until hatching occurs 2–3 days later. Breeding continues through the warm season and there are several generations a year. The adult females are inactive during the day and are often found resting in shelters. Biting usually occurs at night. The flight range varies from about 1 mile (2 km) in some species up to 10 miles (16 km) in others. Light traps, biting collections, and resting station collections are useful methods of sampling.

The genus contains efficient vectors of a number of arthropod-borne types of viral (arbovirus) encephalitis
and filariasis. The control of both types of disease is based on the control of the vector but in filariasis the human hosts are also treated.

**Control**

The chemical methods of control are the same as those for other mosquitoes, particular attention being given to the type of breeding habitat (see Annex 2, Table 2). Pre-hatching treatments cannot be used where fish or wildlife are involved but in many instances fish predators (Gambusia, for example) are very effective in water that is not highly polluted. Residual insecticides are used for the treatment of catchment basins or storm drains along roads.

**GENUS ANOPHELES MEIGEN**

**General**

Mosquitos of the genus Anopheles are the exclusive vectors of human malaria, the most important infectious disease of man. In addition to transmitting malaria, anophelines also transmit filariasis and several virus diseases, although non-anopheline species are the more important vectors of these diseases. Malaria only is considered in this account of the genus Anopheles.

Malaria parasites of man include four species of the genus Plasmodium—namely, *P. vivax*, *P. falciparum*, *P. malariae*, and *P. ovale*.

Although these plasmodia normally infect man, certain species of non-human primates also may be infected under special circumstances; conversely, certain simian (monkey) malarias also may be transmitted to man. However, only the four species of *Plasmodium* species mentioned above are of practical significance in human malaria. The malaria parasites undergo a very complicated life cycle in the blood of infected persons and in the body of various species of mosquito of the genus *Anopheles*.

**Species and distribution**

Approximately 350 species of Anopheles mosquitoes occur throughout the world. Of these, more than 60 species are known to be vectors of human malaria (see Table 1). It is possible that all anopheline species are capable of transmitting various plasmodia but under natural conditions most species have never been shown to be involved in transmission and, hence, are considered to be unimportant. Among the factors determining whether a particular anopheline is a vector are longevity and the frequency of feeding on man. A

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**TABLE 1**

**PRINCIPAL SPECIES OF ANOPHELES KNOWN TO TRANSMIT MALARIA, AND REPORTED RESISTANCE TO INSECTICIDES**

<table>
<thead>
<tr>
<th>Species</th>
<th>Resistance</th>
<th>Species</th>
<th>Resistance</th>
<th>Species</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>aconitus</td>
<td>D, D1</td>
<td>hancocki</td>
<td>—</td>
<td>nili</td>
<td>D1</td>
</tr>
<tr>
<td>albimanus</td>
<td>D, D1, M</td>
<td>hispaniola</td>
<td>—</td>
<td>nunetzovari</td>
<td>D</td>
</tr>
<tr>
<td>albitorsis</td>
<td>D, D1</td>
<td>jeyperiensis</td>
<td>—</td>
<td>patoni</td>
<td>—</td>
</tr>
<tr>
<td>annulatus</td>
<td>D, D1</td>
<td>(including candidiensis)</td>
<td>—</td>
<td>phanensis</td>
<td>D, D1</td>
</tr>
<tr>
<td>aquasalis</td>
<td>D, D1</td>
<td>karwari</td>
<td>—</td>
<td>philippinensis</td>
<td>D1</td>
</tr>
<tr>
<td>argyritorsis</td>
<td>—</td>
<td>kochi</td>
<td>—</td>
<td>pseudopunctipennis</td>
<td>D1</td>
</tr>
<tr>
<td>aztecus</td>
<td>—</td>
<td>koliensis</td>
<td>—</td>
<td>punctimacula</td>
<td>—</td>
</tr>
<tr>
<td>boaei</td>
<td>—</td>
<td>labranchiae</td>
<td>D1</td>
<td>punctulatus</td>
<td>—</td>
</tr>
<tr>
<td>balabacensis</td>
<td>—</td>
<td>(including atroparvus)</td>
<td>D1</td>
<td>quadrimaculatus</td>
<td>—</td>
</tr>
<tr>
<td>bancroftii</td>
<td>—</td>
<td>lelter</td>
<td>D1</td>
<td>sacharovi</td>
<td>D, D1</td>
</tr>
<tr>
<td>barbirostris</td>
<td>D1</td>
<td>leucosphyrus</td>
<td>—</td>
<td>sergentii</td>
<td>D1</td>
</tr>
<tr>
<td>bellator</td>
<td>D1</td>
<td>maculatus</td>
<td>—</td>
<td>sinensis</td>
<td>D1</td>
</tr>
<tr>
<td>claviger</td>
<td>—</td>
<td>maculipennis</td>
<td>D1</td>
<td>stephensi</td>
<td>—</td>
</tr>
<tr>
<td>cruzii</td>
<td>—</td>
<td>(including meseae)</td>
<td>D1</td>
<td>(including mysorensis)</td>
<td>D, D1</td>
</tr>
<tr>
<td>culicificacies</td>
<td>D, D1</td>
<td>manguinys</td>
<td>—</td>
<td>strodei</td>
<td>D1</td>
</tr>
<tr>
<td>darlingi</td>
<td>—</td>
<td>melas</td>
<td>—</td>
<td>subpictus</td>
<td>D, D1</td>
</tr>
<tr>
<td>farauti</td>
<td>D, D1</td>
<td>minus</td>
<td>—</td>
<td>sundacius</td>
<td>D, D1</td>
</tr>
<tr>
<td>fluviatilis</td>
<td>—</td>
<td>merus</td>
<td>—</td>
<td>superpictus</td>
<td>—</td>
</tr>
<tr>
<td>freeborni</td>
<td>—</td>
<td>(including flavirostris)</td>
<td>D1</td>
<td>tesselatus</td>
<td>—</td>
</tr>
<tr>
<td>funestus</td>
<td>D1</td>
<td>moaucheti</td>
<td>—</td>
<td>umbrusus</td>
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</tr>
<tr>
<td>gambiace complex (species A, B, C)</td>
<td>D, D1</td>
<td>multicolar</td>
<td>—</td>
<td>varuna</td>
<td>—</td>
</tr>
</tbody>
</table>


* Resistance: D = DDT resistance; D1 = dieldrin/gamma HCH resistance; M = malathion resistance; — = no resistance reported.
species that normally lives near man, feeds readily or preferably on man, and lives for several weeks or longer is more likely to be a major vector than a species that lives away from human habitation, feeds by preference on non-human hosts and dies within a relatively short time. Another significant, but not always fully understood, fact is that a particular species of Anopheles may be an important vector in one area but in other areas, even if it is prevalent, it may not be important in the transmission of malaria. The presence of a known malaria vector in any area does not necessarily mean that malaria is, or has been, present in that particular place.

Although most frequent in tropical and subtropical regions, anopheline mosquitoes are found throughout most temperate areas, and the range extends even into arctic areas. Certain species are found breeding 400 m below sea level (near the Dead Sea in Israel and Jordan) and others at altitudes above 2,500 m (South America, Africa, Asia). These mosquitoes, therefore, are extremely adaptable and can breed in most places where suitable water for the immature stages is found. A large area of the Pacific Ocean, roughly bounded by and including New Zealand, Juan Fernandez, the Galapagos Islands, Hawaii, Midway Island, Palau Island, the Caroline Islands, the Gilbert Islands, Samoa, Fiji, and New Caledonia, is free from Anopheles mosquitos and there is no indigenous malaria.

The altitude at which anophelines are found is of significance in control programmes. An. minimus flavirostris, for example, normally lays its eggs in foothill streams. Therefore, in the Philippines, where this species is the predominant vector, malaria is most common in the foothill areas. An. albimanus in Haiti is seldom found above a height of 500 m and, for this reason, anti-Anopheles measures are carried out mainly in areas below that altitude. There is some risk, however, in using altitude alone as the main criterion for applying control measures; seasonal climatic variations may lead to changes in the breeding habits of anophelines. For example, An. albimanus in Central America is sometimes found above 1,000 m. In Ethiopia, malaria seldom is found above 1,600–1,700 m since environmental conditions above that altitude are unsuitable for the development of An. gambiae. In 1958, however, excessive rainfall, combined with abnormally high temperatures and a high relative humidity, produced conditions conducive to the development of An. gambiae and, as a result, a catastrophic epidemic of malaria occurred. It was estimated that there were 3 million cases and 150,000 deaths during the epidemic. Thus climatic conditions and other factors, affecting the breeding of anophelines must be taken into consideration in any malaria programme in which vector control is the principal method of controlling the disease. Unless all conditions are considered, control may fail when unexpected factors arise.

Aquatic stages

Eggs of anopheline mosquitoes are usually laid individually on the surface of water or at the margin. A blood meal is required by most species before oviposition takes place. The eggs, which are dark in colour, are usually boat-shaped, pointed at one end, and have so-called “floats” on the sides. A female may lay from several hundred to more than a thousand eggs; the average for An. quadrimaculatus is more than 600 per female. Anopheline eggs are often arranged in geometrical, mesh-like patterns on the water surface, or they may be laid side by side. Newly laid eggs usually require an incubation period of 2–3 days before they hatch, although An. albimanus eggs may remain dormant for 16 days or even longer on mud. When flooded, dormant An. albimanus eggs hatch within 3–4 minutes. Some species of anophelines (e.g., An. walkeri) overwinter in the egg stage.

Anopheline larvae may very easily be recognized by their characteristic appearance as they float horizontally on the surface of the water. The larvae have no breathing tubes, but breathe through inconspicuous spiracles or holes at the tail end. Larval habitats vary from species to species but are frequently exposed to sunlight and commonly, found in association with emergent vegetation, such as grass, or mats of floating vegetation or algae. The larval stages of An. bellator and An. cruzii are commonly found in water retained in the axils of arboreal bromeliads and if the bromeliads are eliminated these species disappear.

Artificial containers, such as pots or tubs, are not suitable for most anopheline species although An. stephensi in India is found in cisterns, wells, tin cans, earthenware pots, and other man-made receptacles. Some species readily breed in temporary rain pools and in small puddles of water, such as those found in the imprints of animals’ hoofs. Large expanses of open water free from vegetation seldom support anopheline larvae, although breeding may occur in quiet pools and pockets of relatively still water along the margins of lakes, streams, and rivers. Although most species prefer clean, fresh water, larvae of some species, including An. albimanus, An. gambiae melas, An. labranchiae atroparvus, An. sacharovi, An. stephensi, and An. sundaicus, may be found in brackish water. The larvae of certain species, e.g., An. stephensi, An. punctipennis, An. albimanus, and An. vagus, may be found in polluted water as well as in clean water. In short, standing or very slowly moving water of almost any kind should be regarded with suspicion, and should not be considered unsuitable for anopheline breeding.
unless frequent and continuous larval surveys have produced negative results.

Larvae feed principally on minute particles of organic matter floating in the surface film, suspended in the water, or adhering to submerged objects. During a period of 4-10 days (sometimes longer) the larvae pass through four instars before they moult and become pupae. The pupal skin bursts after about 3 days. The adult mosquito emerges, crawls on to vegetation and dries its wings, then flies to a suitable resting place, which is usually cool and dark and not far from where it emerged.

Adults

The adult anopheline mosquito moves about readily and may live for several weeks or more. Anophelines often overwinter in this stage. Adults normally rest during the daylight hours and seek secluded natural resting places such as clumps of vegetation, hollow trees and logs, large exposed tree roots, and holes and crevices in rocks and soil; many species also enter man-made structures such as barns, animal shelters, houses, motor-cars, railway wagons, aircraft, and ships. Protected places with a high humidity and little movement of air are preferred.

Distances normally travelled by anopheline mosquitos under natural conditions vary according to the species, wind speed, and topographical features. Adults of some species may not move more than a few hundred metres from the breeding sites; An. pharoensis, on the other hand, has been found in large numbers in Egypt 29-45 km from the nearest breeding place. Such migrations have been noticed, especially during nights with a full moon, in a downwind direction. Generally speaking, for quarantine purposes, the control of anophelines within 2 km of docks, parking sites for aircraft or other systems of transportation, and storage areas where migrating mosquitos may rest, should provide adequate protection. Since many anophelines are poorly attracted to light, light-trap catches are often not a good indication of population size. Night biting collections, captures in traps baited with animals or human subjects, and collections of resting adults are the most satisfactory methods of collecting adult anophelines.

Resting places are frequently inside houses; female mosquitos commonly enter a house after dark, take a blood meal, and then, being heavily engorged with blood, fly to a near-by wall or ceiling. The mosquitos may rest on clothing hanging on a wall, on the back or underside of pieces of furniture or pictures, etc. The females frequently prefer the lower portions of the interiors of houses where temperatures are lower and the humidity is higher.

The adult female often takes its first blood meal the night after it emerges from the pupal stage. Feeding occurs, almost without exception, between dusk and dawn, but anophelines may feed during daylight hours in densely shaded woodland or dark interiors of shelters and houses. The feeding habits vary greatly, some species feed readily on either man or animals, but some species prefer a non-human host and will feed on the animal even if a human host is available, and the converse may be true of other species.

Since all these characteristics are of great importance in control programmes, the habits of the vector species must be well understood by teams engaged in malaria control or eradication.

Dispersal

Anophelines have frequently been found in aircraft and ships. In the 1930s Brazil was invaded by An. gambiae from Africa, probably transported by ship. This invasion resulted in a dramatic epidemic of malaria that ended only when a very large and expensive campaign resulted in the eradication of this mosquito from Brazil. In 1966, An. stephensi was recorded for the first time in Africa, having apparently been carried by aircraft from Saudi Arabia to Egypt. An. subpiches indefinitus was first reported to be present on Guam in 1948; until that time the island was believed to be free from anophelines. In 1969, 6 cases of malaria were reported from Guam and at least one of these cases was transmitted locally on this previously malaria-free island.

Control

Anopheline mosquitos are generally controlled in the larval and adult stages. Larval control is aimed at breeding sites and may be accomplished either by eliminating the favourable conditions in a habitat or by treating the water with an insecticide to destroy the larvae and pupae.

Not all anophelines are important in the transmission of disease and therefore water containing undetermined species of anopheline larvae is not necessarily the source of a vector species. When the larval breeding site has been identified, it is necessary to select the best control method. If the water can be eliminated by draining or filling, this should be done. However, the water may have an economic or aesthetic value, or elimination may be too expensive. In such circumstances, it may be possible to clear away the vegetation or to introduce fish, such as Gambusia, to feed on the larvae. In coastal areas that are subject to tidal action, control may possibly be effected by changing the salinity of the water. A brackish-water breeder such as An. sundaeus sometimes can be controlled by installing
tidal gates that prevent sea water from entering the breeding sites. If the species prefers fresh water, sea water could be used to flood the area frequently, thereby making the site unsuitable for breeding.

The most commonly used materials for controlling larvae are mineral oil, Paris green, and the newer organic insecticides such as malathion, fenthion, and Abate. The application of oil to water is one of the oldest known mosquito control measures. Diesel or fuel oils are commonly used, but special oils also are prepared for control purposes. Paris green is used in a finely ground mixture with a diluent or carrier such as road dust, talc, or other material. Anti-larval measures are especially important in airport or harbour areas where anopheline breeding sites that cannot be permanently eliminated are within flight range of aircraft or ships. In most situations, the newer organophosphorus or carbamate larvicides cost less than oils or Paris green. Abate has the lowest toxicity to mammals and its use offers the greatest safety factor.

Application of larvicides may be made by hand-operated or power-driven fogging machines, sprayers, or dust blowers, or by aircraft. Ultra-low-volume (ULV) aerial applications of insecticide are used to treat larval habitats, but both larval and adult anophelines may be killed, depending upon the insecticide used, the species of mosquito, and the type of breeding place. For example, the Tennessee Valley Authority in the USA uses 4.75 US fluid ounces of 43% Abate per acre (350 ml/ha; equivalent to 0.004 lb of Abate per acre or 4.5 g/ha) for the control of An. quadrimaculatus larvae.

In most cases, larvicidal treatments for other species of mosquito will also be effective against anophelines. In situations where the vector cannot be eliminated permanently, slow-moving and standing water of any kind within a minimum distance of 2 km from airport loading and parking areas, docking installations at seaports, and storage sites for vehicles or conveyances (such as empty freight containers) used in international traffic, should be larvicided regularly.

Adult anopheline mosquitos are most commonly controlled by spraying houses, as recommended for the world-wide malaria eradication programme. DDT is the insecticide of choice and dosages of 1–2 g of pure DDT per square metre are applied several times (1–3 or more) a year to walls and other surfaces where mosquitos rest. DDT is normally applied as a water suspension of 75% DDT-water-dispersible powder, and is sprayed from stirrup pumps or hand-compression sprayers.

Malathion and propoxur, and to a lesser extent dieldrin or gamma-HCH, are sometimes used as residual insecticides in place of DDT, especially in areas where DDT resistance is encountered. Dosages and the average duration of effectiveness are given in Annex 2, Table 1. Malathion and propoxur are considerably more expensive than DDT and the other chlorinated hydrocarbon insecticides but may provide effective control of mosquitos in areas where there are problems of resistance.

Space treatments with fogs, dusts, and mist sprays applied by power-operated equipment on the ground or by aircraft, are effective against adult anophelines as well as most other species of mosquito. If adequate control of breeding is established in and around airports, seaports, and other areas involved in international traffic, neither control measures of this type nor residual spraying will usually be required for anopheline mosquitos. If, however, surveys reveal the presence of adult anophelines or other vector species in quarantine areas, space treatments are effective in quickly eliminating the infestation. This method of control depends upon the particles or droplets of insecticide impingeing on a mosquito as the cloud of insecticide drifts through the treated space. The effect of a space spray is quite transitory if the treated area is subject to a continuous flow of air from outside. Unless prompt measures are taken to eliminate or control mosquito breeding in and around the affected areas, it will be necessary to repeat space treatments at very frequent intervals, and this may be expensive.

In aircraft and small boats, anophelines may be destroyed by sprays of pyrethrum or other insecticide applied by means of an aerosol dispenser. In large ships, insecticidal fogs may be applied with power-operated equipment.

Anopheline mosquitos may develop resistance to the chlorinated hydrocarbon insecticides, especially after several years of exposure. Resistance to dieldrin and gamma-HCH is most common in about 35 species of anophelines but resistance occurs in certain areas only and not necessarily throughout their entire range; about 14 species are resistant to DDT. Table 1 indicates which of the principal malaria vectors are resistant to various insecticides. So far, resistance to organophosphorus insecticides has been negligible but could increase as more of these materials are used; resistance of An. albimanus to malathion and propoxur has been detected in limited areas in Central America. Insecticide resistance is most common in agricultural areas where insecticides are used extensively to protect crops against insect pests, the anophelines being affected also.

The susceptibility of mosquitos to insecticides may change in the course of time and with prolonged exposure to various compounds, and there may also be variations between larval and adult stages with respect to the same compound. Periodic tests should therefore be made to determine the susceptibility of larvae and adults of anopheline and other types of mosquito to the insecticides routinely used in control operations.
OTHER MOSQUITOS

Many other types of mosquito will probably be found in some of the port areas from time to time. Such mosquitoes may appear from breeding sites within the controlled zone or they may enter the area from breeding sites some distance away. The wide variety of breeding sites used by different species of mosquito sets a limit on the generalizations that can be offered; all mosquitoes, however, require water for the aquatic stages. Control measures are generally not intended to be effective against a single species only but rather against all species that, at some stage, occupy a particular ecological niche at the time control measures are applied. Thus the removal or chemical treatment of water containers for the control of *Ae. aegypti* will have a direct effect on all species of mosquito that occupy the same habitats.

Control in an area where there are many species of mosquito requires (1) thorough and repeated surveys of all areas of water and intense sampling of adults, and (2) the positive identification of all mosquito larvae and adults found in the surveys. The control worker should then examine the extensive literature to discover what is known about the biology of each species. If necessary, expert advice should be requested, particularly for assistance with identifications.

FLEAS

General

Fleas are small, wingless insects belonging to the order Siphonaptera (Aphaniptera). The order is divided into two superfamilies, Pulicoidea and Ceratophylloidea which together contain some 17 families and approximately 1500 known species.

The adults are laterally compressed, heavily sclerotized, blood-sucking ectoparasites of warm-blooded animals. The body bears numerous, backwardly projecting spines and hairs, and the legs are equipped with strong grasping claws—features that enable fleas to move quickly between the hairs or feathers of their host. The legs are well developed and the third pair is strongly modified for jumping, the third thoracic segment providing the musculature and the structural strength for this activity.

Life cycle

Information on the life history of most species of flea is limited, but many studies have been made on species associated with man, such as the human flea (*Pulex irritans*) and the cat flea (*Ctenocephalides felis*), and other species that are vectors of human disease, including *Xenopsylla cheopis*, *X. astia*, *X. brasiliensis*, and *Nosopsyllus fasciatus*. The life cycle of *X. cheopis*, illustrated in Fig. 18, can be regarded as typical, although certain details differ from species to species.

The eggs of *X. cheopis* are laid in scattered clusters in or around the nest of the host animal. They are small (0.4-0.5 mm), oval, and glistening white when newly laid, changing to a dull yellowish colour with age. The eggs of some species are attached to the substrate by means of a sticky material that adheres to them when they are laid, but the eggs of *X. cheopis* are usually dry and unattached.

Most species of flea, including *X. cheopis*, have three larval stages. The first instar has an egg burster on the upper surface of the head capsule, but in other respects the three stages are similar. The larvae are small, (2-6 mm) worm-like insects with chewing mouthparts, a hardened (sclerotized) head capsule, and soft thoracic
and abdominal segments with very lightly sclerotized dorsal and ventral plates. Each body segment is equipped with long, backwardly directed hairs, giving the larva a bristly appearance. The characteristic jerky forward movement of the larva is achieved by hooking the mandibles into the substrate, drawing the body towards the head, then propelling the body forward with the help of two small, fleshy appendages at the tip of the abdomen.

Final-instar larvae spin a silken cocoon which incorporates bits of debris. Inside the cocoon, the larva pupates and undergoes a metamorphosis into the adult. During the metamorphosis, the appendages (legs, antennae, etc.) are free of the body.

A single female *X. cheopis* will produce 300–400 eggs in its lifetime. By contrast, female *C. felis* may produce as many as 1,000 eggs, which are scattered about in the general environment rather than in a nest; some other species produce a total of only 100–200 eggs. Eggs hatch in 2–14 days, depending on the environmental conditions.

Under optimal conditions the complete life cycle may take 2–3 weeks but the period may be prolonged, particularly by lower temperatures, suboptimal conditions of humidity, and inadequate diet. Adults may remain in the cocoon for long periods after emerging from the pupal stage. In some species, this resting stage occurs in response to adverse conditions, low humidity in particular, and the flea emerges only when conditions are favourable or when a potential host disturbs the cocoon.

**Food requirements and reproduction**

*X. cheopis* adults require a blood meal from a suitable host before reproduction occurs, and the fleas take a blood meal within 1–3 days after their emergence. Although eggs are occasionally laid before a blood meal is taken, reproductive activities are essentially linked with feeding and oviposition usually occurs 1–4 days after the first blood meal.

The feeding process is fairly typical of most blood-feeding insects with piercing and sucking mouthparts. After settling on a host, a starved flea immediately begins to probe the surface of the skin. The flea then inserts the mandibles and hypopharynx into a suitable capillary or small blood vessel and active feeding begins, blood being drawn into the gut by the vigorous action of the salivary pump. In some species, such as *P. irritans*, feeding does not always stop after the gut becomes distended but may continue, blood and faeces being extruded from the hind gut; this is responsible for the accumulations of dried deposits of blood and faeces frequently observed in the fur and nests of infested hosts.

A number of species of flea have been successfully reared in the laboratory on relatively simple synthetic diets containing essential amino acids, fats, minerals, and vitamins. Larval diets such as powdered dog food, laboratory rat food, powdered dried blood, and powdered casein plus brewer’s yeast have been found to maintain colonies of *X. cheopis*, *C. felis*, *Malariaeus telchinum*, and *Orchopeas howardi*. The food materials are dispersed in a suitable inert medium such as non-abrasive sand or sawdust. Repeated attempts to rear certain species such as *Monopsyllus wagneri* have failed, possibly because of deficiencies in the dietary media.

**Relationship of fleas to man and disease**

Fleas are the primary vectors of bubonic plague and murine typhus, both of which have made a tremendous impact on the history of man. Fleas also are important enzootic vectors of disease in wild or commensal rodent populations. Widespread epizootics of plague periodically decimate rodent populations in parts of Asia, Africa, and the Americas, and directly or indirectly affect man.

In addition to their capacities as vectors of disease, fleas associated with man and domestic animals are serious pests, causing suffering and economic loss. Following its introduction into Africa from South America in the late 19th century, *Tunga penetrans*, a flea that burrows into the skin, caused thousands of human deaths as a result of secondary infection and this species is still a serious pest both in Africa and the Americas. Dog and cat fleas also may transmit the dog tapeworm (*Dipylidium caninum*) and rodent tapeworms (*Hymenolepis deminuta* and *H. nana*).

Fleas become infected with plague bacilli when they ingest human or animal blood containing plague organisms. The plague bacteria may either disappear or remain in the gut, eventually multiplying and causing the formation of a fibrous mass that incorporates large numbers of bacteria. Such “plague masses”, particularly when they form in the proventriculus, may lead to partial or complete blockage of the digestive tract. Although such fleas die from dehydration after a few days or a week, they are particularly dangerous vectors because their repeated attempts to feed result in blood and large numbers of bacteria being regurgitated into the bite wound.

**Important vectors**

The risk of a flea becoming infected and transmitting plague bacteria varies greatly from species to species. While the importance of any one species cannot be disregarded, relatively few species have the capability of initiating and maintaining murine plague epizootics.
that lead to widespread epidemics of human bubonic plague. A list of important vectors likely to be found in ports is given in Table 2. *X. cheopis* is generally considered to be the most important plague vector for man, not only because of the ease with which it becomes infected and blocked, but also because of its close association with man, its tendency to bite man when starved, the fact that it is well adapted to urban conditions, especially to seaports, and its world-wide distribution. *X. brasiiliensis*, an equally efficient vector, is important in parts of Africa, South America, and India where it is found mainly in rural areas and villages. On the other hand, *X. astia*, which is closely relative to *X. cheopis*, is considered to be a relatively poor vector, and so are several other fleas such as *C. felis*, *C. canis*, and *P. irritans*. When present in sufficient numbers, *N. fasciatus*, the northern rat flea, is capable of maintaining a murine plague epizootic but human cases resulting from such epizootics have been infrequent.

Although large numbers of fleas associated with wild rodents have been found to be infected with plague organisms in nature, the vector capabilities of only a few species have been studied. Marked differences in capacity to transmit plague have been found among species studied in the laboratory; some appear to transmit the organisms almost as well as *X. cheopis* while others appear unable to transmit. However, such laboratory results should be interpreted cautiously in relation to natural events. The role played by any particular species is influenced by many factors, which, at best, are poorly understood. Among the extrinsic factors that influence the ultimate vector capability of a particular species of flea are temperature, relative humidity, abundance in any locality, the host species involved, the abundance and population density of host species, and the characteristics of the strain of plague organism in relation to both the host species and the flea. Thus, *M. telchinum*, a poor vector of plague in the laboratory, appears to be instrumental in maintaining enzootic plague among meadow mice in California, and *P. irritans*, a weak transmitter under laboratory conditions, is thought by many workers to be capable of amplifying human plague epidemics, particularly when poor sanitary conditions lead to the occurrence of abundant flea populations.

**Ecology**

The requirements of fleas are, in general, much the same as those of other animals; fleas must have a source of food and a place to live that provides conditions within the tolerance range of the species. Shortage of food may limit the distribution and abundance of fleas, i.e., when suitable hosts are absent or scarce. Temperature and relative humidity may be limiting factors when they are either too high or too low. Because fleas are essentially nest-dwelling insects, factors associated with particular hosts, such as the construction and location of nests or burrows, tend to modify climatic effects by creating microclimatic conditions that are either favourable or unfavourable to a species. Biological factors such as disease, predation, and competition undoubtedly influence the distribution and abundance of fleas but have not been adequately studied.

**TABLE 2**

**IMPORTANT VECTORS OF BUBONIC PLAGUE LIKELY TO BE FOUND IN PORTS AND SHIPS**

<table>
<thead>
<tr>
<th>Vector species</th>
<th>Distribution</th>
<th>Host and habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Xenopsylla cheopis</em></td>
<td>Worldwide, especially between latitudes 35° S and 35° N, but local populations occur much further north</td>
<td>Rattus spp. in cities, ports, ships, and rural situations</td>
</tr>
<tr>
<td><em>Xenopsylla brasiiliensis</em></td>
<td>Africa, South America, and India</td>
<td>Rattus spp. in rural situations, in villages, and to some extent, in ports</td>
</tr>
<tr>
<td><em>Xenopsylla astia</em></td>
<td>South-east Asia and Indonesia</td>
<td>Rattus spp. in fields, villages, and ports</td>
</tr>
<tr>
<td><em>Xenopsylla vexabilis</em></td>
<td>Pacific islands</td>
<td>Rattus spp. predominantly in fields</td>
</tr>
<tr>
<td><em>Pulex irritans</em> a</td>
<td>Worldwide</td>
<td>Wide host range, including man, usually on nesting animals</td>
</tr>
<tr>
<td><em>Nosopsyllus fasciatus</em></td>
<td>Almost worldwide</td>
<td>Rattus spp. in cool temperate areas and in port cities</td>
</tr>
</tbody>
</table>

a Since *Pulex irritans* has frequently been confused with *P. simulans* in North America, distribution may not be worldwide.
Host relationships

The range of host-specificity among fleas may be narrow or extremely broad, some species being adapted to one host only while others are adapted to a wide variety of hosts. In general, the more widely distributed and important disease vectors such as *X. cheopis* and *X. brasiliensis* are capable of reproducing and maintaining a population on any species of host belonging to the same genus. For example, under laboratory conditions, *X. cheopis* will readily feed on *Mus musculus* as well as on *Rattus norvegicus*, *R. rattus*, *R. exulans*, and on other hosts, including man. While individual fleas generally survive on the blood of most of the hosts tested, reproduction is relatively unsuccessful on the blood of *M. musculus* or on that of hosts other than *Rattus* species. At one extreme, the host range of *Echidnophaga gallinacea* includes a broad range of both mammals and birds, its distribution and abundance apparently being affected more by climate, host behaviour, and other factors in the host environment than by the host as a source of food. At the other extreme, the host-specificity of the European rabbit flea (*Spilopsyllus cuniculi*) is so narrow that reproduction takes place only following a blood meal from a pregnant European rabbit.

Host-specificity also involves the adaptation of fleas to conditions in the host’s nest, as well as to conditions in the general host environment. Temperatures in nests and burrows are usually more equable than those outside; and relative humidities are higher. The degree of protection from external conditions offered by the situation and construction of a nest may determine whether or not a host is infested and, if so, by what species of flea. Thus, in Africa and India, *X. cheopis* appears to have an affinity for rats living in burrows; and *X. brasiliensis* for rats living above ground in thatched roofs and walls. Similarly, *X. cheopis* is more frequently found in urban situations while *X. astia* and *X. brasiliensis* are more common in rural areas. Wild rodent fleas demonstrate a similar range of preferences. For example, in California, *Monopsyllus eumolpi* is the commonest flea on chipmunks (*Eutamias*) living in open pine forests but *M. ciliatus* is more frequent on the same hosts living in dense forest.

Climate

A close relationship has been shown to exist between the distribution and abundance of fleas and climate. Among rat fleas, *X. cheopis* appears to prefer a moderately warm, moist climate, whereas *X. brasiliensis* is adversely affected by hot weather. *X. astia* is known to have a narrow range of tolerance for temperature, being restricted by cool or cold climates. *Nosopsyllus fasciatus* is adapted to cool climates but is limited by extreme cold. *X. brasiliensis* and *X. cheopis* appear to have the greatest tolerance for dry conditions, *X. cheopis*, in particular, having a predilection for places such as warehouses and granaries. *N. fasciatus* is associated with damp conditions as well as with cool ones, occurring, for example, in great abundance on *Rattus norvegicus* in rice fields in California. The distribution of many wild rodent fleas is closely tied to relative humidity. *Opisodasys keeni nesius* and *Catallagia wymani*, two North American wild rodent fleas found on the widely distributed species *Peromyscus maniculatus*, are virtually restricted to foggy coastal areas.

The influence of relative humidity is more extreme on larvae than on adult fleas. Flea larvae are extremely susceptible to loss of water through the integument under conditions of low relative humidity but there is a marked difference between various species in this respect. *X. cheopis* larvae cannot tolerate relative humidities below 60% for long periods; however, *X. brasiliensis* is capable of completing its life cycle at a relative humidity of 51%. Tolerance to low relative humidity among North American wild rodent fleas successfully reared in the laboratory was found to be considerably lower; most species required a relative humidity of 70% or more to complete their development.

Control

Long-term control of fleas is best achieved by methods of basic sanitation aimed at reducing or eradicating hosts by eliminating habitats and sources of food. Chemical control should be considered as an emergency measure to control or prevent outbreaks of epidemic disease, as a means of temporarily alleviating a pest problem, or as a preliminary stage in the application of rodent control measures. In some instances, chemical treatments may be the only means of preventing human exposure to plague.

The development of physiological resistance to toxicants by insect populations subjected to continuous treatment should serve as a warning that chemical control is not a satisfactory long-term substitute for good habits of sanitation. Resistance to insecticides has been defined as the development of an ability in a strain of insects to tolerate dosages of toxicants that would be lethal to the majority of insects in a normal population of the same species. Until recent years, DDT has been the insecticide most frequently used to control *X. cheopis*, *X. brasiliensis*, and wild rodent fleas on account of its availability, cheapness, and effectiveness. However, resistance to DDT in *X. cheopis* was detected in South America as early as 1952 and now is known to exist in populations in India, Thailand, and Viet-Nam.
Therefore the use of DDT cannot be recommended until the target flea population has been tested and found to be susceptible. Field test kits have been developed for this purpose by the World Health Organization. 1

Where DDT resistance has developed in flea populations, resistance to other chlorinated hydrocarbons has usually been quick to follow. Nevertheless, dust applications of DDT (5–10%) to rodent burrows, runways, and living areas remain the chief means of controlling *X. cheopis*, *X. brasiiliensis*, and other rat fleas. Carbaryl (3–5%), lindane (1%), and diazinon (2%) in the order listed are effective substitutes for DDT. Names of toxicants and the concentrations for use on pets are given in Annex 2, Table 6. Application should be thorough, since poor control from inadequate dusting may be mistakenly interpreted as resistance. With commensal rodents that do not produce obvious runways or burrows, such as *Rattus rattus diardi* in Java, the entire habitation or building should be treated, especially along walls, overhead beams, and areas around sources of food.

The organophosphorus and carbamate compounds such as diazinon and carbaryl are effective against fleas, such as *P. irritans* and species of *Ctenocephalides*, infesting households and yards. Sprays of lindane (1.0%), diazinon (0.5%), malathion (2%), or ronnel (1%) may be used as spot treatments in houses or for ground treatment outside the house. In enclosed spaces such as cargo containers and closed rooms, dichlorvos resin strips show promise for controlling rat fleas and probably also free-living species. In tests on *X. cheopis* on rats in enclosed cargo containers, one-half of one strip per container (300 ft³; 8.5 m³) gave 98–100% kills in 48 hours at temperatures of 60°F (16°C) or above.

In field trials against wild rodent fleas, carbaryl dusts (2% and 3%) have proved to be effective against the prairie-dog flea, *Opsiocroisits hirsutis*. One treatment of 85–100 g (1.7–2.0 g of active toxicant) per burrow was sufficient to eliminate totally fleas in a treated area for at least 12 weeks. Similar results with carbaryl have been reported against *X. cheopis* in India.

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1 See footnote on p. 7.

**SUCKING LICE**

**General**

Lice have been recorded in association with man since early times. They are common under crowded conditions where personal hygiene is poor or during times of stress, such as wars or natural disasters, when facilities for personal cleanliness are not available. Not only are they extremely troublesome and irritating pests but they are also vectors of two human diseases that, at times, occur as serious epidemics.

Two species of lice commonly infest man, one of which has two forms or subspecies; one species is the crab or pubic louse (*Phthirus pubis*), and the other is the human louse (*Pediculus humanus*) with its two subspecies, the body louse (*P. humanus humanus*), and the head louse (*P. humanus capitis*). These subspecies differ mainly in habit; the head louse lives in the hair of the head while the body louse lives mainly on undergarments near the skin. The two forms can be interbred successfully.

The crab louse belongs to a different genus and is quite distinct from *Pediculus* in appearance and habits, and lives among the body hairs, usually in the pubic region.

**Public health importance of human lice**

Infestations of body lice in economically developed countries are infrequent in normal times but they may be found among individuals with poor personal hygiene; head lice and pubic lice are more common, especially among children in poor neighbourhoods. In developing countries, and especially among communities where families rarely launder their clothes, infestations of body lice are much more common and so are louse-borne diseases. Thus body lice infestation may frequently be a serious problem among refugee populations, prisoners, troops, etc.

The causative organism of epidemic typhus is a minute bacteria-like organism known as *Rickettsia prowazeki*. Lice ingest the organisms when they feed on the blood of infected persons during the febrile period and probably for 2–3 days after. Studies have shown that often half the lice feeding on a typhus patient become infected. The rickettsiae multiply in the midgut of the lice, then invade and destroy the cells lining the gut, which results eventually in the death of the insect.

About a week after a blood meal, rickettsiae appear in the faeces of the lice. Human infections generally arise as a result of lice faeces or crushed lice becoming rubbed into a skin abrasion. Lice excrement dries to a fine black powder that easily becomes air-borne and can cause infection also through small wounds (e.g., scratches) or through the conjunctiva or mucous membranes. The organism remains viable in dried lice faeces for at least 60 days. The disease is apparently not transmitted by biting, unless the mouthparts of the lice are contaminated with organisms from their faeces.
Louse-borne relapsing fever is caused by a spirochaete named *Borrelia recurrentis*. The spirochaetes are especially numerous in the blood of infected persons during attacks of fever. After a louse has taken a blood meal from an infected person, spirochaetes can be found for a few hours in the midgut but nearly all are rapidly digested. Occasionally, however, some spirochaetes persist and appear about a week later in the insect’s body cavity where they often remain during the life of the insect.

Human infection can occur if an infected body louse is crushed and the spirochaetes are released into a scratch or on to a mucous membrane. This not infrequently happens among chronically infested persons.

**Body lice**

Comparative studies have shown that the basic biological characters of head and body lice are closely similar. Both the adults and young of both sexes feed solely on blood, and the methods of feeding and reproduction are identical in the two subspecies.

**Egg**

The egg of the head louse is attached to a human hair with cement and is commonly called a “nit”; the egg of the body louse is attached to fibres of the underclothing. Both kinds of egg are incubated by the body heat and hatch in about a week but hatching is greatly reduced, or completely prevented, by exposure to temperatures above 100°F (38°C) or lower than 75°F (24°C). When the same clothing is worn without laundering during a period of several weeks or months, heavy infestations of body lice may be found. Conversely, if clothing is stored for a month without any treatment, all eggs will hatch or die, and any young that hatch die from lack of food.

**Nymph**

The young is a nymph that passes through three molts and increases in size before becoming a sexually mature adult. The nymphal stages require 8–9 days for lice remaining in contact with the human body but may require up to 4 weeks when the clothing is removed at night. The total life cycle of head and body lice may therefore be completed in about 18 days.

**Adult**

The adult lice differ from nymphs mainly in size and sexual maturity; males are slightly smaller than females. Mating occurs frequently and at any time after the first 10 hours of adult life and, depending upon the temperature, eggs are laid 24–28 hours later. Body lice may lay 9 or 10 eggs each day, a total of 270–300 eggs being produced in a lifetime. Head lice deposit about 4 eggs a day to a total of about 90.

Body lice are completely dependent upon human blood for food. They suck blood for long periods and, while feeding, pass dark red faeces on to the skin. Some of the adults may migrate away from the skin towards the outer garments, and hence to other persons. Both types of body louse can move fairly rapidly and pass from host to host, or from a host to bedding, etc., by simple contact.

**Control**

Control of body lice on small numbers of infested people does not present the same kind of public health problem that arises from general louse infestations among refugees in the disorganized conditions of wars or major disasters. In the latter circumstances, rapid reduction of lousiness is essential in view of the threat of louse-borne disease, and the measures adopted must offer some degree of protection from reinfestation. Under normal conditions, the danger of disease is negligible and the risk of reinfestation is therefore much less serious. Quite different treatment methods can be used and it is desirable that the methods should be widely acceptable to ensure the co-operation of the infested persons.

Treatment for body lice is directed against the clothing of infested persons but in some cases the bedding may also require treatment. In all cases, the hair, head covering, and extra clothing of the infested person should be treated. When clothing cannot be removed it should be treated on the person.

If the lice are not resistant to DDT, dust containing 10% of DDT is the treatment of choice. DDT-resistant lice may be controlled with dusts containing 1% of malathion or lindane. For individual use, dusts containing 0.2% of pyrethrin or 0.3% of allethrin synergized with piperonyl butoxide (1:10) are satisfactory, but these formulations tend to clog the dust blowers during mass treatments. Dust containing carbaryl has also been used in louse control programmes in South Africa.

Powders or dusts are the most satisfactory types of formulation for delousing because they can be applied easily and rapidly. With sifter-topped containers, about 30 g of powder should be used to treat the clothing of each person. The powder is applied evenly over the inner surface of the underwear, special attention being given to the seams. The seams and folds of other garments, including stockings and socks, should also be treated. For the mass treatment of large groups of people, the clothing need not be removed and hand-operated dust blowers or motor-driven air compressors with as many as 10 dusting heads can be used. About 50 g of powder is shaken or blown into the clothing.
through the neck openings, up the sleeves, and all around the loosened waist of trousers. In delousing women, an additional quantity of insecticide may be introduced down the neck of the dress and the application at the waistline omitted.

Control of lice on infested clothing and bedding has been obtained by the following methods: (1) soaking garments, etc., in four times their weight of 1% DDT emulsion; (2) applying 5% DDT emulsion by brush to give a residue of 2 g of DDT per m²; (3) marking clothes in a cross-hatched pattern with wax crayons containing 30% paraffin wax, 63% DDT, and 7% lindane; (4) distributing to each infested family a 500-g cake of soap containing 3% DDT, sufficient for washing the person and clothes for 2 weeks; (5) washing clothes with 7% DDT soap.

One thorough treatment of clothing and bedding with DDT and malathion will often eliminate an infestation. When infestations persist, or reinfections occur, retreatments may be required at intervals of 3-4 weeks. Repeated weekly application of lindane, pyrethrin, or allethrin formulations may be required to eliminate the infestation because the residual activity of these materials is of short duration.

Infrequent infestations

In many areas, body louse infestation is rare, although it may occur occasionally among vagrants and inmates of public-assistance hostels, charitable institutions, prisons, or among crews of ships. Since there is little danger in reinfection, a rapid treatment giving no residual protection is adequate. Although clothing can be disinfested by heating to 70° C, or higher, for 1 hour, the easiest treatment is fumigation in a metal bin or plastic bag. It has been found that ethyl formate applied at 2 ml per litre for 1 hour is adequate. Care should be taken when fumigation is being carried out since ethyl formate is inflammable.

Head lice

In the laboratory, head lice can be made to act as disease vectors, but under natural conditions they are not known to be associated with the transmission of typhus or relapsing fever, particularly in the absence of body louse infestations. The direct effects of head lice, as well as of body lice, are the intense irritation and the consequent scratching. Secondary infection, especially with impetigo, frequently results from heavy neglected infestations.

Head lice have in the past been much more prevalent than body lice in most countries but recent evidence indicates a substantial decline in this prevalence. There is also evidence that head lice tend to infest people in the younger age groups more than those in the older age groups. Persons of all races with an abundant growth of long hair on the scalp are more liable to infestations of head lice than those with short hair. The sex of the host has no influence on the liability to infestation. Although head lice tend to be discouraged by normal brushing, combing, and washing of the hair, it can not be assumed that such operations will eliminate an infestation, unless very thoroughly done.

Since head lice live continuously on the body, treatment is applied to the infested parts. Although DDT powders or dusts can be used to control head lice, liquid shampoos containing DDT or lindane are preferred for aesthetic reasons. Pyrethrum powders quickly stop louse activity, but DDT powder stimulates their activity, which is intensely irritating for a short time. An emulsion concentrate designated NBIN (68% benyl benzoate, 6% DDT, 12% benzocaine, and 14% Tween-80) and another containing 1% lindane in ethyl alcohol both require dilution (1:5) with water before application. One oil formulation contains 0.2% of lindane dissolved in coconut oil or a similar carrier. An emulsion containing 0.5% of deodorized malathion has been used in Israel while in eastern Europe tinctures of derris root (rotenone) and delphinium flowers have been found satisfactory for delousing schoolchildren.

The amount of insecticide applied is 10-20 ml of emulsion or 5-10 ml of solution per head, and treated persons should not bathe or shampoo for at least 24 hours. Powders should be applied at weekly intervals, at the rate of 10-20 g per head, if the hair is washed between treatments. Persistent infestations should be retreated at intervals of 1-2 weeks.

Pubic lice

The irritation caused by the bites of the pubic louse induces scratching and often localized eczematous conditions of the pubic or axillary regions but no definite connexion is known between infestations of pubic lice and disease transmission. The species is nearly worldwide in distribution, but such records as exist suggest that it is considerably less common than head and body lice. This, together with the fact that it is very rarely abundant, suggests that its medical importance is negligible.

The life cycle is not greatly different from that of Pediculus, the methods of feeding and reproduction being generally similar. There are three nymphal stages and all stages are much more sedentary than those of head or body lice. The insects grasp body hairs with their specially adapted claws, and the eggs are cemented to the body hairs. At the temperature of the skin, the

1 Resistance of head lice to DDT has been reported recently in the United Kingdom, by Maunder, J. W. (1971) Med. Offr, 125, 27-29.
Egg, hatch in 7–9 days. Nymphal development occupies 13–17 days and adults live rather less than a month. Eggs are laid at the rate of about 3 per day.

Treatments prescribed for body and head lice can be used against public lice. In addition, 1% lindane dispensed as cream, lotion or shampoo is effective. Ophthalmic ointment containing 0.25% of physostigmine will eliminate crab lice from the eyelashes. The lindane cream or lotion should be massaged into the affected areas of hair and thoroughly washed off after 24 hours. The lindane shampoo is lathered on for 4 minutes, the hair is then rinsed, rubbed with a dry towel, and combed with a fine-tooth comb to remove any remaining nits.

**OTHER INSECTS**

**Flies**

**General**

The insect order Diptera (flies) contains, in addition to the mosquitoes, a large variety of species that vary considerably in their biology, behaviour, and relationship to man. Although of less importance in the incidence of vector-borne diseases than mosquitoes, certain species are essential hosts in a disease chain (e.g., tsetse flies in African sleeping sickness, blackflies in onchocerciasis), while others are mechanical transmitters of disease organisms (e.g., the common housefly). The housefly has a worldwide distribution and is represented by a number of subspecies, some of which differ greatly in their behaviour and breeding habits. Only *Musca domestica* and related species will be considered here.

Good sanitation is fundamental to the success of any control programme against *M. domestica* and allied species. It is particularly important because resistance to insecticides has been found in a number of species of fly, and the housefly in particular is an outstanding example of the ability of an insect to counteract chemical attack. Since 1948, when resistance to DDT was first observed in *M. domestica*, the housefly has developed resistance to many other insecticides, including organophosphorus compounds and carbamates.

Flies of the genera *Musca, Fannia, Phaenicia, Calliphora, Phormia*, and *Stomoxys* are generally termed “synanthropic” or “domestic” species because of their association with man. Since their breeding sites are directly related to the presence of human wastes and other organic debris resulting from human activities, the basic approach to effective fly control is the reduction or elimination of these breeding areas. Chemical measures without the support of sanitary measures may not be successful; the combination of chemical treatment and sanitation, however, provides a high level of control.

The relative abundance of the various species of fly differs according to the geographical area and the season of the year. Moreover, *M. domestica* has numerous subspecies (*vicina, nebulio, calleva, curviforceps*, etc.) some of which may exhibit such marked differences in behaviour that a control procedure effective one subspecies is of limited value against another. Dispersal habits vary in the different genera (e.g., blowflies such as *Phormia* and *Phaenicia* normally travel greater distances and fly more quickly than the housefly). Thus, the problem of infiltration from untreated areas or communities is greater with the blowfly group.

**Control**

Chemical control procedures include the use of pesticides as residual treatments, baits, impregnated cords, space sprays, and larvicides. While each measure by itself is effective to a certain extent, it is frequently desirable to use two or more methods to achieve maximum control. Thus a combination of baits and cords may be more effective than either method alone. Since housefly populations are subject to sudden and rapid increases, measures whose activity persists for a long period (e.g., impregnated cords and residual treatments) should be applied just before the seasonal renewal of vigorous breeding.

**Residual treatment**

The insecticide is applied to surfaces in and around animal shelters, to breeding areas for flies, and to places where adult flies rest, the most suitable surfaces for treatment being those that the flies rest on at night since, in such places, the flies are exposed to the toxicant for the longest period. During the cooler seasons adult flies rest at night on the interior surfaces of barns, chicken houses, rendering plants, and animal shelters, but when average night temperatures are high, many flies rest on the exterior surfaces of buildings and on fences, trees, etc. However, this is not true of all species, some (e.g., *M. domestica calleva, Calliphora megacephala*) normally rest outdoors. Blowflies, such as *Phormia*, rest on exterior surfaces, on vegetation, or on surfaces close to a breeding site, inside or outside of garbage containers, for example.

To control flies around houses screens, doors, window frames, and garbage containers should be treated. In tropical areas the entire house may be treated, particularly when an animal shelter is a part of the dwelling.
Blowflies (except *Phaenicia cuprina* and *Chrysomyia putoria*), species of *Fannia* and *Stomoxys* and, in some areas, the housefly, are susceptible to the chlorinated hydrocarbon compounds such as DDT (5%), methoxychlor (5%), lindane (0.5%), and chlordane (2.5%). For housefly populations that are resistant to DDT and related compounds, the organophosphorous compounds listed in Annex 2, Table 4 are suitable. However, housefly populations in some areas have developed resistance to one or more of these toxicants, and other types of control measure have to be employed. The insecticide is applied either as an emulsion or as a suspension, the former being preferred in situations where the deposit on a surface must be inconspicuous.

In some circumstances, frequent applications of smaller volumes of insecticide per treatment is an accepted procedure. Special care should be taken to prevent the contamination of food or water during spraying operations.

**Impregnated cords and strips**

Cords or strips impregnated with insecticide can be hung from the rafters or ceiling of a building. Various organophosphorous compounds have been used for this type of treatment, but at present only parathion–diazinon cords and dimetilan bands are available in the USA. In Europe, cords containing fenthion or dimethoate are used. The insecticide is incorporated into a cotton cord, spongy plastic band, gauze, or felted cellulose. Impregnated cord is installed at the rate of 1 m per m² of floor space. The period of effectiveness of this type of treatment is between 1 and 6 months. Maximum effectiveness has been obtained in localities where the weather is not characterized by high temperatures (above 32°C) and low humidity (less than 50%).

**Poison baits**

Baits are placed at sites in and around farms and food-handling establishments where adult flies congregate to feed. Similar sites are baited around the exterior of dwellings but not within them. The sites include floors, window-sills, doorways, store-rooms for food, etc.

Diazinon, dichlorvos, malathion, rotenone, naled, dimethoate, and trichlorfon are used alone or combined in dry or liquid baits. Dry baits contain 1–2% of the toxicant in a carrier, such as ground corn-cobs, oyster shells, or sand, with sugar as a sweetening agent. Sugar alone may be used as the carrier. Liquid baits consist of 0.1–0.2% of toxicant and 10% of sugar or other sweetening agent in water. Commercial baits containing various toxicants are available, or the baits can be prepared from water-dispersible powders or emulsifiable concentrates (see Annex 2).

Special formulations of the toxicant in viscous media, such as gelatin or agar, or in resins, are used when baits are dispensed in bait stations. Bait formulations, composed of the toxicant (4–6.5%) plus binder and sugar, that can be applied to a surface with a brush are used in northern Europe.

Dry baits are scattered by hand from a bag or sifter-topped container. The bait is broadcast in thin layers on to surfaces that will remain dry, the rate of application being about 60 g per 100 m². On dirt surfaces the bait should be kept off the ground by placing it on thin metal or plastic sheets, boards, paper, or similar material.

Liquid applications can be made with compressed-air sprayers or from a sprinkling can. If the surface is dirty, or covered with debris, the bait should be applied to burlap sacking or to wood, paper, or metal sheets. The rate of treatment is 4 litres per 100 m². Liquid baits prepared as a slurry or syrup are applied with a paint-brush as spot applications to posts, supports, and walls. Such baits contain dimethoate or trichlorfon and are applied at a rate of 130 g of bait per 100 m² of floor area. They may remain effective for 2 months or more.

To avoid the need for frequent renewal of baits, special reservoir containers can be designed. Gelatin or agar baits may be applied to a wire-mesh square attached to a wooden paddle, such devices are then distributed over the area by inserting the paddle into the ground or by attaching it to above-ground supports. Rectangular wooden trays (30 by 45 cm) can be used to hold a week’s supply of dry bait. Liquid baits can be dispensed from a chicken-watering unit holding between 500 ml and 2 litres of bait (Fig. 19). The trough of the dispenser is fitted with a cellulose sponge to prevent its becoming chocked by dead flies. When the toxicant is produced from a resin formulation (dichlorvos-resin), replenishment of the bait is accomplished simply by refilling the dispenser with 10% sugar solution.

The number of bait stations required depends upon the size of the establishment to be treated. Where flies are numerous, small stations, such as paddles, may be spaced at 1.5–3.0-m intervals; when trays or watering devices are used, 10–15 stations may be needed in each control area.
The need for re-treatment with bait depends upon the level of the fly population, and upon the rapidity with which the bait is degraded by the weather. When bait stations are not used, the bait may be destroyed or consumed within the course of a day. The daily renewal of baits may lower the fly population density within 1-3 weeks to a level that will permit renewals to be made at less frequent intervals. Bait stations require to be refilled at intervals of 2-3 weeks. Dense populations of flies deplete the reservoir rapidly.

**FIG. 19**
POISON BAIT DISPENSER FOR USE IN CONTROLLING HOUSEFLIES

**Space treatment**

Space treatment is directed towards exterior sites such as alleys, refuse dumps, cargo storage areas, and food-handling establishments where there are heavy concentrations of adult flies. For outdoor use DDT (5%), chlordane (2.5%), and lindane (2%) are suitable pesticides for susceptible housefly populations; emulsions in fuel oil are frequently used, and dusts containing 1-5% of toxicant are employed in certain areas. For interior use, deodorized kerosene formulations of synergized pyrethrum (0.1%), dazinon (0.1%), rotenel (2%), or malathion (5%) are suitable. For outdoor treatment, power-operated units are used to produce mists, sprays, or thermal aerosols. For indoor treatment, freon-operated misters, hand-operated sprayers, or small portable power units are used.

Space applications do not provide residual deposits of the insecticide, their effectiveness being based on particles of insecticide impinging on the flies, and daily treatments may therefore be required. In ground-installation programmes, it may be necessary to apply space treatments in a weekly cycle in conjunction with other control techniques.

**Larviciding**

Any accumulation of moist organic matter supports the breeding of domestic flies. Some species, such as *M. sorbens*, breed more frequently in human and animal faeces than in refuse, whereas the converse is generally true for *M. domestica*. The latter is rarely found in individual dog stools but where such faeces accumulate they are soon infested with *M. domestica*, and *M. domestica vicina* readily infests privies in tropical areas. Blowflies have a smaller range of breeding preferences than houseflies but they infest garbage, animal carcasses, fish and abattoir wastes, and excreta. The latrine fly (*Chrysomyia putoria*) is a serious pest infesting human excreta in privies and bored-hole latrines in Africa. A related species, *C. megacephala*, is a similar pest in South-East Asia. The little housefly (*Fannia*) breeds in animal excreta, particularly from poultry. Stabiflies (*Stomoxys calcitrans*) develop readily in accumulations of wet straw, celery wastes, and grass; along beaches, masses of marsh grass are important sites of stabifly production.

The insecticides DDT, dieldrin, lindane, methoxychlor, and endrin are suitable for direct application to breeding sites for use against the larvae of domestic species, except resistant populations of *M. domestica*. Of the various organophosphorous compounds that can be used for this purpose, dazinon gives the most consistent effectiveness; other toxicants that can be used are dimethoate, trichlorfon, rotenel, and malathion. Concentrations of the finished sprays vary from 0.25-2.5%.

Either hand- or power-operated sprayers are used to apply larvicides (solutions or emulsions) to animal excreta at a sufficient rate to wet the medium thoroughly (28-56 litres per 100 m²). Dust applications also are suitable, since dusts are readily visible and help to reduce the moisture content of the medium. Another method of application is the hand broadcasting of insecticide-treated granules. Animal carcasses are treated in the same manner as excreta, the insecticide emulsion (diazinon 0.25%, dieldrin 1%, and endrin 0.25%) being applied directly to the carcass and to a 7.5-12.5 cm strip of earth all around.

For control of stabifly production in accumulations of marsh grass, the piles of grass are given a heavy treatment with DDT (4 g/m²) using power-operated equipment. Where breeding sites are not accessible by land, boats may be used.

Animal excreta requires repeated treatment to ensure continuous control of housefly and *Fannia* larvae. Maximum periods of effectiveness are in the range of 1-2 weeks with dazinon. Other organophosphorous compounds are less effective and reapplications may be required once or twice a week. Carcasses
need not be retreated since one application destroys existing blowfly larvae and prevents reinfestation for periods greater than 30 days.

Cockroaches

Life history and habits

In general, the life history of cockroaches living in association with man may be considered together. They develop through nymphal stages to the adult. The eggs are contained in a capsule containing up to 30 eggs in some species. The capsule may be carried about by the female (e.g., Blatella germanica) until the eggs are ready to hatch, or attached by means of secretions from the mouth of the female to inconspicuous objects, or dropped anywhere in the habitat. The nymphs are similar to the adults except in size but they grow at each moult, of which there are 7–13 in various known species, until they reach the adult stage. B. germanica may have two or three generations in a year; however, the time of development for different species ranges from 2 to 16 months.

Of the many known species of cockroaches, only a few are of concern to man. The genera Blattella, Periplaneta, Supella, and Blatta all contain species that associate with man, but Blattella germanica is the single most important pest species. Cockroaches are annoying because of their generalized feeding habits and their occurrence in food-handling areas. They will feed on almost any organic matter, but they are especially notorious for their consumption of starchy and sugary materials, fabrics, book bindings, fresh and dried blood, excrement, and sputum. Because of their feeding habits, they are potential mechanical carriers of disease organisms and spreaders of filth.

Cockroaches enter premises, including ships and aircraft, from the outside or they may be taken into such places in infested containers of food, laundry, luggage, etc. Cleanliness is the key to cockroach control; insecticide treatment unsupported by sanitation gives only temporary relief. All areas must be kept thoroughly clean so that no food particles, debris, dust, or rubbish remain to encourage infestation. Before applying any insecticide, the premises should be inspected thoroughly to determine the extent of infestation.

Control

Problems of resistance to insecticides have been encountered with the B. germanica. Various resistance and cross-resistance patterns have developed in some areas, notably in the USA where populations have been found that are resistant to chlordane, dieldrin, DDT, diazinon, fenthion, malathion, or pyrethrin. Chlordane-resistant cockroaches exhibit cross-resistance to cyclodiene insecticides but not to DDT. Resistance to DDT in cockroaches does not extend to cyclodiene insecticides but does extend to carbaryl, while cockroaches resistant to DDT and cyclodiene are not cross-resistant to organophosphorus compounds. On the other hand, diazinon-resistance extends to many other organophosphorus compounds and to some carbamate compounds, whereas resistance to malathion appears to be rather specific. Of the other species of concern to man, resistance (to DDT and/or chlordane) has occurred only in Blatta orientalis, at two places in Germany, and in Periplaneta brumnea in Florida, USA.

Area treatment

Areas that should be treated are kitchens or galleys, behind and along baseboards, in and around sinks, in or under cupboards, under chairs and tables, in utility cabinets, near refrigerators and ice boxes, and even under loose floor coverings. In commercial establishments, restaurants, and warehouses, food-storage areas should be treated. Other sites that should be treated are food-preparation areas, ducts, and pipes.

Chlorinated hydrocarbons, organophosphorus compounds, and carbamates are used in cockroach control (see Annex 2). Because of resistance to chlordane in B. germanica, current practice is to use compounds such as malathion, diazinon, and propoxur for residual spraying against this species. For other species, the chlorinated hydrocarbon compounds are the insecticides of choice. Dust formulations are also available with certain of the toxicants listed and several are available as baits (Kepone, dichlorvos, and propoxur). Other compounds such as boric acid are also available in powder form. The organophosphorus compounds and carboxamates are generally effective for shorter periods than are chlordane and dieldrin.

Method of application

Residual sprays are usually applied with household plunger-type sprayers or compressed-air sprayers. A coarse mist, rather than a fine one, should be applied to moisten surfaces thoroughly without runs or drips. Fan-spray or pinstream nozzles should be used. The pinstream is useful for applying chemicals to cracks and areas that are hard to reach. Sprays are applied at approximately 4 litres/100 m², or 4 litres/100 m (linear measure) of cracks and crevices. A paint brush can be used to apply the insecticide when other equipment is not available. Pyrethrum aerosol treatments are sometimes applied with residual sprays, to stimulate cockroaches to leave their harbourage and to speed up the
time of kill. Thorough treatment of runways and harbourage areas is essential for effective control.

Dusts are most useful for treating hollow walls and other inaccessible voids. A light, uniform film of dust may be applied with a puff duster of the bulb, plunger, or bellows type. Heavy dust deposits are repellant to cockroaches and may cause them to move to untreated or more inaccessible locations. Dusts should not be applied to wet surfaces as this reduces their effectiveness. When used in conjunction with residual sprays, dust should be applied after the spray residues are dry.

Baits are most effective in situations where there is little or no food to compete with the bait. Their efficacy depends largely on their correct placement at sites frequented by cockroaches. The baits are prepared commercially for use as pellets or pastes in harbourage areas.

The frequency of retreatment depends on the thoroughness of the application, the rate of reinfestation, and the residual activity of the toxicant used. Sanitation is especially important when baits are used alone; removal of food sources by thorough cleaning causes the cockroaches to feed more readily on the baits. One initial treatment, no matter how carefully executed, rarely results in total extermination. For most species, periodic follow-up treatments may be necessary at monthly intervals to kill newly hatched nymphs or to prevent further reinfestation.

The duration of effectiveness of the residual deposits varies with the chemical, the type of surface to which it is applied, and the degree of abrasion it undergoes. With insecticide having a fumigant action, the porosity of the surface greatly affects the retention or release of the chemical. Pesticide deposits normally effective on unpainted metal may not retain their activity when applied to painted metal.

Precautions

Some formulations may stain fabrics, wallpaper, floor tiles, or finishes applied to other materials. Care must be taken to avoid the contamination of food for human consumption, or the placing of toxicants where children are liable to come in contact with the residue. In special situations, such as animal rooms, zoos, and pet shops, the use of residual sprays or dusts may be precluded, although limited pesticide treatment applied with a brush, as well as applications of boric acid powder, may be possible.
CHAPTER 3

BIOLOGY AND CONTROL OF DOMESTIC RODENTS

GENERAL

Rodents are widely distributed throughout the world and account for about 40% of the mammals living at the present time. In many regions, however, the total number of individual rodents is probably many times greater than that of all other mammals. It is therefore not surprising that rodents have come to play a major role in harbouring and transmitting many diseases to other mammals, including man. In the transmission of human disease, the extent to which some rodents have become adapted to man-made environments is at least as important as rodent numbers.

In the recent past, urban development and intensive agriculture have been extended to meet the needs of rapidly growing populations. During this period, many rodents have remained more or less undisturbed in desert and mountainous regions, but even here they may still cause concern when they increase in number and move out into neighbouring areas, temporarily damaging crops and spreading disease. On the other hand, in agricultural areas, where most of the original native rodent species have tended to become confined to the remaining small patches of undisturbed ground, a few have benefited from the greatly improved food supplies available in fields and plantations and, except where adequately controlled, they have become permanently present in greater numbers. These rodents are particularly notorious for the damage they do to growing crops like rice, sugar cane, and cocoa, but from time to time they may also be responsible for transmitting diseases. Undoubtedly, however, the most important disease-spreading rodents are the domestic species, so-called because of their success in colonizing human habitations.

Unfortunately, during their close association with man, three species of domestic rodent have been carried to most of the countries of the world and today are still continually being ferried back and forth from one country to another, occasionally by aircraft but more often by ship. It is this international aspect of rodent distribution, with its risk of spreading epidemics of disease, such as plague, throughout the world, that makes the elimination of rodents in airports, seaports, planes, and ships a matter of very great importance. Rodents in airports and on aircraft are also a threat to the safety of aircraft, crew, and passengers either by causing sickness or by destroying electrical, or other, control equipment. Aboard ships and in port warehouses, rodents may cause immense damage to cargoes of food and other materials. In many countries to which they have travelled, certain rodents have also become major agricultural pests and there still remain a few areas which they have apparently not yet reached—some of the Pacific islands for example—where similar opportunities await them.

Fortunately, none of these catastrophes, or even much minor rodent damage, need happen if the procedures explained later are carefully carried out. First, however, various important species of rodent are described, together with aspects of their biology that affect control measures.

BIOLOGY OF DOMESTIC RATS AND MICE

One of the main features of rodents is the upper and lower pair of sharp incisor teeth set well forward in both jaws from the ridged cheek teeth leaving a space free from teeth on each side (Fig. 20). This arrangement allows rodents to gnaw through comparatively hard or toxic materials, such as lead-covered pipe (Fig. 21) and aluminium alloy, and to discard fragments without even taking them into the mouth. Thus, rodent-proofing materials generally need to be extremely hard rather than distasteful.

Rodents vary in size from the harvest mice of Europe and Asia weighing less than 10 g to the South American capybara that may weigh over 40 kg. The class Rodentia also includes such well-known animals as the beaver, porcupine, squirrels, and hamster, but the most familiar are the domestic rats and mice, which, together with about 500 other rodents of rather similar appearance, belong to the family Muridae. Some of the domestic rats and mice are rather restricted in distribution, the lesser bandicoot rat (Bandicota
FIG. 20
RAT SKULL TO SHOW THE ARRANGEMENT OF GNAWING INCISOR TEETH AND THE GRINDING CHEEK TEETH

* The space between the two sets of teeth can be closed by contraction of the cheeks to prevent poisonous or unpalatable material entering the mouth (X 3.3).

FIG. 21
MOUSE-GNAWED ELECTRIC CABLE (A) AND RAT-GNAWED LEAD PIPE (B)
Figure 22
BANDICOTA BENGALENSIS (LESSER BANDICOOT RAT) DISTRIBUTED LOCALLY IN THE INDIAN SUBCONTINENT AND PARTS OF SOUTH-EAST ASIA

Figure 23
SUNCUS MURINUS (HOUSE SHREW) LOCALLY DISTRIBUTED IN THE INDIAN SUBCONTINENT AND SOUTH-EAST ASIA

bengalensis) of the Indian subcontinent and parts of south-east Asia being one of these species (Fig. 22).

The house shrew, which has been found to be a vector of plague, is an insectivore and not a rodent, but it is similar in appearance and often occurs in dwellings in some tropical countries (Fig. 23). All local species of rodent represent a threat to human health and should be controlled whenever they come into close contact with man. However, the roof rat (Rattus rattus), the Norway rat (Rattus norvegicus), and the house mouse (Mus musculus) are described here in their capacity as world-wide pest species (Fig. 24, 25, 26).

Relationship of rodents to man and disease

Throughout historical times, the domestic rodents have been responsible for enormous loss of human life by spreading a number of highly dangerous diseases, of
FIG. 24
RATTUS RATTUS (ROOF RAT)

FIG. 25
RATTUS NORVEGICUS (NORWAY RAT)
which the most dreaded, and still potentially the most important, is plague. Curiously enough, however, plague is not a disease generally present in domestic rodents; this is one of the characteristics that explains why the disease often appears rather suddenly in man.

The plague bacillus, Pasteurella pestis, occurs today for the most part in certain populations of wild rodents inhabiting some of the sparsely populated grassland areas of the world. These rodents include prairie-dogs and ground-squirrels in the western USA, and also many gerbil species in Asia and Africa; they maintain a reservoir of disease, which generally remains out of contact with man until an adequate link occurs. Such a link may initially involve a spread of the disease among semidomestic rodents. However, whatever route the disease may take, once the bacillus has reached the tissues of domestic rodents, it multiplies rapidly and causes the death of a high proportion of infected animals. During the course of the disease, bacilli are present in the blood of the animal and many of them are ingested by the rodent fleas when they feed. Infected fleas tend to leave the rodent host soon after its death. Subsequently, these fleas transmit the disease to any animal on which they feed.

At the start of a plague epidemic, the majority of hosts will be other rodents but, as rodents become fewer, the fleas begin to attack man. Thus, in the prevention and control of plague, it is not only the domestic rodents, particularly rats, that need to be considered, but also their external parasites. It is important also to investigate high rates of mortality amongst domestic rodents in case an outbreak of plague amongst the human population is indicated.

The house mouse seems to play a much smaller role in the spread of plague than the roof and Norway rats, perhaps mainly because it is less susceptible to the disease, but it also tends to have fewer fleas and those are of a species that only rarely attack man. On the other hand, these factors may to some extent be offset by the fact that mice are often more difficult to detect, less easy to control, and more readily transported than rats.

Two other important diseases that are transmitted to man from domestic rodents by their external para-
sites, especially in tropical areas, are those caused by Rickettsiae, a group of organisms occupying a position between viruses and true bacteria. Of these rickettsial diseases, murine typhus is transferred to man probably mainly by a rat flea, *Xenopsylla cheopis*, while in tsugamushi disease (or mite typhus) the vectors are usually larvae of a number of species of trombiculid mites.

Many rodent-borne diseases, on the other hand, do not involve external parasites as vectors. *Salmonella typhimurium* and *S. enteritidis*, for example, are two species of bacteria commonly found in the gut of domestic rodents; they cause food-poisoning in man when food contaminated by rodent faeces is eaten. *Spirochaetes* of the genus *Leptospira*, particularly *L. icterohaemorrhagiae*, do not involve external parasites as vectors. *Salmonella typhimurium* and *S. enteritidis*, for example, are two species of bacteria commonly found in the gut of domestic rodents; they cause food-poisoning in man when food contaminated by rodent faeces is eaten. *Spirochaetes* of the genus *Leptospira*, particularly *L. icterohaemorrhagiae*, are carried by a high proportion of individual animals in most populations of domestic rats. The leptospires are passed out in the rat's urine and they remain infective for long periods in damp situations. Since leptospires are able to penetrate the human skin through the smallest abrasion, persons bathing in rat-contaminated water or working in a rat-infested environment continually run the risk of contracting leptospiral jaundice, a disease that is often lethal, particularly to older people. There are also two disease-causing organisms, *Spirillum minus* and *Streptobacillus moniliformis*, that are generally transferred to man only by a rat bite. Consequently, the diseases to which these organisms give rise, sodoku and Haverhill fever, are commonly referred to simply as "rat-bite fever". Other human diseases in which rodents play a role all enter the human body by one or other of the routes already mentioned. They include tularemia, Rocky Mountain spotted fever, rickettsial pox, Q-fever, lymphocytic choriomeningitis, various haemorrhagic fevers, and trichinosis.

**Roof rat**

The roof rat (Fig. 24) occurs in three more-or-less distinct colour forms, each of which was given a different name until it was realized that they interbred freely and were, in fact, the same species. One form has a dark grey back and belly (the *rattus* form or "black rat"), another has a brown back and dark grey belly (the *alexandrinus* form or "Alexandrine rat"), while the third has a brown back and white belly (the *frugivorus* form). A full-grown roof rat is a slim, alert-looking animal weighing generally not more than 250 g and measuring about 400 mm from the tip of its rather pointed nose to the end of its long slender tail, which is usually longer than the combined length of the animal's head and body. The rather protruding eyes are black and shiny and the large mobile translucent ears which project well above the fur are almost circular in outline and virtually hairless. The roof rat apparenently originated in south-eastern Asia, where it still exists as a large number of widely scattered subspecies. From its homeland, this species has been transported by human agency throughout the world from very early times. At the present time it is still by far the most common ocean-going rat (Table 3) and for this reason is often called the "ship rat"; it is also relatively abundant in many ports and the surrounding urban areas. Particularly in tropical countries, the roof rat has also spread inland to other urban areas, both large and small. In some of these places, India for example, the species seems to have remained more or less domestic, while in others, such as the West Indies and many Pacific islands, it has spread to agricultural land and various other habitats.

When living outdoors, the roof rat generally nests under plant debris on the ground, in bushes, or even high in trees. Only occasionally, does it burrow, nest underground, or travel along subterranean routes, such as sewers. Indoors, as the name suggests, it tends to establish itself in roof spaces from where it travels, generally by way of any available pipes, beams, and tops of walls, to sources of food and water. The nests, which are often made from sacking and similar material, can sometimes be detected by the observation of wisps of nesting material hanging from beams or the tops of walls (Fig. 27).

Breeding generally takes place throughout the year although it may be less during cold or dry seasons.

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**TABLE 3**

THE RELATIVE NUMBERS OF ROOF AND NORWAY RATS IN SOME SEA PORTS

<table>
<thead>
<tr>
<th>Port</th>
<th>Year</th>
<th>Roof rats as percentage of total rats (R. rattus + R. norvegicus)</th>
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<tr>
<td></td>
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<td>On ships</td>
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<tr>
<td>Gdynia a</td>
<td>1938</td>
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<tr>
<td></td>
<td>1947</td>
<td>92.0</td>
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<tr>
<td>Hamburg c</td>
<td>1966-1968</td>
<td>99.5</td>
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<tr>
<td>Liverpool d</td>
<td>1959-1966</td>
<td>97.1</td>
</tr>
<tr>
<td>London e</td>
<td>1959-1967</td>
<td>98.9</td>
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<tr>
<td>New York f</td>
<td>1925-1927</td>
<td>99.6</td>
</tr>
<tr>
<td>Yokohama and</td>
<td>1964-1966</td>
<td>97.6</td>
</tr>
<tr>
<td>Kawasaki #</td>
<td>1932-1965</td>
<td>—</td>
</tr>
</tbody>
</table>


b The small proportion of roof rats at this time is believed to have been due to the lack of overseas shipping in the port during the war years.


d Data from the annual reports of the Medical Officer of Health to the Port Health Authority of the Port of Liverpool, England.

e Data from the annual reports of the Medical Officer of Health to the Port Health Authority of the Port of London, England.


The number of young born at a time is about 7 or 8, and in many places the annual number of litters is about 5. These numbers may, however, vary considerably from place to place, from year to year, and from season to season.

The young are born hairless, blind, and helpless. After 1 week, the coat colour becomes apparent, after 2 weeks the eyes open, and soon afterwards the young begin to wander about. They are weaned when about 1 month old and become sexually mature some 2 months later (Fig. 28).

Little is known about the extent to which the young migrate from the parental nest before they settle down but, once settled, they seem to confine their activities to a radius of about 60 m from the nest. Disturbance of nesting areas and removal of food, as often happens for example when ships' cargoes are unloaded, usually cause much more extensive movements.

In the wild state, the roof rat eats an enormous variety of plant and animal food, from coconuts and bananas to beetles and snails. In domestic situations, the rats feed largely on food stored for consumption by man and domestic animals; even such unlikely materials as red chillies (Fig. 29) are eaten.
Norway rat

The Norway rat (Fig. 25) is sometimes known as the brown or grey rat and, in countries where it is particularly abundant, also as the common rat. This species generally has a brown back and pale belly, but very dark forms and albinos occasionally occur. The many strains of this species that are maintained in research laboratories throughout the world are mostly albino but a few are piebald. The Norway rat is the largest of the domestic rodents and adults weighing over 400 g are not uncommon. The tail is relatively thick, paler beneath and usually shorter than the combined length of the head and body. Compared with the roof rat, the nose is blunt and the eyes and ears are relatively small; the ears are covered with short hairs.

The first use of the very inappropriate title of “Norway” and its scientific equivalent “norvegicus” was at a time when it was believed that this particular kind of rat had first reached the British Isles in timber ships coming from Norway. It is now evident, however, that the original home of the Norway rat must lie somewhere in temperate Asia. During the eighteenth century, this rat spread rapidly throughout the world and today it is entrenched in most temperate countries, not only in the towns and agriculture areas but also in many natural habitats such as marshland, forest, and small uninhabited islands. In warmer countries, it has not done so well and tends to be confined to larger towns and ports and has only rarely established itself in rural areas, though it has managed to do so in Hawaii. During its spread, the Norway rat seems often to have displaced the smaller roof rat and if, for example, the two species do occur in the same building, it is generally found that the Norway rat lives below while the more agile roof rat lives above.

Not only, however, is the Norway rat often found in the lower storeys of a building, but if suitable places such as earth floors or bales of fibrous materials, into which the rats can burrow, are not available, many individuals belonging to a population infesting a building will be found living in burrows outside (Fig. 30), only visiting the building at night to obtain food. These outdoor burrows may be made in any soft ground, but the banks of rivers and streams, piles of debris, or low thick-growing herbage, where the burrow entrances remain concealed, are usually the first places to be colonized. The burrows themselves may be quite complex structures with many nesting chambers, tunnels, and burrow entrances. The entrances are usually about 80 mm in diameter while the nesting chambers are more or less spherical, about 250 mm in diameter, and usually lined with grass or other similar plant material. The young are born in the nesting chamber; there are generally about 8 young in a litter, and their development is similar to that described for the roof rat.

The food of the Norway rat is at least as varied as that of the roof rat, but its more frequent foraging expeditions into sewers and refuse dumps, as well as...
its tendency to live in or around such places, increases the danger that its activities will spread human disease.

**House mouse**

The house mouse (Fig. 26) has a brown-grey back and a grey-pale belly. The animal is rather similar in general appearance to the roof rat but is readily distinguished from adults of both roof and Norway rats by its very much smaller size. Adult house mice, for example, are rarely heavier than 20 g or longer than 200 mm whereas adult rats generally fall within the range of 100–500 g in weight and 300–500 mm in length. A young rat about the same size as an adult mouse can be recognized by its relatively large head and feet (Fig. 28).

The house mouse is more widely distributed throughout the world than the two domestic rats and over much of its range can live independently of man. It has become adapted to living in cold stores with apparently nothing to eat but frozen meat and also thrives in warehouses containing only flour; its success in the latter environment seems to be partly due to its ability to survive without water other than the relatively small amount contained in the food. The species must also owe its continued existence in human habitations from
which rats have been successfully eliminated to its small size and more harmless appearance.

The nest of the house mouse is built in crevices in walls, in stocks of stored food, under floors, in roof linings, in outdoor burrows, and, in fact, wherever accumulations of materials provide the very small amount of cover that it needs. Its life history is similar to that described for the domestic rats, but female mice are often able to breed when only 2 months old. The range of movement of adult mice may only be a few metres, which sometimes makes their detection and control inside large stacks of food extremely difficult.

CONTROL OF DOMESTIC RODENT POPULATIONS

Methods are now available not merely to control but also to eliminate the vast majority of domestic rat and mouse infestations. Thus, the presence of an infestation of any appreciable size or of more than a few weeks standing almost always indicates a shortage of staff, a lack of trained personnel, or the absence of adequate authority to carry out the necessary work. The importance of employing conscientious and well-trained operators cannot be too strongly emphasized. Once a site, such as a warehouse or a ship, has been cleared of rodents, it will generally remain clear only if suitable preventive measures are taken. One of the most effective of these measures is to deal with potential sources of reinfection. In other words, rodent control needs intelligent co-ordination over a wide area so that work in one place is not quickly made useless by reinfection from another.

Ideally, the co-ordination of rodent control in a port area should be the responsibility of one man who will obviously require a thorough knowledge of rodent control techniques, but above all will need an ability to organize and the personality to gain the confidence and co-operation of people living and working in the area. The rodent control officer will also need the backing of appropriate legislation aimed at implementing those articles of the International Health Regulations ¹ that are concerned with rodent control; the legislation, to be effective, should include authority for officials to inspect all properties. The properties to be inspected should include both buildings and adjacent areas, and all forms of transportation, particularly aircraft and ships, local and international, entering the area. There must also be provision for enforcing rodent control measures, which should include not only killing rats and mice but also modifying the environment, if necessary, to prevent further trouble. It is important that adequate funds to carry out this work should be made available.

The size and type of area in which rodents are to be controlled depends largely on local conditions. At airports, which are often situated some distance from densely populated urban areas, it is usually advisable to include some of the surrounding land, particularly if crops attractive to rodents are being grown. Seaports, on the other hand, generally spread along the edges of river estuaries and are almost invariably backed by poor-quality urban areas, which, because of their ability to sustain a very large number of domestic rodents, should always be included in any plan to maintain a port area more or less rodent-free.

Unfortunately, however, the control of rodents in port areas and the immediate surroundings is not completely successful in preventing rats and mice from entering aircraft and ships and thus being transported to another country. Rodents carried aboard ships or aircraft in baggage or cargo may not have started the journey in a port area and, indeed, the journey may not end when the ship or aircraft is unloaded at another port. It seems very likely, for example, that some of the rodents found in the baggage and freight compartments of aircraft have emerged from cargoes, such as fresh fruit and vegetables, placed in crates outside the airport area and taken almost directly to the aircraft. On the other hand, rodents enclosed with cargo in rodent-proof containers can escape only when the cargo is unloaded, and this may not occur until it reaches a depot well away from a port area. The carriage of goods in large containers, that are taken from a depot in one country and transported, mostly sealed and unopened, to a depot in another, is becoming increasingly common. Obviously, any country operating containerization services must ensure that the depots do not serve as sources of invasion by rats and mice.

In the area control of rodents as in all well-planned operations, an essential part of the operation is an assessment of the extent to which the work is being properly and successfully carried out. Ways of making such an evaluation will be discussed after the various processes involved in controlling rodents have been described.

Surveys

Whether the area to be surveyed is the whole of a port area or only a small part of it, such as dockside warehouses, the purpose of the survey is the same—namely, to determine if rodents are present and, if so,
which species, where the rodents are living and moving, 
how they should be killed, and what should be done to 
prevent the recurrence of infestations. None of these 
objectives can be satisfactorily attained without a very 
thorough inspection of the area; such a survey is largely 
a matter of discovering, and correctly interpreting the 
significance of, the various traces that rodents leave as 
they go about their normal activities. It should not be 
 forgotten, however, that, to prevent further trouble, it 
may often be important also to identify potential sites 
of infestation. Adequate preventive measures should 
not be neglected simply because a particular site was 
not infested when a survey was made.

In moving about from the nest or burrow, rodents 
tend to use the same routes or "runs" day after day, 
especially when visiting feeding and drinking sites. 
Indoors, these runs are often revealed by the presence 
of black, greasy "smears" along overhead pipes and 
beams (Fig. 31) and on the treads of stairs, but particu-
larly around the bottom edges of holes in metal, wood, 
or brickwork (Fig. 25). It should be remembered, how-
ever, that smears may persist for a long time after the 
runs have become disused. Tail marks and, particu-
larly, footprints are often to be seen in dusty places, 
but sometimes the passage of rodents may be inferred 
from the complete absence of dust along the top of a 
pipe or the absence of cobwebs in the corners of a 
room. After a little experience, the small footprints of 
mice are easily distinguished from those of domestic
rats. Outdoor runs may sometimes be found on open ground (Fig. 32), but they are generally seen more clearly on low-growing vegetation, where the continual running of rats has prevented its growth. Outdoors, footprints are often visible in soft ground (Fig. 33) and the examination in the early morning of mud exposed by the low tide will soon reveal the presence of rats, or at any rate of Norway rats, in a dockside area. Rodent droppings are also often found along runs, but they are generally much more common at feeding places, usually in association with food particles left by the rodents. Droppings of the house mouse can generally be identified by their very small size; the droppings of roof rats tend to be somewhat smaller, and to have more rounded ends, than those of Norway rats (Fig. 34).

The size of toothmarks on food and other materials (Fig. 21), as well as the size of discarded particles, will also provide some indications of whether a mouse or a rat has been at work. The presence of rodents may also be detected by their smell and the noises they make. Occasionally, rodents may be seen running about during the survey, particularly if cover is disturbed or if a bright light is shone into dark corners.

Sometimes, because of the lack of any obvious traces or of obviously fresh traces, the surveyor may not be sure whether or not a site is infested. In most of these cases, the best way of detecting the presence of rodents is to lay a large number of smooth patches of a powder such as talc or basic slag in places where rodents would be most likely to leave tracks, and then to inspect the patches for footprints 1–2 days later. However, in some situations, in sewers, for example, where it is difficult, or impossible, to lay powder patches, it may be necessary to lay small piles of bait that can be examined later to see if any has been eaten.

The results of the survey will determine to what extent the various procedures for environmental improvement, rodent-proofing, and rodent extermination are to be used, and also in what order they should be
carried out. In general, most alterations of the environment likely to affect the rodents' behaviour during control should be left until extermination has been achieved. If, however, it is possible to eliminate the rodents' usual sources of food and water, this action should be taken at the same time as solid and liquid poison baits are laid down. It is obvious also that if further damage to valuable goods can be prevented sooner by some means, such as rodent-proofing, this action should be taken as quickly as possible. However, the most important aspect of timing in rodent control operations is concerned with plague. If plague is present in an area, or if it seems likely to be present, then the control of rodent fleas (see Chapter 2) should precede or accompany rodent control measures, so that no fleas are left to spread the disease to man once the rodent hosts have been killed. If recently dead rodents are found lying about, and the deaths cannot be accounted for by control measures, the bodies should be sent to the appropriate department of the port or airport health authority for pathological examination.

Environmental improvement

In almost any area, there are generally various features that could be modified or eliminated to make the area much less able to support rats and mice. Such environmental improvements are often very simple to carry out and the benefits to a community may extend well beyond those directly associated with rodent control.

The most important factor affecting rodents numbers is the availability of food. All food, whether for human or animal consumption, and whether kept in dwellings, restaurants, warehouses, or any other place, should be stored, as far as possible, in rodent-proof containers, such as glass and earthenware jars or metal cans and bins; even solid wooden boxes provide good protection for a time. An enormous amount of food, such as wheat, rice, groundnuts, etc., is still transported and stored in sacks made of hessian, paper, or plastic. These packing materials are easily penetrated by rodents, and when such damage occurs the cost of re-packing the contents may be considerable. Stacks of sacks containing various food materials provide not only food and harbourage for rodents, but also nesting material as well. It is, therefore, important that such stacks should be kept relatively narrow, not more than a few metres wide, and that sufficient space should be left for a man to walk between the stack and the wall. These measures permit stores to be adequately inspected for rodent traces and make treatments easier to carry out effectively. A further precaution that will prevent extensive breeding of rodents among sacks of food is that a stack should not be allowed to remain in the same place for longer than about 2 months.
FIG. 35
RODENT PROOFING A DOOR BY REHANGING AND PROTECTING THE BOTTOM AND FRAME WITH GALVANIZED SHEET METAL
Food wastes must also be withheld from rodents, and all materials containing edible waste, such as floor sweepings from food stores and kitchen refuse from dwellings and restaurants, should be stored in suitable rodent-proof containers to await collection and subsequent disposal. Collections should be regular and the final disposal of the material is generally carried out most satisfactorily at a refuse tip or dump. Dumps, whenever possible, should be situated well away from urban areas. Disused quarries and gravel pits, or similar excavations, can often be used, and in some cases refuse tipping is a very satisfactory way of raising the level of low-lying or swampy ground. Rodent numbers at the dump site can be controlled by restricting active dumping to the smallest possible area and by limiting the height of the mound of freshly dumped material to about $1\frac{1}{2}$ metres. Vehicles bringing fresh loads will then compact the refuse already there and loads of earth, ashes, and similar material can be spread over the top and edges of the tip to keep most of the edible material adequately covered.

Next in importance to food in the rodents' environment is the availability of nesting sites. Almost any pile of debris, whether indoors or out, can provide rodents with suitable cover for nesting and breeding. This type of material should be therefore removed to the nearest refuse dump and steps should be taken to prevent the further accumulation of debris. Piles of industrial refuse, including damaged packing cases and building materials, deposited on patches of waste ground close to buildings are often a particular source of trouble.

All plant growth likely to harbour rodents or to conceal their activities should be cut down and removed. Tangled undergrowth should be cut back around buildings, and tree branches that could give rodents easy access to roofs should be removed.

**Rodent proofing**

Rodent proofing is really part of the process of environmental improvement considered in the previous section, but it is important enough to merit separate
Proofing is concerned chiefly with the complete exclusion of rodents from certain parts of the environment rather than with making an area less acceptable to them. In rodent proofing a building, for example, the aim is to prevent rodents gaining access to the inside of the building, moving from one room to another, and entering cavities in the fabric in which they could nest. Such proofing is often simply a matter of finding all openings more than 6 mm wide (the smallest hole that a young mouse can enter) and stopping them with suitable rodent-proof material. Particular attention should be paid to spaces under doors (Fig. 35) and where pipes pass through walls (Fig. 36), windows and other openings that must be kept open for purposes of ventilation, and gaps between the tops of walls and eaves (Fig. 37). In some cases it may be possible to prevent access to open windows and caves by placing barriers along overhead cables and external pipes (Fig. 38). If the exterior wall of a building has a fairly rough surface, as is generally the case with ordinary brickwork, it may be necessary to apply a smooth band of paint about 100 mm wide (Fig. 38) to stop rodents from climbing up. If possible, the band should be below window height but more than 1 metre above ground level.

Many buildings in port areas that are used as transit sheds have more-or-less permanently open doors; others, on account of their dilapidated condition, may be extremely difficult to proof against rodents. Nevertheless, as much proofing as possible should be done in both these situations because restricting the number of routes of entry into a building, and the amount of harborage for rodents within it, is almost certain to produce some improvement.

The rodent proofing of other environmental structures should also be considered. The complete sealing of sewage systems to exclude rodents and other animals is fundamental to any public health programme. Rodent-proof covers should be kept over access points and the ends of ventilator shafts, and disused drains should be sealed off, if possible at the point of entry of the drain into the main sewer. Wherever there is evidence that rats are emerging from a sewer, the sewer should be excavated and repaired; a sign is the appearance of a rat hole in open ground without an accompanying mound of earth. Other underground structures such as drains for surface water and conduits for electrical cables should also be rodent proofed as far as possible.
Proofing can also prevent the occupation by rats of two commonly used outdoor nesting sites—namely, trees and harbour walls. Roof rats can be prevented from nesting in many types of tree by placing a metal collar around the trunk (Fig. 39), and Norway rats will be unable to live in harbour walls if cracks and holes above low-water mark are sealed with concrete.

So far, rodent proofing has been considered only in connexion with the repair and modification of existing structures. In many cases, however, it is evident that such work would not be necessary if the need to exclude rodents had been appreciated at the design stage of a building. Thus, the attention of local architects and builders should be drawn to the various activities of rodents that ought to be taken into account when a building is designed or erected, and to the minimum requirements for rodent-proof materials given below.

Probably the best guide to rodent-proof materials for use in any particular area is direct experience of which locally available building materials rodents have managed to penetrate and which they have not. It should also be remembered, however, that factors other than rodent activity may play an important part in determining the choice of material for a particular proofing job. Such factors may include, for example, the degree of expansion of hot-water pipes within a wall, the maximum weight of a vehicle likely to run over a piece of concrete, the extent to which local climatic conditions will cause metal to corrode, and so on. Thus, the following list of materials and simple specifications, while probably adequate for most rodent proofing operations in many situations, should be modified according to local experience and conditions.
follows internal haemorrhages, evidence for which is the blood often seen around the mouth and anus of dead and dying animals. The anticoagulants are cumulative in effect and in practice are used at low concentrations that require most animals to feed on the poison bait several times before a lethal dose is ingested. They are, therefore, often called "chronic" or "multiple-dose" poisons. The most important characteristic of the chronic poisons is undoubtedly their slowness to take effect, which ensures that a lethal dose is almost invariably ingested before an animal becomes too ill to feed. In other words, provided that the bait is sufficiently attractive to entice the rodents away from their normal food for a few days, complete eradication is assured. In addition, since other animals, in order to be affected by anticoagulants, would also need to eat large quantities of bait during a period of several days, and since a massive injection of vitamin K₁ is generally an effective antidote, these poisons are in most cases less hazardous.

Because they are generally very effective and safe, anticoagulants are nearly always the poisons of first choice. Sometimes, however, it is either essential or desirable to use an acute poison. For example, when a rodent population is found to be resistant to anticoagulant poisons, there may be no suitable alternative to an acute poison. On other occasions, there may be insufficient time to carry out a full anticoagulant treatment, or it may be expedient, and perhaps economical, to kill quickly as many individuals as possible in a large population of rodents and to complete the extermination with a slower acting, but ultimately more effective, poison.

Killing rodents with poison baits

Types of poison

Destroying domestic rats and mice by means of poison mixed with bait placed in carefully chosen sites is nowadays generally the most convenient and successful method available. The ultimate effectiveness of the method however, depends largely on the poison or type of poison that is chosen and the way it is used. Most of the rodenticides fall clearly into one of two categories. First, there are the acute or "one-dose" poisons that together form a miscellaneous assemblage of chemicals with a wide variety of physiological effects on the animals that eat them. All these poisons act rapidly; once a rat or a mouse has started to eat bait containing an acute poison, it will begin to feel the effects in about half an hour. Thus, only a relatively short time is available for an animal to ingest a lethal dose. Moreover, some individual animals, having suffered the effects of a sublethal dose, may refuse to eat the same poison or the same bait again for a period that may be as long as several months. This phenomenon is generally referred to as "poison-" or "bait-shyness". Therefore, the successful use of acute poisons largely depends on getting the rodents to eat as rapidly and as continuously as possible during their first evening meal, and on using different poisons and baits, or completely different methods, to eliminate any survivors.

In contrast to the acute poisons, the anticoagulant rodenticides all have a similar physiological effect—namely, preventing the clotting of blood. Death generally follows internal haemorrhages, evidence for which is the blood often seen around the mouth and anus of dead and dying animals. The anticoagulants are cumulative in effect and in practice are used at low concentrations that require most animals to feed on the poison bait
attractive by incorporating sugar at the rate of 5% by weight. In places where baits tend to become mouldy rather quickly, a fungistatic substance, such as parani­trophenol (0.25% by weight) or dehydroacetic acid (0.1% by weight), may be added to the bait. Unfortunately, both the chemicals mentioned tend to lower the bait’s palatability to rodents. Paraffin wax can also be usefully incorporated into baits to prevent deterioration due to damp and mould.

Nowadays, it is possible in many places to buy ready-to-use baits that already have a poison incorporated. They are often rather expensive and, of more importance, the user cannot readily change the bait when the need arises. It is generally better, therefore, to obtain a poison concentrate and mix it with a freshly prepared bait. The bait ingredients may be any of those already mentioned, but there are plenty of other possibilities and the rodent control officer should not hesitate to try new baits when it seems necessary.

**Using acute poisons**

The various acute poisons used as rodenticides, and the concentrations at which they should be mixed with bait, are given in Annex 2 together with the names of the rodents against which they are effective. When acute poisons are used, unpoisoned plain baits of the same type that will later be mixed with the poison should generally be laid down at first, this procedure is called “prebaiting.” Small quantities of bait—about 50-100 g for rats and 10 g for mice—are placed wherever traces of rodents have been found and, in particular, as close as possible to the places where the rodents are living, burrow entrances, for example, and along their runs, so that they will be induced to feed on the bait before they reach their normal food source. For mice, which often do not feed for long in any one place, many small baits, rather than a few large ones, should be laid down. As far as possible, baits should be laid under cover and, where necessary, protected from other

**FIG. 40**

VARIOUS MEANS OF PROTECTING POISON BAITS LAID DOWN FOR RODENTS

- Plank against wall
- Wooden box (450 x 300 x 150 mm)
  - with lid removed and holes at ends (60 x 60 mm)
- Wooden or metal tray (200 x 150 mm)
- Polythene bag
  - stapled at end and slit in the middle
- Pitch-fibre pipe (600 x 150 mm)
  - ends partly closed by wooden ring with 60-mm diameter hole
  - and held in place by a wooden wedge
animals and the weather. Adequate protection can often be constructed from materials, such as bricks and planks, already available in the vicinity, but sometimes it will be desirable to use special bait containers, like those shown in Fig. 40.

Once prebaiting sites have been chosen, they should be visited every 1–2 days and fresh bait laid down where necessary. In places where all the bait has been eaten, it is a good rule to lay down at least twice as much fresh bait as on the previous occasion. The main purpose of prebaiting is to induce the rodents to eat freely from the bait stations before poison bait is laid down, and it is particularly necessary when Norway rats are to be controlled since many of them tend initially to avoid new objects, even piles of food, placed in their environment. Once their purpose has been achieved—in about 4–8 days—all prebaits should be removed and those that have been eaten by rodents should be replaced by the same type of bait containing poison. The poison bait should be left for one or two nights, and during that time the treated area should be disturbed as little as possible, particularly during the first few hours of the first evening. Immediately after the poisoning operation, all uneaten poison bait, and all dead rodents, should be collected and disposed of by incineration or deep burial. Burrows should be filled in and, as far as possible, all other obvious traces of rodents should be removed.

A few days after the poison bait has been removed, by which time animals that have eaten only a sublethal dose will have had time to recover and become active again, the treated area should be examined for fresh rodent traces. Any places where rodents still appear to be active should be rebaited with a different unpoisoned bait, and if any of it is eaten, it should be replaced with poison bait containing a poison different from that used in the previous treatment. These changes of bait and poison are desirable in case the rodents have become shy of previously used baits. This process of retreatment should continue until all the rodents have been killed.

In situations mentioned previously, when time is important, the use of acute poisons with prebaiting may have little, if any, advantage over anticoagulants and it is then necessary to put down baits containing acute poisons at the outset, a method usually called "direct" poisoning. The most effective direct poisons for rats are almost certainly sodium fluoroacetate, fluoroacetamide, and thallium sulfate, but they are among the most hazardous substances to man and other animals, and they should be used only by very experienced operators in places, such as locked warehouses, where access by man and animals can either be prevented or very strictly controlled. In other places, less hazardous acute poisons must be used.

Using anticoagulant poisons

When anticoagulants are to be used (see Annex 2 for names of poisons and concentrations to use), the poison should be included in the bait at the start of the treatment. However, the numbers and types of baiting station, and the need to protect the bait are the same as for acute poisons. On the other hand, if larger quantities of bait are laid down initially at each station—say, 25 g for mice and 200 g or more for rats—and further liberal quantities are put down when necessary at subsequent visits, intervals between visits can be longer. It is important that there should be a surplus of anticoagulant bait at each station every night of the treatment until no more bait is being taken. At this stage, all obvious rodent traces should be removed as far as possible and a survey made for fresh traces a few days
systematically carried out, can deal effectively with even more if it is later found to be needed. The bait also be placed along the routes that rodents are likely to take to reach an infested site. Permanent baiting, if should be checked about once a month and replenished or changed when necessary. Similar bait stations should preferably be a solidly constructed container holding about 3 mm deep and Cy metre long, and further applications should be made as necessary during the course of a treatment. Anticoagulant powder should not be used in places where it is likely to contaminate foodstuffs or where it will be rendered non-sticky by becoming too damp.

All rodent carcasses discovered during the treatment should be incinerated or deeply buried. Uneaten poison bait should also be removed and destroyed unless it has been decided to use anticoagulant bait on a permanent basis.

Permanent baiting
Once a particular site has been cleared of rodents, action must be taken to prevent further trouble or, at least to keep it to a minimum. Mention has already been made of the part that can be played by co-ordinated area-wide control, environmental improvement, and rodent proofing in preventing reinestation. Nevertheless, there will always be many rodents outside a port area and some will eventually enter the area and find a few places where they can settle down and breed. In protecting these places, permanent baiting with anticoagulants can play a major role.

All places that are liable to become infested by rodents in a port area, whether or not they are known to have been infested previously, should have anticoagulant baits laid in and around them. Each bait station should preferably be a solidly constructed container holding about 500 g of anticoagulant bait, or even more if it is later found to be needed. The bait should be checked about once a month and replenished or changed when necessary. Similar bait stations should also be placed along the routes that rodents are likely to take to reach an infested site. Permanent baiting, if systematically carried out, can deal effectively with most, if not all, domestic rats that attempt to recolonize a cleared urban area; the area can therefore be maintained more or less rat-free. The value of this method in dealing with rats in large rural areas or with mice in any large area has not yet been proved.

Finally, if a few anticoagulant rodent baits are distributed among cargoes when they are packed into large containers for shipping overseas, the importance of such containerized cargo in spreading rodent-borne disease will be kept to a minimum. Alternatively, if it is practicable, cargoes can be fumigated inside the container, thus killing both rodents and fleas at the same time.

Resistance to anticoagulants
One of the most significant aspects of rodent control in recent years has been the appearance among the domestic species of individual animals physiologically resistant to anticoagulant rodenticides. Fortunately, this phenomenon seems so far to have been more or less confined to a few countries in western Europe. It has been recorded in the Norway rat from several areas in the United Kingdom and from one area each in Denmark, the Netherlands, the Federal Republic of Germany, and the USA. Resistance in the house mouse appears to be well documented only in the United Kingdom, where it is not infrequent. On the other hand, resistance to anticoagulants in the roof rat has apparently not yet been detected. Recently, however, a case of resistance to warfarin in Rattus rattus has been reported from the Port of Liverpool, England, and there is an obvious possibility that resistant rats may be transferred by shipping to other seaports. It seems almost certain that resistance will eventually become widespread in domestic, and probably other, rodents and it is, therefore, important that rodent control officers are able to recognize it and understand its significance.

Once anticoagulant bait has been laid down, any normally susceptible Norway rat that feeds on it will almost invariably have stopped feeding and will have died after 3 weeks, and most will have done so much sooner. Comparable periods for roof rats and house mice are probably about 4 and 5 weeks, respectively. It may very occasionally happen that there is a great deal of migration into a treated area, and feeding on the bait continues for much longer, but in this case the amount of poison bait eaten is likely to fluctuate considerably and evidence that the poison is still effective can be expected in the form of recently dead animals. If, on the other hand, feeding on the bait continues at a relatively high and constant level, or even rises gradually, and no further dead rodents are found, it is very likely that the surviving rodents are physiologically resistant to the poison.
At this stage, and especially if this is the first suspected case of resistance for a particular species of rodent in a certain area, some of the rodents should be trapped for careful tests in a laboratory if suitable facilities are available for this purpose. In any event, the circumstances of the case should be reported to any official organization responsible for rodent control in the country concerned and also, if possible, every effort should be made to eliminate the surviving rodents with any method not involving anticoagulants. Complete elimination of resistant rodents is important because resistance to anticoagulants can be passed from parent to offspring. Thus, resistant rodents that migrate may establish resistant populations elsewhere. The spread of resistance is accelerated by the use of anticoagulants, since they kill susceptible animals and leave only the resistant ones. The appearance of resistant rodents in an area means that the less-effective acute poisons must be used and any idea of keeping an area virtually rodent-free by using permanent baits has to be abandoned.1

Using poisons safely

The need to protect animals and man from contact with poison bait by keeping it under cover and removing it when a treatment is completed has already been mentioned. These precautions can be helped if the operator keeps a record of all the bait stations and displays suitable warning notices in places where the baits may suffer from human interference. When the bait is of such a nature that it could readily be mistaken for human food, a dye—preferably blue or black—should be added. Chlorazol Sky Blue (0.05% by weight) is very suitable for this purpose since it seems not to be distasteful to rodents.

All poisons and poison baits when not in use should be kept in a locked container, and a special room in which no eating or smoking is permitted should be reserved for mixing poison bait. Operators responsible for mixing or laying poison bait should wear rubber or plastic gloves that should be washed before being removed.

If there is any danger that particles of poison might be inhaled, gauze masks should be worn by operators except when cyanide gassing powders are being used. The latter readily give off a highly dangerous poisonous gas (hydrogen cyanide) when they become moist, and operators should wear a gas mask when applying these powders.

Killing rodents by other means

General

Methods of killing rats and mice other than with poison baits are generally either relatively ineffective or only appropriate in rather special situations. Amongst the former may be mentioned cats and other predators which, while they may tend to keep a site free from reinestation, cannot be expected to control adequately rodent populations already present. Only poor results also can be expected from shooting and hunting with dogs or ferrets. The use of cultures of certain varieties of the bacterium Salmonella enteritidis mixed with bait has apparently been more successful, but since this organism can cause food poisoning in man, its use as a rodenticide is in any case strongly to be discouraged. Research workers in a number of countries have begun to examine the possibility of controlling rodent populations with chemicals that will inhibit reproduction, but there is no indication that such methods are yet ready to replace techniques for killing rodents. Among the latter, and still deserving some attention, are the use of traps and poison gases.

Trapping

Usually, the best traps to use are break-back traps activated by a treadle, the trap being placed at right angles to a run with the treadle across it (Fig. 42). For rats, the traps should be left unset for several days to allow the animals to get used to moving freely over them. For mice, a smaller trap should be used and this can be set the first time. Break-back traps can also be nailed to beams or wired to pipes to catch rodents on overhead runs.

Trapping is rarely an effective method of controlling medium–large infestations, but it may be the quickest way to eliminate the few survivors of a poison treatment that have been found difficult to attract to bait. For this purpose, good results can only be expected if traps are placed liberally all over the infested area.

Gassing

Rodents living in burrows can be gassed by placing a teaspoonful of cyanide gassing powder well inside each burrow entrance, which is then blocked. The treatment should be repeated each day until all reopened holes remain closed. This method should only be used in well-consolidated ground away from buildings when the weather is neither wet nor windy. Pellets of aluminium phosphide have also been used in a similar way to control some field rodents, but they have not yet been adequately tested against domestic rodents.

1 A test kit for determining the susceptibility or resistance of rats to anticoagulants is available from Vector Biology and Control, World Health Organization, 1211 Geneva 27, Switzerland.
Using fumigants, such as methyl bromide, it is possible to treat individual stacks of commodities, large containers, or even whole buildings if the latter are rendered gasproof before the operation begins. Such work, which is best left to the specialist, is often carried out against insect infestations in stored food, and it is worth remembering that fumigation designed to kill all insects will almost certainly kill all rodents as well. However, it is rarely worth fumigating against rodents alone while poison baiting remains effective and much cheaper.

Evaluation

As indicated earlier, successful area control depends on the properly co-ordinated activities of a large-enough team using the correct control methods, but an integral and essential part of the operation is to check that the required activities are being carried out in the right way and that good results are being achieved. The control methods have already been described; the number of men needed to apply them and to check that they are used correctly will vary considerably from place to place, and can probably be discovered only by experience. Checking that the proper control methods are being used effectively will largely depend upon a particularly experienced man making independent inspections of selected sites, either while a treatment is in progress or immediately afterwards. On some occasions, it may also be important to make checks again later to see that any necessary proofing or other environmental improvement has been correctly carried out. The operator should be encouraged to produce a written record of what he has done and the progress of the treatment but good operators who have the ability to keep satisfactory records are very rare indeed, and it is probably wise not to expect, or even to ask for, too much in this direction.

On the other hand, to evaluate the success of rodent control in a whole port area, records of some sort, even if only very simple ones, are essential. The first requirement for keeping adequate records for this purpose is a map of the area on a large enough scale—say about 1:5 000—to show all the individual sites that can be regarded as natural units for the purposes of rodent control. A site may be an individual dwelling house, a block of flats, a patch of derelict ground, a section of river bank, a warehouse and an adjacent wharf, or an aircraft hangar; in fact, whatever seems the most appropriate natural unit in a particular place. All sites should be listed so that a complete inventory is available of the type and location of all places that are liable...
to become infested with rats and mice. It is then possible to record when each site was inspected, whether it was infested, and by which species of rodent. These simple records should be summarized every year to reveal what proportion of the total number of sites has been inspected each year and what proportion of the total number has been found to be infested by each rodent species. Comparisons of results from successive years should show what improvements, if any, have taken place.

If no previous systematic rodent control work has been done in an area, it will be necessary to start with a survey of every possible site. Experience indicates that such a survey often reveals an infestation level of over 10% of all sites inspected, and it may be very much higher. Once an infestation has been treated, and permanent bait has been laid, it may be possible to confine inspections to those places from which complaints are received—provided, of course, people have been asked to make complaints—and any places such as river banks and waste-ground, about which complaints are unlikely. In that case, it should be possible to maintain the annual infestation rate, at least for rats, at less than 1%. It will generally be desirable, however, to check periodically by further inspection that complaints about rodents are revealing all the infestations, and suitable publicity should be used to encourage personnel and members of the public to make such complaints.

Once the infestation rate has been reduced to a relatively low level, all further infested sites should be plotted on the map and this will help to show where more work can usefully be done to prevent further reinfestation. It may also be worthwhile at this stage to summarize the annual infestation data according to the type of site to see whether any particular environments are creating special problems. Properly planned area-control of rodents should be a continuous process of evaluation and improvement where this is seen to be practicable and desirable.
CHAPTER 4

VECTOR CONTROL IN SHIPS

GENERAL

As far as vector control is concerned, ships may be considered as warehouses or hotels, or as a combination of both, similar to those on land. They harbour the same vectors and pests, and the same prevention or control procedures can be used. The major difference, and one of particular importance, is that ships continually move from place to place and the home range often consists of large segments of the world. Insects, rodents, and many other pests may invade ships in one part of the world and be transported to some other place where they may become established. Thus quarantine regulations for ships must be drawn up and enforced by the quarantine services to prevent the international spread of disease.

Whatever the type of ship, the presence on board of insects pests and rodents depends upon a number of factors connected with:

1. the sanitary conditions in the ports entered, their degree of infestation and, in some cases, the geographical area in which the port is situated;
2. the nature of the cargo taken on board; and
3. the general state of cleanliness of the ship, which depends on the interest shown by the captain and the owners in hygiene and in general preventive and control activities. If control measures are applied continuously in every port, and if the goods embarked are subjected to inspection and vector-control procedures, if necessary before they are taken on board, any search for vectors on board a ship will very often produce negative results. However, a pest-free seaport would be the ideal and ships calling at such ports would almost certainly remain pest-free.

In dock, ships can be invaded by a wide variety of insects and rodents that are found in the immediate port area. They may also become infested by species originating considerable distances from the port and which are transported to the ship in cargo or stores. Thus every ship must have at least one well-trained person responsible for vector control work and additional help should be available to carry out inspections and control activities.

SURVEYS

The first stage of vector control should be a thorough survey of the entire ship to locate: (1) areas that are supporting vector production; (2) sites that could harbour any stage in the life cycle of a vector; and (3) any potential breeding area. Plans of each structural level of the ship should be used and all actual or potential vector sites should be plotted during the inspection. If plans are not available, outline drawings will serve the purpose. All parts of the ship should be examined, including superstructures and cabins, the engine and boiler rooms, lifeboats, all compartments in the forecastle and poop, the crew's quarters, the holds, and the propeller-shaft housing. Special attention should be given to those areas above deck which, being exposed, could hold fresh water from precipitation and support the production of Aedes aegypti.

The details of the inspection will vary according to the type of ship, and larger vessels require considerably more time. A complete knowledge of the ship's layout will provide information relating to the areas preferred by insect vectors and rodents. The survey should include a search for signs of rodent activity, and for water, food, and harbourage, that could support either rodents or insects.

CONTROL ACTIVITIES

Control consists of eliminating vector habitats, modifying habitats so that vectors and rodents are excluded, and applying chemical control agents. An additional activity, common to all phases of control, is to provide passengers and crew with information about vector control activities and to seek their co-operation. Quite often, this approach makes vector control in ships much easier to accomplish.
Environmental improvement

The primary concern of vector control aboard ships is to eliminate, if possible, any places that are favourable for the production and support of vectors. These activities include work to be carried out during maintenance and repair operations. The person responsible should make certain that large but necessary structural opening above deck are screened. Screening to exclude *Ae. aegypti* mosquitos should be BS 200 (750-μm) mesh. To exclude rodents, openings should not be wider than 6 mm (to exclude young mice) and rodent-proofing materials must be hard enough that rats cannot gnaw through them and thick enough that they are not easily torn or dented. Galvanized iron sheet about 1 mm thick or woven wire-cloth made from 1-mm gauge wire are suitable proofing materials.

Since ships are continually becoming reinfested, particularly from certain types of cargo, environmental improvements and proofing also serve to confine these reinfestations, or to restrict the area of the ship in which they occur, and thus simplify the eradication programme. Repairs and proofing that are not accomplished during routine maintenance operations should be listed together with specifications, for inclusion in the programme of work to be done during the annual dry-docking, and every effort should be made to have them carried out.

Sanitation

Good sanitation is very important in ships. It can be justified on the grounds of safeguarding health and preventing the international transmission of disease, while for economic reasons, the aesthetic importance of proper sanitation, particularly when passengers are involved, cannot be underestimated. However, when food, water, and harbourage materials become available to vectors and rodents through improper storage and waste, disposal, sanitary measures are fully justified on these grounds alone.

The occurrence of many activities aboard ships frequently leaves inadequate time for proper sanitary practices to be carried out. It is important that sanitation work should be placed on an equal footing with other functions for both health and economic reasons. Owners and ships’ officers should be well informed on the importance of good sanitation so that the necessary measures are taken as an expression of pride in a well-run ship rather than on account of regulations.

Insects and rodents need food and water but the water requirements of insects are negligible (except for those that have aquatic stages in their development) and this approach to control is impracticable. The access of rodents to a supply of fresh water can however be prevented and this is an important method of control, particularly if no food is available to them. It is important, therefore, to (1) store edible materials in insect- or rodent-proof rooms and containers; (2) keep all places where food is handled as clean as possible at all times; (3) keep waste food material in tightly covered, insect- and rodent-proof containers; (4) dispose of accumulations of refuse and garbage at frequent intervals; (5) clean waste-disposal chutes (if provided) after they have been used.

Further information on general sanitation practices and rodent proofing aboard vessels is contained in the *Guide to ship sanitation.*

Chemical control

Since insects of many kinds may be taken aboard a ship in cargoes and stores, port and shipping authorities should both be concerned with, and should co-operate in making, inspections and carrying out treatments. Flies may be numerous in cargoes of copra, castor oil seeds, and in oil seeds in general, transported in bulk. Bones and bananas may be highly infested, though to a lesser extent when carried in plastic sacks or containers. Materials packed in jute sacking and exposed to prolonged weathering on loading wharfs will ferment and become a breeding habitat for flies when placed in a ship's hold. Cockroaches are common in cargoes of flour and fleas usually accompany animals on board. Rats and mice may be found in many types of cargo, but may also enter ships independently. Flying insects usually have easy access to ships in port and, as the vector of yellow fever, *Ae. aegypti* is particularly important in this respect.

When they are present in port areas, gravid female *Ae. aegypti* may fly into a ship and deposit eggs in many types of water container. This mosquito is often transported in the egg stage and various kinds of container (even depressions in canvas coverings) may be a source of infestation in a ship if such containers are exposed and collect rain water.

The techniques of using chemicals to control vectors and rodents in ships are the same as those described in previous sections for control in ground installations, particular emphasis being given to the methods and materials for space treatment. Additional information is also given in Annex 2. It is most important that the specified precautions should be taken to avoid contaminating cargoes and foodstuffs. Modern methods of vector control will give excellent results in ships. Insecticide-impregnated cords and baits, and dichlorvos strips are easily used and work very well in enclosed

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spaces against many species of insect. Very promising results have been obtained in experiments on rat fleas. Rodents may be controlled by the methods described in Chapter 3. Trapping is successful for the rodents taken aboard modern rat-proof ships with cargo; however, it is only successful in very limited infestations and if it is applied very soon after the infestation occurs. Massive infestations are best handled by sanitary measures and a well-developed programme of poisoning, using anticoagulants or acute poisons as dictated by the conditions. On some occasions fumigation with toxic gases (hydrocyanic acid gas, for example) may be used, but this is a dangerous and inconvenient technique that is best reserved for use when the whole ship can be subjected to fumigation or if plague is present or suspected. It may be only be possible when the ship is in dry dock.

International health regulations require that every ship shall be either (1) periodically deratted, or (2) kept permanently in such a condition that the number of rodents on board is negligible. Deratting by fumigation or poisoning with acute poisons can be most effective if properly done but it is at best very temporary. Ships can easily become reinfested in a week or even less by taking on board rat-infested cargo. It is most important, therefore, that a single deratting operation should be followed by a continuous, well-organized control programme on all ships.
CHAPTER 5
VECTOR CONTROL IN AIRCRAFT

GENERAL

Present-day air transportation is so rapid that disease from one part of the world may be spread to another before the recognizable symptoms of the disease become apparent.

Many species of mosquito and other insects of medical importance have, in the past, been recovered in association with international air traffic and certain new distribution records have been reported for exotic species of insects introduced into different territories by this means. Until such time as ports and cargoes are totally free of insect vectors and other vermin, disinsection of aircraft will remain a major concern in international health. The International Health Regulations (see Annex 4) recommend that the crew and other airline personnel should apply measures for insect control, such as the inspection and disinsection of aircraft. Provision is also made in some of the regulations for the prevention of the spread of specific vector-borne diseases.

WHO Expert Committees on Insecticides have stipulated certain insecticidal aerosol formulations considered to be appropriate for the disinsection of aircraft, while the Twenty-First World Health Assembly, meeting in Geneva, passed a resolution on 24 May 1968 recommending to Member States that, for disinsecting aircraft in international passenger and freight traffic, the methods approved by WHO should be used.

SPECIAL CONSIDERATIONS

The advances in structural design, aerodynamics, materials, and controls of modern aircraft require the best products and materials to be used. These components pass rigorous tests to eliminate hazards from fire or toxicity and to establish ease of maintenance. The electronic and electrical systems are highly sensitive and delicate, and vital to the proper functioning of the aircraft. Failure of any of these materials or systems is highly dangerous. Since many of the materials are of synthetic origin, it is most important that any chemicals that might be introduced for vector control purposes should be evaluated for safety in use. The effect of vector control formulations on aircraft surface furnishings is a major consideration that has to a large degree determined the type of insecticidal aerosol approved for use in these aircraft.

The effect of insecticide aerosols on the passengers and crew is of equal concern; the health, comfort, and safety of all those in the aircraft must be protected by the instructions concerning the disinsection measures to be used in aircraft. Certain insecticidal materials presenting risks of toxicity to man have been discarded; repeated toxicological tests and years of in-service exposure of airline and quarantine personnel, as well as many thousands of passengers, to approved insecticidal aerosols have failed to indicate any serious clinical disorders arising from their use. However, other aerosols are currently being evaluated as alternatives for use in countries where other materials are preferred.

The bringing into service of “jumbo” jet aircraft has complicated in several ways the problems faced by the various health administrations in their efforts to prevent the introduction of arthropod-borne diseases and insect vectors. The greater size of the aircraft to be treated requires higher expenditure on control materials and increases the size of inspection teams needed to maintain surveillance.

The appearance of supersonic aircraft in the next few years will increase still further the demands upon the various government agencies to accelerate their inspection and control activities. In addition, relatively short flying times will make it necessary to use quicker-acting pesticides to ensure the death of all insects before the aircraft’s arrival at another airport.

Vertical take-off jets will pose all the problems to health authorities that are, or will be, presented by conventional, jumbo, and supersonic aircraft. Recent demonstration flights of prototype aircraft have shown not only the usefulness of these carriers for moving
passengers from one urban area to another, but also
the enhanced danger of introducing insectborne diseases
into densely populated areas.

Containerized cargo processed for transportation
by air is being effectively employed by many airlines
throughout the world. Aircraft that are specifically
designed for carrying either freight or passengers can
be modified to permit the installation of massive cargo
containers, which are loaded ahead of flight time and
fitted tightly into the available space. It is often impos-
sible to inspect these cargo carriers and difficult for
aerosols to penetrate the cargoes once they are aboard
the aircraft. Thus, this type of cargo processing
offers excellent opportunities for mosquitoes and other
insect vectors, and rodents and their ectoparasites to
be transported internationally. Nevertheless, contain-
erized cargo handling has great operational advan-
tages, and with the utilization of larger aircraft the
vapourization of insecticides, such as dichlorvos, inside
containers and aircraft will provide effective controls.

**ACCEPTABLE METHODS OF INSECT CONTROL**

Efforts to standardize aircraft disinsection proce-
dures at the international level were first made by the
International Sanitary Convention for Aerial Naviga-
tion. WHO Expert Committees on Insecticides have
attempted since this time to modify the techniques and
procedures and to make them applicable to the com-
plex and continually changing patterns of air traffic.

The Eleventh Report of the WHO Expert Committee
on Insecticides in 1961 reviewed the evidence that had
accumulated since the Seventh Report in 1957, and
made recommendations; the basic principles of this
report are still appropriate although the specific
details were modified and enlarged upon by the World
Health Assembly in 1968.

It is most essential that all aircraft engaged in inter-
national traffic should be properly disinfected with an
effective insecticidal aerosol applied at an appropri-
te time and in an effective manner.

**Aerosols**

A pressurized formulation of insecticidal materials
that can be discharged from a container as an aerosol
provides the basis for all recommended aircraft dis-
infestation procedures at the present time.

Any aerosol formulation may be used if its biological
effectiveness has been shown to be equal to, or better
than, that of the standard reference aerosol (see
Annex 3) and the other characteristics of the alternative
formulation and its dispenser have been shown to con-
form to, or exceed, the specifications for aerosol
formulations and dispensers.

Excluding the dichlorvos vapour system, the use
of insecticidal aerosols has proved to be the most
effective and practical way to assure the control of
most species of potentially harmful disease-carrying
insects that can gain access to the interior of an air-
craft and is the least troublesome and objectionable
means of application. The cloud of insecticide spreads
rapidly to most parts of the aircraft. When aerosols are
properly applied there is no staining of aircraft interi-
ors or clothing, and the odour, although somewhat
disagreeable to many passengers and crew members,
quickly passes and is generally soon forgotten. Other
means of applying insecticides in aircraft are unsatis-
factory. Aerosol particles are very small in size but can
impinge and remain upon various surfaces and in
certain instances cannot penetrate into spaces that are
blocked by luggage, clothing, etc. For this reason, the
operator should direct the insecticidal discharge into
all spaces that could shelter mosquitoes and other insects.

The primary insecticidal ingredients in all aerosols
available at present are pyrethrins and DDT but aero-
sols without DDT will soon become available.1 To kill a
susceptible insect, these materials must come into
actual contact with it. The pyrethrins are rapid knock-
down agents and have no effective residual activity;
DDT remains toxic for a longer period of time and
has a prolonged residual activity. It should not be
expected, however, that residual activity will lead to
any effective control of insects on aircraft, even after
aerosols have been in continual use for several months,
because the residues inside an aircraft are very minute
and soon disappear.

There is a constant need for control personnel to
be alert to insecticide resistance in insects occurring on
aircraft or in areas of insect-borne disease throughout
the world. The development of alternative insecticide
formulations for use in areas where resistant species
are known to occur has been advocated.

**Disinsection procedures**

Procedures for disinsecting aircraft have been laid
down in the *International Health Regulations* and are
reproduced in Annex 4. For pressurized aircraft, disin-
secting before take-off("blocks away") or disinsecting
on the ground on arrival, using an acceptable formu-
lation effectively employed, has been recommended.

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In applying aerosol formulations of insecticides all possible resting places for mosquitoes inside the aircraft should be treated, including cupboards, chests, clothing, and luggage and freight compartments. Particular attention should be given to spaces under seats and behind cargo and luggage where penetration and diffusion of the aerosol particles is slow and uncertain. Foodstuffs and galley utensils in the aircraft should be protected from contamination.

**Semiautomatic disinsection system**

Currently used aerosol disinsection methods for aircraft have a number of disadvantages. Among them, and of particular concern, is that a biologically effective concentration must be released that will reliably kill all mosquitoes in the aircraft. The distribution of aerosol by a member of the crew walking slowly down the cabin aisle may be subject to human error. Baggage compartments cannot be treated in flight, or on the ground after the aircraft is closed.

A new semiautomatic disinsection system developed after years of in-flight testing by the Technical Development Laboratories of the US Public Health Service is a most promising method of aircraft disinsection and is very effective in killing mosquitoes in all parts of the aircraft. The insecticide presently used in the system is dichlorvos.

The dichlorvos aircraft disinsection system is designed to distribute controlled amounts of dichlorvos vapour into the cabin, baggage compartments, and flight deck areas. It may be used with passengers and crew aboard while the aircraft is moving on the ground or while it is airborne. The system cannot, by accident or intent, produce an overdose and people are unaware of its operation because odour and visible evidence are imperceptible. Since the system operates semiautomatically the only attention required is for a member of the crew to place a specially designed insecticide cartridge on a holder and press a “start” button; this procedure takes 15–20 seconds. A small air-compressor forces ambient cabin air through the cartridge containing an absorbent membrane charged with a small amount of dichlorvos. The air stream carries the insecticide vapour to all areas of the aircraft through a system of heated tubes with selectively spaced outlet orifices. The tubes extend the length of the cabin and side branches lead into the baggage compartment and to the flight deck.

The dichlorvos vapour mixes with the incoming stream of conditioned air as it enters the cabin and flight deck, and diffusion and convection currents carry the insecticide into hidden and semiclosed spaces. The vapour is dispersed for a period of 30 minutes and the system stops automatically. The concentration of vapour in the air of the cabin quickly reaches an equilibrium value that cannot be exceeded. The effectiveness of the insecticide vapour is directly related to the concentration and the duration of the application. It has been repeatedly shown that flies and mosquitoes die when they are exposed to air containing 0.0000002 g of dichlorvos vapour per litre for 30 minutes. This is exactly the amount of insecticide the system is designed to maintain. As soon as the discharge stops, all the vapour in the aircraft is rapidly eliminated by the air-replacement system.

The concentration of dichlorvos produced by the disinsection system is safe for man, as shown by routine and intensive toxicological studies of the insecticide. A comprehensive toxicological experiment some years ago showed conclusively that passengers and crew were unaffected, even though they were exposed several times on flights. Although this system of disinsection is still subject to exhaustive operational testing, it has been shown to be highly effective and should be a major advance in preventing the dissemination of disease vectors. It will be effective in treating the larger aircraft now coming into service as well as those planned for the future.

Since the dichlorvos vapour system is more efficient and foolproof than presently used disinsection methods, it will directly affect the airport health services by reducing the time and manpower required for inspection. However, until such time as the system comes fully into use, it is essential that control using “blocks-away” and arrival treatments should be intensified and that careful inspections should be made by qualified personnel.

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**RODENT CONTROL**

Rodents have occasionally been found in cargo transported by aircraft. The high speeds of modern aircraft and the great distances covered enhance the risks arising from rodent transportation. The danger of introducing plague organisms into a country is of particular concern when the cargo, which may contain rodents and fleas, comes from an area where plague is endemic. Rodents aboard an aircraft are also a threat to safety since they may damage vital cables and wiring systems. It is obvious that insect and rodent control
operations in airports are the most effective preventive measures that can be taken. Control methods described in previous chapters are applicable to airports. To prevent the spread of plague from endemic areas by way of infested containerized cargo, dichlorvos resin strips can be used at the rate of one strip to every 9 m$^3$. It appears that complete kills of adult *Xenopsylla cheopis* on rats can be achieved with a 24-hour exposure. Trapping is the recommended method of control when the presence of rodents suspected on aircraft; in this way the rodents are removed and the dangers arising from the use of poisons is avoided. Dead or dying poisoned rodents may become lodged in some part of an aircraft, preventing the proper functioning of an important system and thus causing serious difficulty or hazard.
ANNEXES
IDENTIFICATION OF VECTORS

GENERAL

It is important that quarantine officials and vector-control personnel should be able to recognize the main vectors of disease, should know how to collect specimens of these vectors, and should be able to identify them, at least approximately. The commonest and most important groups of vectors are the arthropods (including the true insects, ticks, and mites) and the rodents.

Arthropods are small or very small animals with jointed appendages (legs, etc.) and an external skeleton. The true insects (Class Insecta) are distinguished by having three body regions (head, thorax, and abdomen), three pairs of legs, one pair of antennae, and frequently one or two pairs of wings. Ticks, mites, and spiders (Class Arachnida) are distinguished by having one or two body regions, four pairs of legs, no antennae, and never any wings. The Key to some common classes and orders of arthropods of public health importance, reproduced in this Annex (Appendix I) includes all the more important groups. Additional information on these arthropods may be found in standard textbooks on entomology or medical entomology.

The Class Insecta contains five groups (orders) that are of major importance in public health— namely, Order Diptera, flies and mosquitoes; Order Siphonaptera, fleas; Order Anoplura, sucking lice; Order Hemiptera, bed bugs and triatomid bugs that transmit Chagas disease in South America; and Order Orthoptera or Blattaria, cockroaches. These five orders are illustrated in Appendix 1.

Order Diptera
The flies and mosquitoes are insects with one pair of wings, one pair of halteres, and usually blood-sucking or sponging mouthparts. The housefly and mosquitoes are the types of diptera most frequently encountered in aircraft, ships, or ground transportation vehicles that may be travelling from one country to another. Illustrated keys to the principal families of diptera (muscoid flies, anopheline and culicine mosquitoes) are given in Appendices 3, 6, 7, 12, 13.

Order Siphonaptera
The fleas are wingless insects with blood-sucking mouthparts, a body that is strongly compressed from side to side, and legs adapted for jumping. There are frequently “combs” on the head, thorax, or abdomen which are useful for purposes of identification. The most important species for public health are included in the Pictorial key to some common fleas (Appendix 9) or in An illustrated key to fleas found during plague investigations (Appendix 10). Additional information on fleas is given in the monograph on plague by Pollitzer.

Order Anoplura
The sucking lice are wingless insects with blood-sucking mouthparts, a body that is strongly depressed from top to bottom, and legs that are modified for clasping hairs. The pictorial key to lice commonly found on man (Appendix 11) shows the characteristics of the head, body, and crab lice.

Order Hemiptera
The group of true bugs includes the bed bug and triatomids, or kissing bugs; they are either wingless or possess one or two pairs of wings; the forewing, when present, is modified into hemi-elytra, the basal part being thickened and the outer part being membranous. The mouthparts are of the sucking type and include a segmented proboscis.

Order Orthoptera (Blattaria)
The cockroaches are insects with or without wings; the forewings, if present, have many veins arranged in a net-like pattern. The head is usually largely covered by the shield-like pronotum; the mouthparts are of the chewing type. The commonest domestic species are illustrated in Appendix 14, Pictorial key to some common adult cockroaches, and Appendix 15, Key to some common species of cockroach found in the USA.

Rodents
Many types of mammal are encountered by quarantine officials, the most important being the Norway, roof, and Polynesian rats, and the house mouse. Appendix 16, Field identification of domestic rodents, illustrates characteristic features of the Norway and roof rats, and the house mouse.

USE OF THE IDENTIFICATION KEYS

The reader is advised to study the illustrations and to learn the characters used in the identification of the various insects and rodents, the object being to learn to compare the actual insect or rodent with the illustrations given here.

Use the illustrations as much as possible to learn more about the characters used in the dichotomous identification keys. To use a key, start at the beginning and choose the line in the first couplet that agrees with the description of the specimen. The number on the right indicates the next couplet to be considered. A key is valid only for the species included in it, and if an attempt is made to identify a species that has not been included an incorrect determination will be made. More advanced and complete keys are available in various monographs and works of reference.

The following dichotomous keys, pictorial keys, and diagrams are included in Annex 1.

Appendix 1. Key to some common classes and orders of arthropods of public health importance

Appendix 2. *Aedes aegypti* larva, with external features labelled

Appendix 3. Key to larval mosquitoes found in receptacles

Appendix 4. Generalized adult mosquito, with external features labelled

Appendix 5. Comparisons of heads of male and female *Anopheles* and *Culex* mosquitoes, and lateral aspect of the thorax of a generalized mosquito

Appendix 6. Pictorial key to some common adult mosquitoes associated with *Aedes aegypti*

Appendix 7. Key to adults of receptacle-breeding mosquitoes

Appendix 8. Generalized adult flea, with external features labelled

Appendix 9. Pictorial key to some common fleas

Appendix 10. An illustrated key to fleas found during plague investigations

Appendix 11. Lice commonly found on man

Appendix 12. Pictorial key to principal families of diptera of public health importance

Appendix 13. Pictorial key to common domestic flies

Appendix 14. Pictorial key to some common adult cockroaches

Appendix 15. Key to some common species of cockroach found in the USA

Appendix 16. Field identification of domestic rodents

Appendix 1

KEY TO SOME COMMON CLASSES AND ORDERS OF ARTHROPODS OF PUBLIC HEALTH IMPORTANCE *

1. Three or four pairs of legs (Fig. 1A and 1B) .................................................. 2
   Five or more pairs of legs or swimmerets (Fig. 1C and 1D) .................................. 22

* Prepared by H. D. Pratt, C. J. Stojanovich & K. S. Littig, Training Branch, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
2. Three pairs of legs; antenna present (Fig. 2A). Class INSECTA (true insects) 3

Four pairs of legs; antenna absent (Fig. 2B). Class ARACHNIDA (scorpions, spiders, ticks, mites) 20

3. Wings present, well developed (Fig. 3A) 4

Wings absent or rudimentary (Fig. 3B) 12

4. One pair of wings (Fig. 4A). Order DIPTERA (2-winged flies) 5

Two pairs of wings (Fig. 4B and 4C) 6

5. Wings with scales (Fig. 5A). Family CULICIDAE Mosquitos

Wings without scales (Fig. 5B). Other DIPTERA Flies
6. Mouthparts, consisting of an elongated proboscis, adapted for sucking (Fig. 6A) .............................................. 7
   Mouthparts adapted for biting and chewing (Fig. 6B) ................................................................................................. 8

7. Wings densely covered with scales; proboscis coiled up under head (Fig. 7A). Order LEPIDOPTERA .................. Moths and Butterflies
   Wings not covered with scales; proboscis directed backward between front legs when not in use (Fig. 7B). Order HEMIPTERA ......................................................... True Bugs and Kissing Bugs

8. Both pairs of wings membranous and similar in structure, though they may differ in size (Fig. 8A) ................. 9
   Front pair of wings leathery or shell-like, serving as covers for membranous hind wings (Fig. 8B) ................. 10
9. Hind wings much smaller than front wings (Fig. 9A). Order HYMENOPTERA...Bees, Wasps, Hornets, Ants
Both pairs of wings similar in size (Fig. 9B). Order ISOPTERA...Termites

10. Front wings horny or shell-like without distinct veins, meeting in a straight line down the middle (Fig. 10A). Order ORTHOPTERA...Cockroaches, Crickets, Grasshoppers
Front wings leathery or paper-like with a network of veins, usually overlapping at the middle (Fig. 10B). Order COLEOPTERA...

11. Abdomen with prominent forceps; wings shorter than abdomen (Fig. 11A). Order DERMAPTERA...Earwigs
Abdomen without forceps; wings typically covering abdomen (Fig. 11B). Order COLEOPTERA...Beetles

12. Abdomen with three elongate, tail-like appendages at tips; body usually covered with scales (Fig. 12A). Order THYSANURA...Silverfish and Fire Brats
Abdomen without three long tail-like appendages at tips; body not covered with scales (Fig. 12B)
13. Abdomen with narrow waist (Fig. 13A). Order HYMENOPTERA
Abdomen without narrow waist (Fig. 13B)  

14. Abdomen with prominent pair of forceps (Fig. 14A). Order DERMAPTERA
Abdomen without forceps (Fig. 14B)  

15. Body strongly flattened from side to side; antenna small, fitting into grooves in side of head (Fig. 15A). Order SIPHONAPTERA
Body not flattened from side to side; antenna projecting from side of head, not fitting into grooves (Fig. 15B)  

16. Antenna with 9 or more segments (Fig. 16A)  
Antenna with 3–5 segments (Fig. 16B)  

Fig. 13 A

Fig. 13 B

Fig. 14 A

Fig. 14 B

Fig. 15 A

Fig. 15 B

Fig. 16 A

Fig. 16 B
17. Pronotum covering head (Fig. 17A). Order ORTHOPTERA. Cockroaches
Pronotum not covering head (Fig. 17B). Order ISOPTERA. Termites

18. Mouthparts consisting of tubular jointed beak; tarsi 3-5 segmented (Fig. 18A). Order HEMIPTERA. Bedbug
Mouthparts retracted into head or of chewing type; tarsi having 1 or 2 segments (Fig. 18B).

19. Mouthparts retracted into head, adapted for sucking blood (Fig. 19A); external parasites of mammals. Order ANOPLURA. Sucking Lice
Mouthparts of chewing type (Fig. 19B); external parasites of birds and mammals. Order MALLOPHAGA. Chewing Lice
20. Body oval, consisting of a single sac-like region (Fig. 20A). Order ACARINA. Ticks and Mites
   Body divided into two distinct regions, a combined head-thorax (cephalothorax) and an abdomen (Fig. 20B, 21A, 21B).

21. Abdomen joined to cephalothorax by slender waist; abdomen with segmentation indistinct or absent; sting absent (Fig. 21A). Order ARANEIDA. Spiders
   Abdomen broadly joined to cephalothorax; abdomen distinctly segmented, ending in sting (Fig. 21B). Order SCORPIONIDA. Scorpions

22. Five–nine pairs of legs in some species, swimmerets in others; one or two pairs of antennae; principally aquatic animals (Fig. 22A, 22B). Class CRUSTACEA. Crabs, Crayfish, Shrimps, Lobsters, Sow Bugs, Copepods
   Ten or more pairs of legs; swimmerets absent; 1 pair of antennae; terrestrial animal (Fig. 23A, 23B).

23. Body segments each with only one pair of legs (Fig. 23A). Class CHILOPODA. Centipedes
   Body segments each with two pairs of legs (Fig. 23B). Class DIPLOPODA. Millipedes
Appendix 2

*AEDES AEGYPTI LARVA*
Appendix 3

KEY TO LARVAL MOSQUITOS FOUND IN RECEPTACLES *

1. Air tube present; palmate hairs absent on abdominal segments (Fig. 1A) .......................... 2
   Air tube absent; palmate hairs present on some abdominal segments (Fig. 1B); (Genus Anopheles) .................. 22

2. Pecten present at base of air tube (Fig. 2A) ................................................................. 3
   Pecten absent at base of air tube (Fig. 2B) ................................................................. 20

* Prepared by Milton E. Tinker & Chester J. Stojanovich, Training Branch, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
3. Air tube with a single hair or tuft on each side; eighth abdominal segment with 1–3 rows of 6–21 comb scales (Fig. 3A)  
(Aedes atropalpus has 21–58 comb scales) ................................................................. 4

Air tube with several hairs or tufts on each side; eighth abdominal segment with a triangular patch of many (30–60 or more) comb scales (Fig. 3B) ................................................................. 12

4. Individual comb scales thorn-shaped with a strong median spine and stout lateral spines (Fig. 4A) .......................... 5

Individual comb scales slipper-shaped, evenly tapered with a fringe but no stout lateral spines (Fig. 4B) .................. 6
5. Many pecten teeth on air tube (10-19); anal segment not completely ringed by sclerotized plate; air tube not inflated; lateral spines on thorax long and curved; head hairs single (Fig. 5A, 5B, 5C) .......................................................... Yellow fever mosquito (Aedes aegypti)

Few pecten teeth on air tube (3-6); anal segment completely ringed by sclerotized plate; air tube inflated; lateral spines on thorax short and blunt; head hairs multiple (Fig. 5D, 5E, 5F) .................................. Psorophora conff URLSession 1

6. Anal segment not completely ringed by sclerotized plate (Fig. 6A) .................................................. 7

Anal segment completely ringed by sclerotized plate (Fig. 6B) .................................................. 10

\* Usually not found in receptacles.
7. Pecten with all teeth evenly spaced (Fig. 7A) ........................................... 8
   Pecten with one or more distal teeth more widely spaced (Fig. 7B) .................. 9

![Fig. 7 A](image)

![Fig. 7 B](image)

8. Anal segment without a light-coloured depression anterior to the lateral hair (Fig. 8A); larva dark ................................................................. Tree-hole mosquito (Aedes triseriatus)

   Anal segment with a light-coloured depression anterior to the lateral hair (Fig. 8B); larva light; Texas, Oklahoma, and Kansas, USA .................................. Aedes zoosophas

![Fig. 8 A](image)

![Fig. 8 B](image)

9. Tuft of hairs inserted on air tube within the pecten (Fig. 9A) ............................. Aedes atropalpus

   Tuft of hairs inserted on air tube beyond the pecten (Fig. 9B) ......................... Aedes vexans

![Fig. 9 A](image)

![Fig. 9 B](image)

* Usually not found in receptacles.
10. Air tube average length, 3-3.5 times as long as basal width; pecten not quite reaching middle of the air tube (Fig. 10A); upper head hair and lower head hair well barbed. Aedes mitchellae

Air tube short, 2-2.5 times as long as basal width; pecten reaching middle of air tube or slightly beyond (Fig. 10B); upper head hair and lower head hair smooth or finely barbed. Aedes sollicitans

11. Individual comb scale long and pointed apically (Fig. 11A); lateral abdominal hairs double on segments 3-5. Aedes sollicitans

Individual comb scale short and rounded apically (Fig. 11B); lateral abdominal hairs triple on segments 3-5. Aedes taeniorhynchus

12. Air tube without basal pair of tufts; 4-5 hairs or tufts of hairs beyond pecten (Fig. 12A); Genus Culex. Culex

Air tube with a basal pair of hair tufts; many hairs or tufts of hairs beyond pecten (Fig. 12B, 12C); (Genus Culiseta) Culiseta
13. Antenna with antennal tuft inserted at about middle of the shaft; air tube with a number of scattered single or double hairs (Fig. 13A, 13B) ................................. Culex restuans

Antenna with antennal tuft inserted beyond the middle of the shaft; air tube with most of the tufts with two or more branches (Fig. 13C, 13D) ................................. 14

14. Air tube moderately long, usually 4–6 times as long as basal width (Fig. 14A) ................................. 15

Air tube very long, 6–10 times as long as basal width (Fig. 14B) ................................. 16

15. Basal tubercle of hair tufts on air tube in straight line (Fig. 15A) ................................. Culex tarsalis

Basal tubercle of hair tufts on air tube not in straight line (Fig. 15B)

Southern house mosquito (Culex quinquefasciatus)
16. Upper and lower head hairs single or double (Fig. 16A) ........................................  Culex territans
   Upper and lower head hairs with 3–4 branches (Fig. 16B) ...........................................  17

   Fig. 16 A

   Fig. 16 B

17. Air tube with strong subapical spines (Fig. 17A); Texas, USA .....................................  Culex coronator
   Air tube without strong subapical spines (Fig. 17B) ......................................................  18

   Fig. 17 A

   Fig. 17 B

18. Thorax densely spiculate (spicules dark); lateral hair of anal segment usually single (Fig. 18A, 18B) ..........................................................  Culex nigripalpus
   Thorax with few or no spicules; lateral hair of anal segment usually double (Fig. 18C) ..........  Culex salinarius

   Fig. 18 A

   Fig. 18 B

   Fig. 18 C

* Usually not found in receptacles.
19. Air tube long, 6 or more times as long as basal width, pecten followed by row of tufts; tuft of antenna inserted near end of shaft (Fig. 19A, 19B) .......................... _Culiseta melanura_

Air tube average length, 2-4 times as long as basal width, pecten followed by row of hairs; tuft of antenna inserted at about middle of shaft (Fig. 19C, 19D) .......................... _Culista inornata_

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20. Large larvae without comb scale on eighth abdominal segment, simply a plate bearing four hairs (Fig. 20A) .......................................................... _Toxorhynchites rutilus_

Small-medium larvae with a double row of comb scales on eighth abdominal segment (Fig. 20B); (Genus _Orthopodomyia_) ....................................................... 21
21. Anterior row of comb scales about twice as wide as posterior row (17–23; 6–10); in the fourth instar the eighth abdominal segment with large dorsal plate; lateral hair on anal segment single (Fig. 21A); larva usually pink

   Orthopodomyia signifera

   Anterior row of comb scales only slightly wider than posterior row (12–17; 8–12); dorsal plate absent on eighth abdominal segment in all stages; lateral hair on anal segment multiple (Fig. 21B); larva usually straw-coloured

   Orthopodomyia alba

   ![Fig. 21 A](image1)
   ![Fig. 21 B](image2)

22. Outer clypeal hairs densely branched (Fig. 22A) ........................................ 23

   Outer clypeal hairs simple (Fig. 22B) .................................................. 25

   ![Fig. 22 A](image3)
   ![Fig. 22 B](image4)

23. Basal tubercles of inner clypeal hairs usually separated by at least the diameter on one tubercle; antepalmate hair usually single on segments IV and V (Fig. 23A, 23B) ........................................... Anopheles quadrimaculatus

   Basal tubercles of inner clypeal hairs usually separated by less than the diameter of one tubercle; antepalmate hair usually double or triple on segments IV and V (Fig. 23C, 23D) ........................................... 24

   ![Fig. 23 A](image5)
   ![Fig. 23 B](image6)
   ![Fig. 23 C](image7)
   ![Fig. 23 D](image8)

1 Usually not found in receptacles.
24. Abdominal segments 4 and 5 with several hairs with 3-5 branches or more in front of palmate hairs (Fig. 24A)  
   Abdominal segments 4 and 5 with a large single or double hair in front of palmate hairs (Fig. 24B)  
   Anopheles crucians  
   Anopheles punctipennis

25. Lateral abdominal hairs long and plumose on segments I-VI; all head hairs single (Fig. 25A, 25B); larvae small  
   Lateral abdominal hairs long and plumose only on segments I-III; many of the head hairs branched (Fig. 25C, 25D); Texas, USA  
   Anopheles barberi  
   Anopheles pseudopunctipennis

* Usually not found in reseptacles.
Appendix 4

GENERALIZED ADULT MOSQUITO
Appendix 5

COMPARISONS OF HEADS OF MALE AND FEMALE ANOPHELES AND CULEX MOSQUITOS, AND LATERAL ASPECT OF THE THORAX OF A GENERALIZED MOSQUITO

Head of Anopheles female

Head of Anopheles male

Head of Culex female

Head of Culex male

Lateral view of mosquito thorax
Appendix 6

PICTORIAL KEY TO SOME COMMON ADULT MOSQUITOS ASSOCIATED WITH Aedes aegypti *

* Prepared by Harry D. Pratt & Chester J. Stojanovich, Training Branch, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
KEY TO ADULTS OF RECEPTACLE-BREEDING MOSQUITOS *

1. Legs with white bands (Fig. 1A) .......................................................... 2
   Legs unbanded, entirely dark or terminal segments white (Fig. 1B) ........ 13

2. Proboscis unbanded (Fig. 2A) ............................................................... 3
   Proboscis with white band (Fig. 2B) ................................................... 8

3. Tarsal segments with white bands at basal ends (Fig. 3A) ....................... 4
   Tarsal segments with white bands on both ends (Fig. 3B) ..................... 6

4. Thorax with lyre-shaped marking formed by silvery-white scales on a blackish background; silvery-white scales on clypeus and palpi (Fig. 4A) ..................................................... Yellow fever mosquito (Aedes aegypti)
   Thorax without lyre-shaped marking; clypeus and palpi dark (Fig. 4B) .... 5

* Prepared by Milton E. Tinker & Chester J. Stojanovich, Training Branch, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
5. Hind femur entirely pale on all aspects of anterior or basal half (Fig. 5A); abdomen with pale bands not notched on midline (Fig. 5B); Texas, USA .................................................. Aedes zoosophus
Hind femur with anterior or basal half of ventral surface dark or with scattered pale scales (Fig. 5C); abdomen with pale bands on segments 3–6 notched at middle (Fig. 5D) .......................................... Aedes vexans

6. Abdomen pointed, segment 7 of abdomen narrowed, segment 8 much narrowed and retractile (Fig. 6A); mesonotum with a broad patch of pale scales on each side (Fig. 6B) .................................................. Aedes atropalpus
Abdomen blunt, segment 7 of abdomen not narrowed, segment 8 short but not retractile (Fig. 6C); mesonotum uniform or with fine lines of pale scales (Fig. 6D) .................................................. 7

7. Four fine longitudinal white lines on thorax (Fig. 7A); scattered white scales on femur and tibia (Fig. 7B); mixed dark and white scales on wings (Fig. 7C) .................................................. Orthopodomyia signifera or Orthopodomyia alba
No fine lines on thorax (Fig. 7D); no scattered white scales on femur and tibia (Fig. 7E); dark scales on wings (Fig. 7F); Texas, USA .................................................. Culex coronator

1 Usually not found in receptacles.
8. Abdomen blunt at tip (Fig. 8A) ........................................ 9
Abdomen pointed at tip (Fig. 8B) ........................................ 10

9. White stripe on side of femur, no pale band near apex of tibia, no pale ring at middle of first segment of hind tarsus
(Fig. 9A, 9B) ................................................................. Culex tarsalis
No stripe on side of femur, pale band present near apex of tibia, pale ring present at middle of first segment of hind
tarsus (Fig. 9C, 9D) ....................................................... Mansonia perturbans

10. Pale ring at middle of first segment of hind tarsus (Fig. 10A); mixed dark and white scales on wings (Fig. 10B) 11
No pale ring at middle of first segment of hind tarsus (Fig. 10C); only dark scales on wings (Fig. 10D) 12

11. Pale band near apex of femur, white spots on side of tibia (Fig. 11A); upper surface of abdomen with cross bands
only (Fig. 11B) ............................................................... Psorophora confluens
No pale band on femur or tibia, no spots on side of tibia (Fig. 11C); upper surface of abdomen with long longitudinal
stripe as well as cross bands (Fig. 11D) ................................ Aedes sollicitans

1 Usually not found in receptacles.
12. Scattered white scales on legs (Fig. 12A); upper surface of abdomen with median longitudinal pale stripe as well as cross-bands (Fig. 12B) ........................................... 12

No scattered white scales on legs (Fig. 12C); upper surface of abdomen with only pale basal cross-bands (Fig. 12D) .......................... 12

Aedes mitchelli 1

Aedes toenniophyiii 1

13. Palpi much shorter than proboscis (Fig. 13A) ......................................................... 14

Palpi at least half as long as proboscis (Fig. 13B) .......................... 21

14. Abdomen pointed, segment 7 of abdomen narrowed, segment 8 much narrowed and retractile (Fig. 14A); mesonotum with a broad patch of pale scales on each side (Fig. 14B) .......................... 14

Abdomen blunt, segment 7 of abdomen not narrowed, segment 8 short but not retractile (Fig. 14C); mesonotum without a patch of pale scales on each side (Fig. 14D) .......................... 15

15. Base of subcosta without a tuft of hairs on underside of wing (Fig. 15A); spiracular bristles absent; proboscis short and straight; Genus Culex .......................... 16

Base of subcosta with tuft of hairs on underside of wing (Fig. 15B); spiracular bristles present (Fig. 15C); proboscis long and recurved; Genus Culiseta .......................... 20

1 Usually not found in receptacles.
16. Abdomen with white scales at apex of segments (Fig. 16A) ................................................. *Culex territans*
Abdomen with white scales at bases of segments (Fig. 16B) .................................................. 17

![Fig. 16 A](image1)

![Fig. 16 B](image2)

17. Abdominal segments with distinct basal bands or lateral spots of white scales (Fig. 17A) ........... 18
Abdominal segments with narrow dingy white basal bands (Fig. 17B) .................................... 19

![Fig. 17 A](image3)

![Fig. 17 B](image4)

18. Abdomen with rounded pale bands (Fig. 18A); mesonotum without pale spots, covered with relatively coarse brownish, greyish or silvery scales (Fig. 18B) .................. Southern house mosquito (*Culex quinquefasciatus*)
Abdomen with pale bands almost straight (Fig. 18C); mesonotum with two or more pale spots (sometimes only one or two scales) against a background of fine coppery scales (Fig. 18D) .......................... *Culex restuans*

![Fig. 18 A](image5)

![Fig. 18 C](image6)

![Fig. 18 B](image7)

![Fig. 18 D](image8)

19. Pleuron with several groups of broad scales, each group usually comprising more than six scales (Fig. 19A); seventh and eighth abdominal segments almost entirely covered with dingy yellow scales (Fig. 19B) ........................ *Culex salinarius*
Pleuron with few or no scales (when present, rarely more than five or six in a single group (Fig. 19C); seventh and eighth abdominal segments banded (Fig. 19D) ...................................................... *Culex nigripalpus*

![Fig. 19 A](image9)

![Fig. 19 C](image10)

![Fig. 19 B](image11)

![Fig. 19 D](image12)
20. With broad lightly scaled wings (Fig. 20A); legs and wings sprinkled with white scales; a large species

\[ \text{Culiseta inornata} \]

Wings and legs entirely dark scaled (Fig. 20B); a small dark species 

\[ \text{Culiseta melanura} \]

![Fig. 20 A](image)

![Fig. 20 B](image)

21. Palpi about 2/3 length of proboscis; proboscis strongly turned downwards (Fig. 21A); large mosquito with brilliant metallic bluish greenish or purplish colouring

\[ \text{Toxorhynchites rutilus} \]

Palpi about as long as proboscis, proboscis not strongly turned downwards (Fig. 21B) 

![Fig. 21 A](image)

![Fig. 21 B](image)

22. Wings with definite areas of white or yellowish scales (Fig. 22A) 

![Fig. 22 A](image)

Wings without definite areas of white or yellowish scales (Fig. 22B) 

![Fig. 22 B](image)
23. Palpi entirely dark (Fig. 23A); costa with two white spots (Fig. 24B) ........................................... *Anopheles punctipennis*

Palpi marked with white (Fig. 23B); costa with one or two spots (Fig. 24A, 24B) ........................................... 24

Fig. 23 A

Fig. 23 B

24. Costa with white spot at tip of wing only (Fig. 24A) ........................................................ *Anopheles crucians*¹

Costa with two white spots (Fig. 24B) ........................................................................................................... *Anopheles pseudopunctipennis*

Fig. 24 A

Fig. 24 B

25. Wing spotted (Fig. 25A); thoracic bristles not very long (Fig. 25B); mesothorax dull in rubbed specimens; medium sized species .......................................................... *Anopheles quadrimaculatus*¹

Wing not spotted (Fig. 25C); thoracic bristles very long (Fig. 25D); mesothorax shiny in rubbed specimens; small species .......................................................... *Anopheles barberi*¹

Fig. 25 A

Fig. 25 B

Fig. 25 C

Fig. 25 D

¹ Usually not found in receptacles.
Appendix 8

GENERALIZED ADULT FLEA

[Diagram showing the anatomy of a generalized adult flea, with labels for various body parts such as Antenna, Eye, Genal comb, Maxillary palpus, Labial palpus, Mesopleuron, Coxa, Trochanter, Femur, Tibia, Tarsus, Pronotal comb, Tergite, Antepygidal bristles, Pygidium, Spermatheca, and Sternite.]
Appendix 9

PICTORIAL KEY TO SOME COMMON FLEAS

Genal and pronotal combs present

Genal comb of 5 or more spines. Eye present

MOUSE FLEA
Lepismatomyia segnis

Genal comb of 4 spines. Eye absent

Labial palps not extending beyond trochanter of first leg

GROUND SQUIRREL FLEA
Diamanus montanus

Labial palps extending beyond trochanter of first leg

STICKTIGHT FLEA
Echidnophaga gallinacea

Front margin of head angular

Thorax normal

Head length less than twice height

Thorax extended

Segment 5 of hind tarsus with 5 pairs lateral plantar bristles

MESSPLEURON not divided by vertical thickening

RABBIT FLEA
Ceratophyllus simplex

Segment 5 of hind tarsus with 4 pairs lateral plantar bristles

Segment 5 of hind tarsus with 1 pair ventral (median) and 4 pairs lateral plantar bristles

Segment 5 of hind tarsus divided by vertical thickening

CAT FLEA
Ctenocephalides felis

DOG FLEA
Ctenocephalides canis

SQUIRREL FLEA
Orchaeas Ansonii

HUMAN FLEA
Pulex irritans

ORIENTAL RAT FLEA
Xenopsylla cheopis

NORTHERN RAT FLEA
Nosopsyllus fasciatus

Dorsal bristle inserted behind eye

Spermatheca

Plantar bristles

Dorsal bristle

Spermatheca

ORIGIN PREPARED BY M.L. PEAC
DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
COMMUNICABLE DISEASE CENTER
ATLANTA, GEORGIA
JUNE, 1966

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AN ILLUSTRATED KEY TO FLEAS FOUND DURING PLAGUE INVESTIGATIONS *

1. Pronotal and genal combs absent (Fig. 1A) .............................................. 2
   Pronotal combs present; genal comb present or absent (Fig. 1B, 1C) .......... 5

2. Front margin of head with two angles; the three thoracic tergites together shorter than the first abdominal tergite (Fig. 2A) .................................................. Sticktight flea (Echidnophaga gallinacea)
   Front margin of head rounded; the three thoracic tergites together longer than the first abdominal tergite (Fig. 2B) 3

3. Ocular bristle in front of eye; mesopleuron divided by internal sclerotization; female with spermatheca partially pigmented (Fig. 3A, 3B); (Genus Xenopsylla) .............................................. 4
   Ocular bristle beneath eye; mesopleuron without internal sclerotization; female with spermatheca entirely without pigment (Fig. 3C, 3D) ................................................................. Human flea (Pulex irritans)

* Prepared by H. D. Pratt, Training Branch, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
4. Genus *Xenopsylla*

*Xenopsylla cheopis*, male terminal segments.

*Xenopsylla cheopis*, female terminal segments.
5. Genal comb absent (Fig. 5A) .................................................. 6
Genal comb present (Fig. 5B) .................................................. 8

6. Pronotal comb with about 12 teeth on each side (Fig. 6A); India .............................................. Stivalius ahalae
Pronotal comb with 5–10 teeth on each side (Fig. 6B) .................................................. 7

7. Labial palpus long, extending beyond trochanter of first leg (Fig. 7A) .......................... Rock squirrel flea (Diamanus montanus)
Labial palpus short, not extending to tip of coxa of first leg (Fig. 7B) .......................... Northern rat flea (Nosopsyllus fasciatus)
8. Genal comb with 2 teeth (Fig. 8A); (Genus *Neopsylla*)  
   *Neopsylla setosa* (important in USSR, Mongolia, and Manchuria)

Genal comb with 3 teeth (Fig. 8B); (Genus *Ctenophthalmus*)  
*Ctenophthalmus breviatus* and *C. pollex* (potential vectors in USSR)

Genal comb with 4 teeth (Fig. 8C); (Genus *Leptopsylla*)  
*Leptopsylla segnis* (cosmopolitan)

Genal comb with more than 5 teeth; (Genus *Ctenocephalides*)

---

9. Head strongly rounded anteriorly; first spine of genal comb about half as long as second; hind tibia with the spiniform setae A and B (Fig. 9A, 9B)  
   Dog flea (*Ctenocephalides canis*)

Head not strongly convex anteriorly; first spine of genal comb almost as long as second spine; hind tibia with spiniform seta B, spiniform seta A replaced by a minute seta which may be absent in some specimens (Fig. 9C, 9D)  
   Cat flea (*Ctenocephalides felis*)
Appendix 11
LICE COMMONLY FOUND ON MAN

BODY LOUSE
AND
HEAD LOUSE

PEDICULUS HUMANUS

First pair of legs smaller than second and third pairs of legs
Abdomen shorter with hairy processes laterally

CRAB LOUSE

PHTHIRUS PUBIS

All legs of about the same length
Abdomen elongate without hairy processes laterally
Appendix 13

PICTORIAL KEY TO COMMON DOMESTIC FLIES *

Body dull, grey or brown to black

- 4th vein angled
  - Thorax dark, with 4 black stripes (Sarcophaga spp.)
  - Proboscis elongate, stiff, non-retractile, blood-sucking. Thorax with pale spot behind head

- 4th vein curved
  - Thorax grey, with 3 black stripes (Abdomen checked, with tip usually red, the sides never pale)

- 4th vein straight
  - Scutellum with 3 pairs of marginal bristles (Muscina spp., Hylemya spp.)

Body brocaded, thorax dark, abdomen metallic

- Scutellum with 4-5 pairs of marginal bristles (Cyanomyopsis cadaverina)

Body shining, metallic or black

- Scutellum with 4-5 pairs of marginal bristles, with pale hind margin of lower lobe

- 4th vein sharply angled
  - 4th vein straight

- Head dark below, never yellow (Phormia regina)
  - Anterior spiracle red, dorsal thoracic bristles reduced

- Head yellow below, The secondary screw-worm fly (Phaenicia)
  - Anterior spiracle dark, dorsal thoracic bristles strong

MUSCA DOMESTICA
The housefly

SARCOPOAGA SPP.

FANNIA SPP.

CYNOMYOPSIS

GADABERINA

CALLIFORA SPP.

DOHYRA
Body bluish-black, palpi black

O. LEUCOSTOMA
Body brassy-black, palpi red

O. AENESCENS

STOMOXYS CALCITRANS
The stable fly

MUSGINA
Legs in part reddish-brown
M. STABULANS
Legs wholly black
M. ASSIMILIS

Prepared by H. R. Dodge, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
Appendix 14
PICTORIAL KEY TO SOME COMMON ADULT COCKROACHES

**Small, about 5/6" or shorter**

- **Pronotum with 2 longitudinal black bars**
  - **German Cockroach** *(Blattella germanica)*

**Medium to large, longer than 5/6" inch**

- **Pronotum without longitudinal black bars**
  - **Oriental Cockroach** *(Blatta orientalis)*

**Wings covering nearly all of abdomen or extending beyond; pronotum narrower**

- **Wings absent; or shorter than abdomen**
  - **Wood Roach** *(Parcoblatta spp.)*

**Wings covering abdomen, often extending beyond**

- **Pronotum more than 1/4 inch wide**
  - **German Cockroach** *(Blattella germanica)*
- **Pronotum about 1/4 inch wide with pale border**
  - **Brown-Banded Cockroach** *(Supella superlunans)*

**Pronotum usually with some pale area; general color seldom darker than reddish chestnut**

- **Front wing with outer pale streak at base; pronotum strikingly marked**
  - **Wood Roach** *(Parcoblatta spp.)*

**Pronotum solid dark color; general color very dark brown to black**

- **Smoky Brown Cockroach** *(Periplaneta fuliginosa)*

**Last segment of cercus not twice as long as wide**

- **Brown Cockroach** *(Periplaneta brunnea)*
- **Australian Cockroach** *(Periplaneta australasiae)*

**Last segment of cercus twice as long as wide**

- **American Cockroach** *(Periplaneta americana)*

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Prepared by
H. C. Pratt
DEPARTMENT OF
Health, Education, and Welfare
PUBLIC HEALTH SERVICE
COMMUNICABLE DISEASE CENTER
ATLANTA, GEORGIA
October, 1953
Appendix 15

KEY TO SOME COMMON SPECIES OF COCKROACH FOUND IN THE USA *

1. Middle and hind femora both with numerous strong spines along the ventral margin (Fig. 1A) ........... 2
   Middle and hind femora without strong spines along the ventral margin (Fig. 1B) .................. 12

2. Comparatively large species 18 mm or longer; subgenital plate of female divided longitudinally, valvular (Fig. 2A); male styli similar, slender, elongate and straight (Fig. 2B) .................. 3

Species usually less than 18 mm long, or, if longer, anterior-ventral margin of front femur with several large stout spines on basal portion, followed by a row of smaller spines (Fig. 2C); female subgenital plate simple, not divided (Fig. 2D); male styli variable, frequently modified, asymmetrical, or unequal in size (Fig. 2E) ........... 8

* Prepared by Harry D. Pratt & Chester J. Stojanovich, Training Branch, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
3. Front wing in both sexes extending beyond tip of abdomen (Fig. 3A) ........................................ 4
Front wing in both sexes not reaching tip of abdomen (Fig. 3B) ...................................................... 7

4. Uniformly dark blackish-brown, shining species (Fig. 4A) . . . . . Smoky brown cockroach (Periplaneta fuliginosa)
Species with some yellowish markings on pronotum or front wing or both (Fig. 4B) ..................... 5

5. Front wing with yellowish and darker areas very contrastingly marked (Fig. 5A) ............................... 6
Australian cockroach (Periplaneta australasiae)
Front wing entirely brownish; pronotum with yellowish and darker areas less contrastingly marked (Fig. 5B) 6
6. Styli very long and slender, longer than space between their bases (Fig. 6A); cercus long and slender particularly in the male; male supra-anal plate deeply notched (Fig. 6B) . . . . American cockroach (*Periplaneta americana*)

Styli shorter, not as long as space between their bases (Fig. 6C); cercus stouter and more evenly spindle-shaped; male supra-anal plate truncate or feebly notched (Fig. 6D) . . . . . . Brown cockroach (*Periplaneta brunnea*)

7. Blackish species, 15–27 mm long; male front wings covering two-thirds of abdomen (Fig. 7A); female front wings widely separated pads (Fig. 7B); first segment of hind tarsus longer than segments 2–5 combined, pulvilli of second and third segments small (Fig. 7C) . . . . . . . . . . . . . . . . . . . . . . . . Oriental cockroach (*Blatta orientalis*)

Mahogany brownish species, 30–40 mm long; front wings reduced to short pads, not widely separated (Fig. 7D); first segment of hind tarsus shorter than segments 2–5 combined, pulvilli of second and third segments large (Fig. 7E) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . Large Florida cockroach (*Eurycotis floridana*)
8. Pronotum with two conspicuous longitudinal dark bars on a pale background (Fig. 8A)  
   Pronotum variously marked, but without two conspicuous dark longitudinal bars (Fig. 8B)  

9. Face pale (Fig. 9A); male subgenital plate asymmetrical, styli very unequal, short and rounded (Fig. 9B)  
   Face dark; male subgenital plate almost symmetrical, styli somewhat elongate and subequal in size (Fig. 9C)  

10. Pronotum with a broad dark central stripe; front wings of both sexes appearing to have two transverse brownish bars, some pale specimens showing bars poorly (Fig. 10A); width of pronotum usually not exceeding 4.5 mm  
   Pronotum and front wings otherwise, or, if pronotum is so marked, its width exceeding 4.5 mm (Fig. 10B)
11. Larger species 9–25 mm or more in length; front wing without small dark spots in winged specimens (Fig. 11A); claws equal (Fig. 11B); ventral anterior margin of front femur with three long apical spines (Fig. 11C). Wood cockroaches (Parcoblatta species)

Small species, 8–9 mm long; front wing with small dark spots (Fig. 11D); claws unequal (Fig. 11E); ventral anterior margin of front femur with two long apical spines (Fig. 11F). Spotted Mediterranean cockroach (Ectobius pallidus)

12. Top of eyes close together (Fig. 12A); general colour a nearly uniform greenish; posterior margin of pronotum somewhat angularly produced (Fig. 12B). Cuban cockroach (Panchlora nivea)

Top of eyes sometimes distant (Fig. 12C); general colour various shades of brown and grey; pronotum usually not angularly produced posteriorly (Fig. 12D).
13. Medium-sized species, 30 mm or less in length including folded wings (Fig. 14A, 14B) .......................... 14
Large species 40 mm or more in length, including folded wings (Fig. 15A, 15C) .......................... 15

14. Pronotum uniformly blackish except a narrow yellowish band along anterior and lateral margins (Fig. 14A) .......................... Surinam cockroach (*Pycnoscelus surinamensis*)
Pronotum pale with a narrow dark longitudinal submarginal band on each side and irregular brownish blotches on disk (Fig. 14B) .......................... Cinereous cockroach (*Nauphoeta cinerea*)

15. Disk of pronotum with shield-like design, sometimes skull-like design (Fig. 15A); front femur with one or more stout spurs on underside (Fig. 15B) .......................... Giant cockroach (*Blaberus giganteus; Blaberus cranifer*)
Disk of pronotum with shield-like design darkened in outline only, not solid black (Fig. 15C); front femur with a line of stiff hairs on anterior-ventral margin (Fig. 15D) .......................... Madeira cockroach (*Leucophaea maderae*)
Appendix 16

FIELD IDENTIFICATION OF DOMESTIC RODENTS *

ROOF RAT  Rattus rattus

LONGER THAN HEAD + BODY
TAIL

LIGHT SLENDER
BODY

HEAVY THICK
SHORTER THAN HEAD + BODY

LARGE
EAR

LARGE
EYE

LARGE POINTED
NOSE

YOUNG RAT

LARGE FEET
LARGE HEAD

SMALL FEET
SMALL HEAD

HOUSE MOUSE
Mus musculus

NORWAY RAT  Rattus norvegicus

LONGER THAN HEAD + BODY
TAIL

LIGHT SLENDER
BODY

HEAVY THICK
SHORTER THAN HEAD + BODY

LARGE
EAR

LARGE
EYE

LARGE POINTED
NOSE

* Prepared by Robert Z. Brown, Center for Disease Control, US Public Health Service, Atlanta, Ga., USA.
ANNEX 2

TABLES OF DATA FOR INSECT VECTOR AND RODENT CONTROL *

TABLE 1
PESTICIDES SUITABLE AS RESIDUAL SPRAY APPLICATIONS AGAINST MALARIA VECTORS

<table>
<thead>
<tr>
<th>Toxicant</th>
<th>Dosage in g/m²</th>
<th>Average duration of effectiveness (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDT</td>
<td>1 or 2</td>
<td>6 to 12</td>
</tr>
<tr>
<td>dieldrin</td>
<td>0.5</td>
<td>6 to 12</td>
</tr>
<tr>
<td>lindane</td>
<td>0.5</td>
<td>3</td>
</tr>
<tr>
<td>malathion</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>propoxur</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

* Because of the hazard to man and domestic animals, the use of this insecticide has been abandoned by most countries. It has been found that in long-term programmes poisoning has occurred among spray operators, even when veils, caps and gloves were worn in addition to hats and overalls. Dieldrin should not be used for indoor spraying without full justification and unless strict precautionary measures and medical supervision are ensured.

TABLE 2
PESTICIDES EMPLOYED AS LARVICIDES IN MOSQUITO CONTROL

<table>
<thead>
<tr>
<th>Toxicant</th>
<th>Dosage (g/ha)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abate</td>
<td>56-112</td>
<td>Use oil or water emulsion formulations in areas with minimum vegetative cover. Granular formulations are suitable for penetration of heavy vegetative cover.</td>
</tr>
<tr>
<td>DDT</td>
<td>224</td>
<td>For use as residual larvicides or pre-hatch treatments higher dosages are necessary (see section 2.4.7, p. 193).</td>
</tr>
<tr>
<td>Dursban c</td>
<td>11-16</td>
<td>DO NOT APPLY PARATHION IN URBAN AREAS.</td>
</tr>
<tr>
<td>fenthion c</td>
<td>22-112</td>
<td>Apply Paris green pellets (5%) at rate of 16.8 kg/ha with ground machines or aircraft.</td>
</tr>
<tr>
<td>fenitrothion</td>
<td>224-336</td>
<td>Apply to cover water surface in catch basins or at a rate of 142-190 l/ha in open water courses. With a spreading agent the volume can be reduced to 19-47 l/ha.</td>
</tr>
<tr>
<td>heptachlor</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>lindane</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>malathion</td>
<td>224-672</td>
<td></td>
</tr>
<tr>
<td>parathion</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>parathion-methyl</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>Paris green</td>
<td>840</td>
<td></td>
</tr>
<tr>
<td>fuel oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>larvicidal oil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* As there may be regulations restricting the use of these compounds, the user should consult the appropriate authorities. He should also read the label carefully for any mention of restrictions on the type of persons approved for handling the compound or of hazard to non-target animals.

* Where insecticides are to be applied to croplands, pasture, range land, or uncultivated lands, the agricultural authorities should be consulted regarding acceptable application procedures.

* Dursban and fenthion should not be applied to waters containing valuable fish.

## TABLE 3
PESTICIDES EMPLOYED AS EXTERIOR SPACE SPRAYS FOR MOSQUITO CONTROL

<table>
<thead>
<tr>
<th>Toxicant</th>
<th>Dosage (g/ha)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbaryl</td>
<td>224-1120</td>
<td></td>
</tr>
<tr>
<td>DDT</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>dichlorvos</td>
<td>56-280</td>
<td></td>
</tr>
<tr>
<td>fenitrothion</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>lindane</td>
<td>112-224</td>
<td></td>
</tr>
<tr>
<td>malathion</td>
<td>112-560</td>
<td></td>
</tr>
<tr>
<td>naled</td>
<td>56-280</td>
<td></td>
</tr>
</tbody>
</table>

The treatments are applied as thermal or non-thermal fogs, mists or dusts. Applications are most commonly made by ground equipment. Environmental conditions, particularly wind movement, affect the efficacy of space treatments. Effective swath widths are usually from 30 to 90 m (100-300 ft).

## TABLE 4
ORGANOPHOSPHORUS COMPOUNDS * USED AS RESIDUAL TREATMENTS IN FLY CONTROL

<table>
<thead>
<tr>
<th>Toxicant</th>
<th>Strength of finished formulation (a) (%)</th>
<th>Dosage (g/m²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>diazinon</td>
<td>1.0-2.0</td>
<td>0.4-0.8</td>
<td>AVOID CONTAMINATION OF FOOD AND DRINKING WATER with any toxicant. Do not treat any milk room or food-processing plant when it is in operation. Can be used in all types of food-handling establishments b including the milk rooms of dairies. On poultry farms do not spray chickens or excreta that may come into contact with them.</td>
</tr>
<tr>
<td>dimethoate</td>
<td>1.0-2.5</td>
<td>0.4-1.6</td>
<td>Acceptable for dairy and poultry farm treatment but animals must be removed. Not to be used in milk rooms.</td>
</tr>
<tr>
<td>fenthion</td>
<td>1.0-2.5</td>
<td>0.4-1.6</td>
<td>Not acceptable in all countries for use in dairies, poultry houses, or food-processing plants.</td>
</tr>
<tr>
<td>Gardona</td>
<td>1.0-5.0</td>
<td>1.0-2.0</td>
<td>Can be used in dairies and other animal shelters but not acceptable for use in poultry houses in all countries.</td>
</tr>
<tr>
<td>malathion</td>
<td>5.0</td>
<td>1.0-2.0</td>
<td>Used in dairies, poultry houses and other food-handling establishments; b only premium grade malathion can be used in milk rooms and food-processing plants. On poultry farms treatment can be made without removing birds.</td>
</tr>
<tr>
<td>naled</td>
<td>1.0</td>
<td>0.4-0.8</td>
<td>Acceptable for application in dairies (except milk rooms) and in food-handling establishments. At 0.25% strength can be applied to chicken roosts, nests, etc., without excluding the birds. Acceptable for use in dairies including milk rooms, in food-handling establishments b and on poultry farms. Removal of chickens during spraying is unnecessary but avoid spraying animals directly; do not spray excreta unless inaccessible to the chickens.</td>
</tr>
<tr>
<td>roanel</td>
<td>1.0-5.0</td>
<td>1.0-2.0</td>
<td>Can be used in dairies including milk rooms, in food-handling establishments b and on poultry farms. Removal of chickens during spraying is unnecessary but avoid spraying animals directly; do not spray excreta unless inaccessible to the chickens.</td>
</tr>
</tbody>
</table>

* Read and follow directions on the label. For information on chemicals to be used against livestock or crop pests consult the national, state or local agricultural service or agency. Use of organophosphorus compounds is not permitted inside restaurants in certain European countries (e.g., Denmark).

b Addition of sugar at 2.5 times the strength of toxicant increases the effectiveness of the treatment.

b Includes dairies, milk rooms, restaurants, canneries, food stores, warehouses and similar establishments.
### TABLE 3
**ORGANOPHOSPHORUS COMPOUNDS USED FOR OUTDOOR SPACE TREATMENTS**

<table>
<thead>
<tr>
<th>Toxicant</th>
<th>Dosage (g/ha)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>diazinon</td>
<td>336</td>
<td>Apply at rates of 24–48 litres/km to obtain required dosage.</td>
</tr>
<tr>
<td>dichlorvos</td>
<td>336</td>
<td></td>
</tr>
<tr>
<td>dimethoate</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>fenthion</td>
<td>448</td>
<td></td>
</tr>
<tr>
<td>malathion</td>
<td>672</td>
<td></td>
</tr>
<tr>
<td>naled</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>ronnel</td>
<td>448</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 6
**PESTICIDES USED ON PETS FOR FLEA CONTROL**

<table>
<thead>
<tr>
<th>Toxicant</th>
<th>Formulation</th>
<th>Concentration (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbaryl</td>
<td>dip or wash</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dust</td>
<td>2.0–5.0</td>
<td></td>
</tr>
<tr>
<td>chlordane</td>
<td>dust</td>
<td>2.0–4.0</td>
<td></td>
</tr>
<tr>
<td>coumaphos</td>
<td>dust c</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>spray</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>lindane</td>
<td>dip</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dust</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>malathion</td>
<td>spray</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dust</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>propoxur</td>
<td>spray</td>
<td>0.2 + 2.0</td>
<td>synergist</td>
</tr>
<tr>
<td>pyrethrum</td>
<td>dust</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>rotenone</td>
<td>dust</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 7
**INSECTICIDES COMMONLY EMPLOYED IN CONTROL OF GERMAN COCKROACHES**

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Formulation</th>
<th>Concentration (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>propoxur</td>
<td>spray</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>bait</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>chlorданe</td>
<td>spray</td>
<td>2.0–3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dust</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>diazinon</td>
<td>spray</td>
<td>0.5–1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dust</td>
<td>2–5</td>
<td></td>
</tr>
<tr>
<td>dichlorvos</td>
<td>spray</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>bait</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>dieldrin</td>
<td>spray</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dust</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Dursban</td>
<td>spray</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>fenthion</td>
<td>spray</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Kepon</td>
<td>bait</td>
<td>0.125</td>
<td></td>
</tr>
<tr>
<td>malathion</td>
<td>spray or dust</td>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 8
**SINGLE-DOSE RODENTICIDES USED AGAINST NORWAY AND ROOF RATS**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Acute oral dose (mg/kg)</th>
<th>Percentage commonly employed in baits</th>
</tr>
</thead>
<tbody>
<tr>
<td>antu</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>arsenious oxide</td>
<td>13</td>
<td>1.5</td>
</tr>
<tr>
<td>fluoracetamide</td>
<td>13–15</td>
<td>2.0</td>
</tr>
<tr>
<td>norbormide</td>
<td>12</td>
<td>1.0</td>
</tr>
<tr>
<td>phosphorus, yellow</td>
<td>1.7</td>
<td>0.05</td>
</tr>
<tr>
<td>red squill</td>
<td>500</td>
<td>10.0</td>
</tr>
<tr>
<td>sodium fluoracetate</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>thallium sulfate</td>
<td>25</td>
<td>0.3–1.5</td>
</tr>
<tr>
<td>zinc phosphide</td>
<td>40</td>
<td>1.0–2.5</td>
</tr>
</tbody>
</table>

### TABLE 9
**MULTIPLE-DOSE RODENTICIDES EMPLOYED AGAINST MICE, ROOF RATS, AND NORWAY RATS**

<table>
<thead>
<tr>
<th>Rodenticide</th>
<th>Dosage in parts per million</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mice</td>
</tr>
<tr>
<td>diphascinone</td>
<td>125–250</td>
</tr>
<tr>
<td>coumafuryl \ pindone \</td>
<td>250–500</td>
</tr>
<tr>
<td>warfarin</td>
<td>250–500</td>
</tr>
</tbody>
</table>

### TABLE 10
**AMOUNT OF WATER-DISPERSIBLE POWDER REQUIRED FOR PREPARATION OF SPRAY SUSPENSIONS**

<table>
<thead>
<tr>
<th>Percentage of toxicant in wdp a</th>
<th>Kg (lb) of wdp a required for about 380 litres (100 US gal; 83 UK gal) of finished spray suspension with concentrations of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 %</td>
</tr>
<tr>
<td>90</td>
<td>21.0 (46.3)</td>
</tr>
<tr>
<td>75</td>
<td>25.2 (55.6)</td>
</tr>
<tr>
<td>50</td>
<td>37.8 (83.3)</td>
</tr>
<tr>
<td>25</td>
<td>75.6 (166.7)</td>
</tr>
</tbody>
</table>

a Maximum concentrations stated should be used by experienced personnel or pest control operators only.

b Pest control operators only.

c Water-dispersible powder.
### Table 11
PREPARATION OF EMULSION CONCENTRATES FROM TECHNICAL MATERIAL

<table>
<thead>
<tr>
<th>Concentration desired (%)</th>
<th>Weight of technical material required to make the following volumes of concentrate: *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 litres</td>
</tr>
<tr>
<td>35</td>
<td>35 kg</td>
</tr>
<tr>
<td>25</td>
<td>25 kg</td>
</tr>
<tr>
<td>15</td>
<td>15 kg</td>
</tr>
<tr>
<td>12.5</td>
<td>12.5 kg</td>
</tr>
<tr>
<td>6.25</td>
<td>6.25 kg</td>
</tr>
</tbody>
</table>

* To every 100 parts of concentrate 2 parts of emulsifier should be added.

### Table 12
PREPARATION OF EMULSION FROM CONCENTRATES OF DIFFERENT STRENGTHS

<table>
<thead>
<tr>
<th>Percentage of toxicant in emulsion concentrate</th>
<th>Parts of water to be added to 1 part of EC when concentration of final form is:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 %</td>
</tr>
<tr>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>60</td>
<td>11</td>
</tr>
<tr>
<td>50</td>
<td>9</td>
</tr>
<tr>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

* EC — emulsifiable concentrate.

### Table 13
REQUIREMENTS FOR SPRAY FORMULATIONS OF INSECTICIDE

<table>
<thead>
<tr>
<th>Dosage (weight per unit area)</th>
<th>Litres of spray required per 100 m² (1000 ft²) using following concentrations of technical insecticide:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25 %</td>
</tr>
<tr>
<td>2 g/m² (200 mg/ft²)</td>
<td>—</td>
</tr>
<tr>
<td>1 g/m² (100 mg/ft²)</td>
<td>—</td>
</tr>
<tr>
<td>0.5 g/m² (50 mg/ft²)</td>
<td>20</td>
</tr>
<tr>
<td>0.2 g/m² (20 mg/ft²)</td>
<td>8</td>
</tr>
</tbody>
</table>

* 1 litre is approximately equal to 0.25 US gal or 0.25 UK gal.

### Table 14
REQUIREMENTS FOR EMULSION CONCENTRATE AND DUST

<table>
<thead>
<tr>
<th>Dosage</th>
<th>Amount of 25% concentrate needed</th>
<th>Amount of 5% dust required</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/ha</td>
<td>lb/acre</td>
<td></td>
</tr>
<tr>
<td>4.54</td>
<td>10</td>
<td>18.2 litres</td>
</tr>
<tr>
<td>2.27</td>
<td>5</td>
<td>9.1 litres</td>
</tr>
<tr>
<td>1.36</td>
<td>3</td>
<td>5.5 litres</td>
</tr>
<tr>
<td>1.0</td>
<td>2.2</td>
<td>4.2 litres</td>
</tr>
<tr>
<td>0.45</td>
<td>1</td>
<td>1.8 litres</td>
</tr>
<tr>
<td>0.23</td>
<td>0.5</td>
<td>0.9 litres</td>
</tr>
<tr>
<td>0.045</td>
<td>0.1</td>
<td>200 ml</td>
</tr>
</tbody>
</table>

* Containing 0.25 kg/litre (0.1 lb/US gal; 2.5 lb/UK gal).

### Table 15
CONCENTRATIONS OF TOXICANT EQUIVALENT TO ONE PART PER MILLION

- 1 mg (0.015 grain) per kg
- 1 g (15.4 grains) per metric ton
- 0.007 grain (0.45 mg) per lb
- 1 ml (0.035 UK fl oz) per 1000 litres
- 0.16 UK fl oz (4.5 ml) per 1000 UK gal
- 0.13 US fl oz (3.8 ml) per 1000 US gal

### Table 16
DILUTION FACTORS FOR 25% CONCENTRATE

<table>
<thead>
<tr>
<th>Required concentration (ppm)</th>
<th>Volume of 25% concentrate needed for the following volumes of water:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 million litres</td>
</tr>
<tr>
<td>1</td>
<td>4 litres</td>
</tr>
<tr>
<td>0.1</td>
<td>400 ml</td>
</tr>
<tr>
<td>0.01</td>
<td>40 ml</td>
</tr>
<tr>
<td>0.001</td>
<td>4 ml</td>
</tr>
</tbody>
</table>

* Containing 0.25 kg/litre (0.1 lb/US gal; 2.5 lb/UK gal).
**TABLE 17**

**RELATIONSHIP OF CONCENTRATION TO TREATMENT DOSAGE AND WATER DEPTH**

<table>
<thead>
<tr>
<th>Treatment dosage</th>
<th>Concentration (ppm) at depth of a</th>
<th>2.5 cm (1 in)</th>
<th>30 cm (1 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2240 g/ha</td>
<td>2.0</td>
<td>8.8</td>
<td>0.74</td>
</tr>
<tr>
<td>1120 lb/acre</td>
<td>1.0</td>
<td>8.8</td>
<td>0.37</td>
</tr>
<tr>
<td>560</td>
<td>0.5</td>
<td>2.2</td>
<td>0.18</td>
</tr>
<tr>
<td>280</td>
<td>0.25</td>
<td>1.1</td>
<td>0.092</td>
</tr>
<tr>
<td>112</td>
<td>0.10</td>
<td>0.44</td>
<td>0.037</td>
</tr>
<tr>
<td>56</td>
<td>0.05</td>
<td>0.22</td>
<td>0.018</td>
</tr>
<tr>
<td>28</td>
<td>0.025</td>
<td>0.11</td>
<td>0.0092</td>
</tr>
<tr>
<td>11</td>
<td>0.01</td>
<td>0.044</td>
<td>0.0037</td>
</tr>
</tbody>
</table>

a The concentration in parts per million (ppm) at other depths or other treatment dosages can be obtained by simple proportion; for example, the ppm concentration at depths of 10 and 20 cm are 1/4 and 1/8, respectively, of those at 2.5 cm.

**TABLE 18**

**NUMBER OF SOILS IN AREAS OF DIFFERENT DIMENSIONS**

<table>
<thead>
<tr>
<th>Length of area (m)</th>
<th>Number of ha in areas of the following widths:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 m</td>
</tr>
<tr>
<td>1600</td>
<td>4.0</td>
</tr>
<tr>
<td>1000</td>
<td>2.5</td>
</tr>
<tr>
<td>600</td>
<td>1.5</td>
</tr>
<tr>
<td>400</td>
<td>1.0</td>
</tr>
<tr>
<td>250</td>
<td>0.63</td>
</tr>
</tbody>
</table>

* Other values can be determined by simple proportion or by the formulae:

\[
\text{Hectares} = \frac{\text{length (m)} \times \text{width (m)}}{10000} \text{ or } \frac{\text{length (km)} \times \text{width (m)}}{10}
\]

\[
\text{Acres} = \frac{\text{length (ft)} \times \text{width (ft)}}{43560} \text{ or } 0.121 \times \text{length (miles)} \times \text{width (ft)}
\]

**TABLE 19**

**AERIAL SPRAY COVERAGE IN RELATION TO SPEED OF AIRCRAFT AND SWATH WIDTH**

<table>
<thead>
<tr>
<th>Speed of aircraft *</th>
<th>Aerial spray coverage per minute for swath widths of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>km/h</td>
<td>15.2 m (50 ft)</td>
</tr>
<tr>
<td>128</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>8 acres</td>
</tr>
<tr>
<td>144</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>9 acres</td>
</tr>
<tr>
<td>160</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>10 acres</td>
</tr>
<tr>
<td>192</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>12 acres</td>
</tr>
<tr>
<td>240</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>15 acres</td>
</tr>
</tbody>
</table>

* 1 knot = 1.85 km/h = 1.15 mi/h.
THE SAFE USE OF PESTICIDES *

The following recommendations are intended as a guide to those responsible for the use of pesticides in public health programmes of vector control. They are based mainly on recommendations made by the WHO Expert Committee on Insecticides. 1, 2

The use of such highly toxic rodenticides as sodium fluoroacetate, fluoroacetamide, and thallium sulfate, should be restricted to specially trained personnel already instructed in the safe handling of these compounds and in the treatment of poisoning by them. Under no circumstances should these rodenticides be released to the general public.

1. General principles of safety measures

All pesticides are toxic to some degree. Care in handling them should therefore be routine practice and should form an integral part of programmes involving the application of pesticides. The general principles on which safety measures are based are discussed below, with special emphasis on the indoor use of residual sprays.

1.1 Toxicity and hazard

In recommending safety measures it is necessary to take into account both the nature of the pesticide and the proposed method of applying it. A measure of the potential toxicity of pesticides to man and other mammals is obtained from the acute oral and/or dermal LD50 values, 3 i.e., a statistical estimate of the number of milligrams of toxicant per kilogram of body weight required to kill 50% of a large population of test animals (Table 1). While these figures represent the relative acute toxicities of various compounds to the test animals, they do not measure the actual hazard involved when a pesticide is used under the particular conditions of its application. Factors that influence hazard are: type of formulation, concentration of the pesticide in the finished formulation, method of application, amount of surface or area to be treated, dosage required, association of human or animal populations with treated surface or area, and the species involved, its age, sex and condition. Thus parathion, which is far too toxic to be considered for use indoors as a residual spray, has been safely used for many years indoors in the form of impregnated cords for fly control.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Type</th>
<th>Oral LD50 (mg/kg)</th>
<th>Dermal LD50 (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abate</td>
<td>OP</td>
<td>13000</td>
<td>&gt;4000</td>
</tr>
<tr>
<td>carbaryl</td>
<td>C</td>
<td>300</td>
<td>&gt;4000</td>
</tr>
<tr>
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* Except in the case of methoxychlor, all the values were determined under standardized conditions by the Toxicology Section, Pesticides Program, Center for Disease Control, Atlanta, Ga., USA.

a C = carbamate; CH = chlorinated hydrocarbon; OP = organophosphorus compound; IA = inorganic arsenic; B = botanical; HC = hydroxycoumarin; IF = inorganic fluorine; l = indandione.

b Sex not specified.

c For male rats.

1.2 Supplies and equipment

The planning of a vector control campaign must include provision for the safe transport and secure storage of the pesticide concentrates; these should not

3 Information of this type can be obtained from the pesticide manufacturer or from Vector Biology and Control, World Health Organization, 1211 Geneva, Switzerland.
be stored in rooms in which people live or in which food is kept. Protection against theft, misuse, and accessibility to children must be provided. Those in charge of programmes using pesticides must ensure that suitably qualified people take full responsibility for the custody of stocks and the disposal or treatment of empty or half-empty containers.

When either a provisional or a final specification recommended by the WHO Expert Committee on Insecticides for a pesticide formulation is available, only those materials that comply with the specification should be used. The containers must be suitably designed to withstand transport and handling.

All pesticide containers should be adequately labelled to identify the contents and show, in a form comprehensible to the operator, the nature of the material and the precautions to be employed.

All equipment used to distribute the pesticides should conform to the general and specific recommendations with regard to design and maintenance published by WHO. There must be regular, systematic inspection of all equipment to ensure that there is no leakage from faulty valves, gaskets, or hose.

1.3 Responsibility for safety

Any authority approving the use of a pesticide, including the substitution of a new material for one already in use, must ensure that the application is carried out under appropriate supervision. In some instances, consultants or technical experts will have to be recruited to undertake specialized training and give advice. Their function would be to inform the local medical and other specialized staff in the public health programmes on such matters as the proper training of field operators. The containers must be suitably designed to be handled and stored.

1.4 Training for safety

Training in the safe use of pesticides should be on two levels: (a) for the medical specialist, entomologist, engineer or sanitarian, instruction should be given on the mode of action of the new pesticide, the significance of any diagnostic measures, recognition of the signs and symptoms of any toxic effects, and the facilities for treatment of cases of poisoning; (b) for the foreman and other responsible field operators, training should be given in the techniques of proper spraying, safety precautions and protective equipment, recognition of the early signs and symptoms of poisoning, and first aid measures including resuscitation.

The staff who will carry out the work must be organized into squads with a precise definition of the duties and responsibilities of each man. Before toxic materials are used, a training period is essential. During the training period, the men should wear and work in the protective clothing required, to ensure that it is acceptable to the operator and that work can be carried out properly while it is being worn.

1.5 Medical surveillance

Arrangements must be made to ensure that any exposed person can easily report any symptoms to a supervisor who will then bring the complaint to the attention of a medical officer. Any undue prevalence of illness not associated with well-recognized signs and symptoms of poisoning by the particular pesticide should be noted and reported to the appropriate authorities. Apart from clinical surveillance, quantitative biochemical tests may be carried out in an attempt to assess the degree of exposure. The significance and importance of regular determination of blood cholinesterase activity where organophosphorus compounds are used are discussed below. Detailed procedures have been described for measuring the exposure of spray operators.

1.6 Protective equipment and personal hygiene

The various items of protective clothing that may have to be used are described below, with notes on their proper care:

1. Hats. These should be of impervious material with a broad brim to protect the face and neck. Hats should be able to withstand regular cleaning unless they are made from cheap material and are discarded when they become soiled.

2. Veils. A plastic mesh net will afford adequate protection of the face from the larger spray droplets and permit adequate visibility.

3. Capes. Short capes of light plastic may be cut to suspend from the hat and protect the shoulders.

4. Overalls. These should be of light, durable cotton fabric. They must be washed regularly, the frequency depending on the pesticide being used. Washing with

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soap, detergent, or washing soda in the case of organophosphorus compounds, is adequate. A rinse in light kerosene may be needed for compounds such as chlorinated hydrocarbons and this should be followed by washing.

5. **Aprons.** Rubber or polyvinyl chloride aprons will protect from spills of liquid concentrates.

6. **Rubber boots.** These will complete the protection afforded by the apron.

7. **Gloves.** Polyvinyl chloride or rubber gloves or gauntlets should be used when handling concentrates but are unsuitable for continuous wear. Cotton gloves offer some protection for the hands. Impervious gloves must be cleaned regularly both inside and out.

8. **Face masks.** Masks of gauze or similar material are capable of filtering the particles from a wettable powder spray and may be worn to reduce respiratory exposure if such protection is considered desirable for compounds of moderate toxicity. They must be kept clean and the gauze renewed regularly, so that the face is not contaminated.

9. **Respirators (masks with cartridge or canister).** These are designed to protect from toxic vapours, gases or droplets of very toxic materials. They must be specifically chosen for each compound being used. The cartridge or canister must be renewed regularly according to usage. To be effective the respirator must fit the face closely. It must be cleaned regularly.

A drill for carrying out and supervising personal hygiene and the cleaning of protective clothing and equipment must be organized. All working clothes must be removed at the end of each day’s operation and a shower or bath taken. Sufficient water and soap should be provided in the field for washing. The wearing of contaminated gloves may be more dangerous than not wearing gloves at all. The hours of work must be arranged so that exposure to the material being used is not excessive and transport arranged so that too long a delay does not occur between the end of the day’s operations and the return to the base for washing. Feeding arrangements must be such that it is not necessary for the men to eat while they work or before they can clean themselves. Smoking during work must be strictly forbidden.

1. **Disposal of empty or nearly empty containers**

   It is important to ensure the safe disposal of empty or nearly empty containers. They must not be allowed to go astray or be removed by unauthorized people, who might use them as containers for food or drinking water, especially in areas where such containers are scarce.

   Used containers can be effectively decontaminated by rinsing two or three times with water, scrubbing the sides thoroughly. If a drum has contained an organophosphorus compound an additional rinse should be carried out with 5% washing soda and the solution allowed to remain in the container overnight. Rubber gauntlets should be worn during this work, and a soakage pit should be provided for the rinsings.

2. **Operative procedures**

2.1 **Preparation of spray materials**

   The greatest degree of exposure occurs during handling of the concentrates and facilities for their safe handling must be provided.

   In preparing concentrates of water-dispersible powders, use must be made of deep mixing-vessels and long-handled mixers to protect the operator from splashing and to permit stirring from a standing position.

   For the dilution of solid pastes, electrically operated or power appliances are satisfactory and permit the dilution to be prepared in a closed vessel. Where such appliances are not available, long-handled mixers and tall vessels should be provided. No vessel should be filled to a point where the operator will be endangered through splashing. Long-handled dippers or scoops should be used for transferring the insecticide from one vessel to another. The concentrates may be subdivided into bags or small containers suitable for safe mixing by the spraymen in the field. All smaller containers should be secured and packed to withstand transport to the periphery of the area of application.

   Adequate protective clothing should be available for those handling concentrates. Adequate washing facilities must be available and immediately accessible so that spills on the skin can be quickly removed.

2.2 **House treatment with residual sprays**

   This procedure is of paramount importance in all malaria eradication programmes. It must be recognized that spraymen will inevitably be exposed to the sprayed material and that absolute protection of the skin and respiratory tract would impose physical limitations that would make such work impossible in hot climates.

   The skin can be protected to a considerable degree by cotton clothing and by regular washing with soap and water. When more toxic compounds are sprayed it may become necessary to provide respiratory protection also.

   During the spraying of houses, all bedding and as much furniture as possible should be removed, together with cooking utensils and food. Anything that has to be left inside should be protected from the spray. Contamination of the floor should be reduced to a minimum to protect crawling children. Parents should
be advised to prevent children from rubbing off newly applied spray deposits.

2.3 Larvicide treatments

Persons applying larvicides are generally liable to a much lower degree of exposure than are spraymen engaged in the indoor treatment of houses with residual insecticides. With outdoor application exposure of the operators is confined mainly to the hands and arms, since most of the spraying or dusting is done below eye level.

With the majority of larvicides, care must be taken to avoid the contamination of drinking water or of waters inhabited by non-target organisms of value, such as fish and crustaceans. However, to control mosquitoes that breed in drinking-water containers, specially selected pesticides may be used. Such treatment should always be made with formulations of the pesticides that ensure accurate and reliable dosage.

2.4 Application by motorized equipment and aircraft

The main hazards are to those who handle the bulk concentrates in loading the machines and to the pilots, operators and ground staff. Proper equipment, including pumps for transferring liquids and pouring devices, must be available. The cleaning and maintenance of machines also require care so that mechanics do not unwittingly contaminate themselves with concentrates during routine maintenance. Washing facilities to deal with large spillages of concentrate must be available at loading points.

The aircraft and machinery must be properly designed for the purposes for which they will be used and pilots given a specific training course in the use of toxic pesticides.

As large tracts of land and urban areas may be treated, there must be prior consultation with the health authorities responsible for the residents and for the food and water supplies in these areas, and the limits laid down by them must be strictly adhered to. The residents should be told the purpose and the times of such pesticide applications.

2.5 Fumigation

This is normally done with highly toxic gases after the premises have been sealed and evacuated. The main danger occurs when operators re-enter the building to ventilate it. Properly tested respirators of the canister or airline type must be used as the gas may still be present in lethal concentration. Detector tubes for cyanide, methyl bromide, and other fumigant gases are available. Special care must be taken to prevent the residents of treated premises re-entering them before they have been adequately ventilated. Only highly trained, specialized personnel should undertake fumigations.

2.6 Application to people

Liquid or dust formulations may be applied directly to people or to their clothes to control external parasites. Special care must be taken to ensure that only the correct formulation is used, as a mistaken use of a concentrate may have disastrous results.

2.7 Special devices

These include vapour release devices, baits, and impregnated cords and cloth.

In operations using these devices, the materials will normally be commercially available and will have been prepared under factory conditions. The proper protection of the workmen is the responsibility of the contractor.

The manufacturers of these devices must supply them with a full description of how they may be safely used. Baits may sometimes be prepared by mixing pesticide concentrates with the appropriate food for the pest to be attacked. Such baits should not be prepared or used inside homes.

3. Diagnosis and treatment of poisoning by organophosphorus compounds and carbamate pesticides

3.1 Signs and symptoms

Symptoms of exposure to organophosphorus insecticides may not appear until after the individual has left work, and their association with occupational poisoning may not be recognized immediately. The first symptom of poisoning is usually giddiness and a feeling of weakness. This may be followed by headache, nausea, vomiting, stomach cramps, and diarrhoea. Excessive sweating and excessive salivation may be present. In severe cases of poisoning, respiratory difficulties, convulsions, and unconsciousness may develop.

The carbamates have certain common characteristics that distinguish them in several important aspects from organophosphorus insecticides. In the case of overexposure to an insecticidal carbamate the signs of poisoning (such as headache, nausea, vomiting, and excessive sweating) develop rapidly, i.e., during or immediately after exposure; the incapacitating symptoms prevent further exposure, making the operator stop work long before a dangerous dose can be absorbed; recovery is rapid and complete and chronic or cumulative effects are extremely improbable. Owing to these characteristics there have been no cases of severe poisoning after occupational exposure to carbamates.

3.2 Cholinesterase determination

The diagnosis can be confirmed by the blood cholinesterase activity, which should be determined regularly in operators exposed to organophosphorus compounds.
of intermediate or greater toxicity; if there is a gradual, continuous decline in activity or a drop of more than 25% below a well-established pre-exposure level the operator should be removed from contact with the insecticide.

As carbamates do not have a cumulative inhibitory effect and as there are very marked, symptomless daily fluctuations in cholinesterase activity, routine cholinesterase determination has little if any practical value in indicating when a worker should be withdrawn from further exposure to these pesticides.

Several methods are available for determining cholinesterase activity; the choice of method will depend on the nature of the compound and the laboratory facilities available. Most of the organophosphorus compounds depress cholinesterase activity in the plasma before that in the red cells. On the other hand, with some carbamates (carbaryl, propoxur), the erythrocyte cholinesterase is inhibited more than the plasma cholinesterase.

3. 3 Treatment of poisoning by cholinesterase inhibitors

Serious poisoning is unlikely to occur in occupational exposure in public health programmes: a brief description of the treatment of severe cases is set out below, however, as large doses of insecticide may occasionally be absorbed intentionally or as the result of an accident.

As with all other types of intoxication, treatment is based on measures of the following two kinds: (1) removal of non-absorbed material; (2) specific antidotes and symptomatic treatment, such as artificial respiration. These procedures must be instituted rapidly in order to prevent a fatal outcome. As a rule, neither type of treatment is sufficiently effective if used alone.

In intoxication by mouth, rapid gastric lavage is imperative. For removal of secretions and maintenance of a patent airway, place the patient in a prone position with head down and to one side, the mandible elevated and the tongue pulled forward. If the body is soiled with the insecticide or if vomiting or hypersalivation has occurred, clothes must be removed and the skin washed with soap and water for at least 10 minutes. Contamination of the eyes is treated by washing the conjunctiva.

Deposits of organophosphorus compounds may be present on the skin or in the gut, from which continued absorption may occur for days. The condition of exposed persons who have become free of symptoms may deteriorate when new toxic material reaches the circulation.

(a) Intoxication with organophosphorus compounds

On signs of systemic absorption, both atropine and reactivators of the inhibited cholinesterase must be given parenterally. Treatment with reactivators will be most effective if given within a few hours after poisoning by an organophosphorus compound.

Cases of mild or moderate severity: Persons without signs of respiratory insufficiency but with manifest peripheral symptoms should be treated with 2–4 mg of atropine sulfate, and 1–2 g of pralidoxime chloride or 250 mg of Toxogonin (adult doses) by slow intravenous injection. More atropine with or without the reactivator may be given, depending upon the severity of the intoxication and the response to the first dose. The intravenous injection of reactivators should be made slowly, especially in small children. After the administration of reactivators, less atropine may be required.

Severe cases: In unconscious persons with respiratory difficulties and convulsions, the airways must be kept free and artificial respiration applied if required. Mouth-to-mouth respiration is to be avoided when it is suspected that the patient has been intoxicated by mouth, since vomited material may contain dangerous amounts of toxic material. As soon as cyanosis is overcome, 4–6 mg of atropine sulfate should be given initially, followed by repeated doses of 2 mg: the patient's condition, including respiration, convulsions, blood pressure, pulse rate and salivation should be carefully observed as a guide to further administration of atropine. Initially, atropine may have to be given at 5- or 10-minute intervals. Atropine should not be given to a cyanotic patient since it may lead to ventricular fibrillation and death. Besides atropine, reactivators—pralidoxime or Toxogonin—should be given (see above).

Morphine and tranquillizers must not be given to persons poisoned with anticholinesterases. Under exceptional circumstances, short-acting barbiturates such as sodium thiopental may be given intravenously for the relief of convulsions, but this treatment should be given only in hospital.

(b) Intoxication with carbamates

Since symptoms of intoxication with carbamates disappear comparatively rapidly, atropine treatment is often not necessary by the time the patient reaches the place where the antidote is at hand. In the event of accidental poisoning or manifest symptoms, 1–2 mg of atropine sulfate (adult dose) may be given intramuscularly or even intravenously and repeated as necessary. Care should be taken to avoid overdosage in cases of carbamate poisoning, especially in children. Oximes should not be given to persons poisoned with carbamates.
ANNEX 4

EXTRACTS FROM THE INTERNATIONAL HEALTH REGULATIONS *
RELATING TO VECTOR AND RODENT CONTROL

DEFINITIONS

Article 1
For the purposes of these Regulations—
“aerosol dispenser” means a dispenser holding a pressurized formulation which produces an insecticidal aerosol when the valve is opened;
“aircraft” means an aircraft making an international voyage;
“airport” means an airport designated by the State in whose territory it is situated as an airport of entry or departure for international air traffic;
“baggage” means the personal effects of a traveller or of a member of the crew;
“container (freight container)” means an article of transport equipment—
(a) of a permanent character and accordingly strong enough to be suitable for repeated use;
(b) specially designed to facilitate the carriage of goods, by one or more modes of transport, without intermediate reloading;
(c) fitted with devices permitting its ready handling, particularly its transfer from one mode of transport to another;
(d) so designed as to be easy to fill and empty.
The term “container (freight container)” does not include vehicles or conventional packing;
“diseases subject to the Regulations” (quarantinable diseases) means cholera, including cholera due to the eltor vibrio, plague, smallpox, including variola minor (alastrim), and yellow fever;
“disinsecting” means the operation in which measures are taken to kill the insect vectors of human disease present in ships, aircraft, trains, road vehicles, other means of transport, and containers;
“health administration” means the governmental authority responsible over the whole of a territory to which these Regulations apply for the implementation of the health measures provided herein;
“health authority” means the authority immediately responsible in its jurisdiction for the appropriate health measures permitted or prescribed by these Regulations;
“in flight” means the time elapsing between the closing of the doors of the aircraft before take-off and their opening on arrival;
“Organization” means the World Health Organization;
“port” means a seaport or an inland port;
“ship” means a seagoing or an inland navigation vessel making an international voyage;

NOTIFICATIONS AND EPIDEMIOLOGICAL INFORMATION

Article 4
1. Each health administration shall notify the Organization immediately of evidence of the presence of the virus of yellow fever, including the virus found in mosquitos or in vertebrates other than man, or the plague bacillus, in any part of its territory, and shall report the extent of the area involved.

Article 6
2. In the case of plague, the measures taken against rodents shall be specified. In the case of the diseases subject to the Regulations which are transmitted by insect vectors, the measures taken against such vectors shall also be specified.

HEALTH ORGANIZATION

Article 14
1. Each health administration shall ensure that ports and airports in its territory shall have at their disposal an organization and equipment adequate for the application of the measures provided for in these Regulations.

Article 15
There shall be available to as many of the ports and airports in a territory as practicable an organized
medical and health service with adequate staff, equipment and premises, and in particular facilities for the prompt isolation and care of infected persons, for disinfection, disinfesting and deratting, for bacteriological investigation, and for the collection and examination of rodents for plague infection, for collection of water and food samples and their dispatch to a laboratory for examination, and for other appropriate measures provided for by these Regulations.

Article 16
The health authority for each port and airport shall:
(a) take all practicable measures to keep port and airport installations free of rodents;
(b) make every effort to extend rat-proofing to the port and airport installations.

Article 17
1. Each health administration shall ensure that a sufficient number of ports in its territory shall have at their disposal adequate personnel competent to inspect ships for the issue of the Deratting Exemption Certificates referred to in Article 54, and the health administration shall approve such ports for that purpose.
2. The health administration shall designate a number of these approved ports, depending upon the volume and incidence of its international traffic, as having at their disposal the equipment and personnel necessary to derat ships for the issue of the Deratting Certificates referred to in Article 54.
3. Each health administration which so designates ports shall ensure that Deratting Certificates and Deratting Exemption Certificates are issued in accordance with the requirements of the Regulations.

Article 19
2. Every sanitary airport shall have at its disposal:
(c) facilities for efficient disinfection and disinfesting, for the control of vectors and rodents, and for any other appropriate measure provided for by these Regulations;

Article 20
1. Every port and the area within the perimeter of every airport shall be kept free from Aedes aegypti in its immature and adult stages, and the mosquito vectors of malaria and other diseases of epidemiological significance in international traffic. For this purpose active anti-mosquito measures shall be maintained within a protective area extending for a distance of at least 400 metres around the perimeter.
2. Within a direct transit area provided at any airport situated in or adjacent to an area where the vectors referred to in paragraph 1 of this Article exist, any building used as accommodation for persons or animals, shall be kept mosquito-proof.
3. For the purposes of this Article, the perimeter of an airport means a line enclosing the area containing the airport buildings and any land or water used or intended to be used for the parking of aircraft.
4. Each health administration shall furnish data to the Organization once a year on the extent to which its ports and airports are kept free from vectors of epidemiological significance in international traffic.

Article 23
1. Wherever the volume of international traffic is sufficiently important and whenever epidemiological conditions so require, facilities for the application of the measures provided for in these Regulations shall be made available at frontier posts on railway lines, on roads and, where sanitary control over inland navigation is carried out at the frontier, on inland waterways.

Health Measures and Procedure

Article 26
1. Disinfection, disinfesting, deratting, and other sanitary operations shall be carried out so as:
(a) not to cause undue discomfort to any person, or injury to his health;
(b) not to produce any deleterious effect on the structure of a ship, an aircraft, or a vehicle, or on its operating equipment;
2. In carrying out such operations on cargo, goods, baggage, containers and other articles, every precaution shall be taken to avoid any damage.
3. Where there are procedures or methods recommended by the Organization they should be employed.

Article 27
1. A health authority shall, when so requested, issue free of charge to the carrier a certificate specifying the measures applied to a ship, an aircraft, a train, road vehicle, other means of transport or container, the parts thereof treated, the methods employed, and the reasons why the measures have been applied. In the case of an aircraft this information shall, on request, be entered instead in the Health Part of the Aircraft General Declaration.
2. Similarly, a health authority shall, when so requested, issue free of charge:
(b) to the consignor, the consignee, and the carrier, or their respective agents, a certificate specifying the measures applied to any goods.
Article 31
1. The health authority for a port or an airport or for the area in which a frontier post is situated shall take all practicable measures:

(b) to prevent the introduction on board a ship, an aircraft, a train, a road vehicle, other means of transport or container, of possible agents of infection or vectors of a disease subjects to the Regulations.

Article 37
2. The further health measures which may be applied to the ship, aircraft, train, road vehicle, other means of transport, and container shall be determined by the conditions which existed on board during the voyage or which exist at the time of the medical examination, without prejudice, however, to the measures which are permitted by these Regulations to be applied to the ship, aircraft, train, road vehicle other means of transport, and container if it arrives from an infected area.

Article 45
2. A ship or an aircraft arriving at a port or an airport situated in an area where the vector of yellow fever is present shall not, in the following circumstances, be allowed to depart and shall be subject to the measures required by the health authority in accordance with these Regulations:

(a) if the aircraft is infected with yellow fever;
(b) if the ship is infected with yellow fever, and Aedes aegypti have been found on board, and the medical examination shows that any infected person has not been isolated in good time.

Article 48
Except in the case of an infected person or suspect, baggage may be disinfected or disinsected only in the case of a person carrying infectious material or insect vectors of a disease subject to the Regulations.

Article 49
2. Postal parcels may be subject to health measures only if they contain:

(d) living insects and other animals capable of being a vector of human disease if introduced or established.

Article 50
A health administration shall ensure as far as practicable that containers used in international traffic by rail, road, sea or air shall, in packing, be kept free of infectious material, vectors or rodents.

Special Provisions Relating to Each of the Diseases Subject to the Regulations

Article 53
1. Each State shall employ all means in its power to diminish the danger from the spread of plague by rodents and their ectoparasites. Its health administration shall keep itself constantly informed by systematic collection and regular examination of rodents and their ectoparasites of the conditions in any area, especially any port or airport, infected or suspected of being infected by rodent plague.

2. During the stay of a ship or an aircraft in a port or an airport infected by plague, special care shall be taken to prevent the introduction of rodents on board.

Article 54
1. Every ship shall be either:

(a) permanently kept in such a condition that it is free of rodents and the plague vector; or
(b) periodically deratted.

2. A Deratting Certificate or a Deratting Exemption Certificate shall be issued only by the health authority for a port approved for that purpose under Article 17. Every such certificate shall be valid for six months, but this period may be extended by one month for a ship proceeding to such a port if the deratting or inspection, as the case may be, would be facilitated by the operations due to take place there.

3. Deratting Certificates and Deratting Exemption Certificates shall conform with the model specified in Appendix 1.

4. If a valid certificate is not produced, the health authority for a port approved under Article 17, after inquiry and inspection, may proceed in the following manner:

(a) If the port has been designated under paragraph 2 of Article 17, the health authority may derat the ship or cause the deratting to be done under its direction and control. It shall decide in each case the technique which should be employed to secure the extermination of rodents on the ship. Deratting shall be carried out so as to avoid as far as possible damage to the ship and to any cargo and shall not take longer than is absolutely necessary. Wherever possible deratting shall be done when the holds are empty. In the case of a ship in ballast, it shall be done before loading. When deratting has been satisfactorily completed, the health authority shall issue a Deratting Certificate.

(b) At any port approved under Article 17, the health authority may issue a Deratting Exemption
Certificate if it is satisfied that the ship is free of rodents. Such a certificate shall be issued only if the inspection of the ship has been carried out when the holds are empty or when they contain only ballast or other material, unattractive to rodents, of such a nature or so disposed as to make a thorough inspection of the holds possible. A Deratting Exemption Certificate may be issued for an oil tanker with full holds.

5. If the conditions under which a deratting is carried out are such that, in the opinion of the health authority for the port where the operation was performed, a satisfactory result cannot be obtained, the health authority shall make a note to that effect on the existing Deratting Certificate.

Article 55

In exceptional circumstances of an epidemiological nature, when the presence of rodents is suspected on board, an aircraft may be disinfected and deratted.

Article 57

1. A ship or an aircraft on arrival shall be regarded as infected if:
   (a) it has a case of human plague on board;
   (b) a plague-infected rodent is found on board.

2. A ship on arrival shall be regarded as suspected if:
   (b) there is evidence of an abnormal mortality among rodents on board of which the cause is not yet known;

Article 58

1. On arrival of an infected or suspected ship or an infected aircraft, the following measures may be applied by the health authority:
   (a) disinfecting of any suspect and surveillance for a period of not more than six days reckoned from the date of arrival;
   (b) disinfecting and, if necessary, disinfection of:
      (i) any baggage of any infected person or suspect; and
      (ii) any other article such as used bedding or linen, and any part of the ship or aircraft, which is considered to be contaminated.

3. If there is rodent plague on board a ship, or in its containers, it shall be disinfected and deratted, if necessary in quarantine, in the manner provided for in Article 54 subject to the following provisions:
   (a) the deratting shall be carried out as soon as the holds have been emptied;
   (b) one or more preliminary derattings of a ship with the cargo in situ, or during its unloading, may be carried out to prevent the escape of infected rodents;
   (c) if the complete destruction of rodents cannot be secured because only part of the cargo is due to be unloaded, a ship shall not be prevented from unloading that part, but the health authority may apply any measures, including placing the ship in quarantine, which it considers necessary to prevent the escape of infected rodents.

4. If a rodent infected with plague is found on board an aircraft, the aircraft shall be disinfected and deratted, if necessary in quarantine.

Article 59

A ship shall cease to be regarded as infected or suspected, or an aircraft shall cease to be regarded as infected, when the measures required by the health authority in accordance with Articles 39 and 58 have been effectively carried out, or when the health authority is satisfied that the abnormal mortality among rodents is not due to plague. The ship or aircraft shall thereafter be given free pratique.

Article 60

On arrival, a healthy ship or aircraft shall be given free pratique, but, if it has come from an infected area, the health authority may:

(b) require the destruction of rodents on board a ship and disinsecting in exceptional cases and for well-founded reasons which shall be communicated in writing to the master.

Article 61

If, on arrival of a train or a road vehicle, a case or human plague is discovered, the measures provided for in Article 39 and in paragraphs 1 and 2 of Article 58 may be applied by the health authority, disinfecting and, if necessary, disinfection being applied to any part of the train or road vehicle which is considered to be contaminated.

Article 74

2. Every aircraft leaving an airport situated in an infected area shall be disinfected in accordance with Article 26, using methods recommended by the Organization, and details of the disinfecting shall be included in the Health Part of the Aircraft General Declaration, unless this Part of the Aircraft General Declaration is waived by the health authority of the airport of arrival. States concerned shall accept disinfecting of aircraft by the approved vapour disinfecting system carried out in flight.
3. Every ship leaving a port in an area where *Aedes aegypti* still exists and bound for an area where *Aedes aegypti* has been eradicated shall be kept free of *Aedes aegypti* in its immature and adult stages.

4. An aircraft leaving an airport where *Aedes aegypti* exists and bound for an area where *Aedes aegypti* has been eradicated shall be disinsected in accordance with Article 26, using methods recommended by the Organization.

**Article 77**

1. On arrival, a ship shall be regarded as infected if it has a case of yellow fever on board, or if a case has occurred on board during the voyage. It shall be regarded as suspected if it has left an infected area less than six days before arrival, or, if arriving within thirty days of leaving such an area, the health authority finds *Aedes aegypti* or other vectors of yellow fever on board. Any other ship shall be regarded as healthy.

2. On arrival, an aircraft shall be regarded as infected if it has a case of yellow fever on board. It shall be regarded as suspected if the health authority is not satisfied with a disinsecting carried out in accordance with paragraph 2 of Article 74 and it finds live mosquitoes on board the aircraft. Any other aircraft shall be regarded as healthy.

**Article 78**

1. On arrival of an infected or suspected ship or aircraft, the following measures may be applied by the health authority:

   (b) inspection of the ship or aircraft and destruction of any *Aedes aegypti* or other vectors of yellow fever on board; in an area where the vector of yellow fever is present, the ship may, until such measures have been carried out, be required to keep at least 400 metres from land.

**Article 79**

On arrival of a healthy ship or aircraft coming from an infected area, the measures provided for in subparagraph (b) of paragraph 1 of Article 78 may be applied. The ship or aircraft shall thereupon be given free pratique.

**Article 81**

On arrival of a train, a road vehicle, or other means of transport in an area where the vector of yellow fever is present, the following measures may be applied by the health authority:

(b) disinsecting of the train, road vehicle or other means of transport if it has come from an infected area.

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**Charges**

**Article 95**

2. Where charges are made for applying the measures provided for in these Regulations, other than the measures referred to in paragraph 1 of this Article, there shall be in each territory only one tariff for such charges and every charge shall:

(a) conform with this tariff;

(b) be moderate and not exceed the actual cost of the service rendered;

(c) be levied without distinction as to the nationality, domicile, or residence of the person concerned, or as to the nationality, flag, registry or ownership of the ship, aircraft, train, road vehicle, other means of transport, and containers. In particular, there shall be no distinction made between national and foreign persons, ships, aircraft, trains, road vehicles, other means of transport, and containers.

**Various Provisions**

**Article 96**

1. Every aircraft leaving an airport situated in an area where transmission of malaria or other mosquito-borne disease is occurring, or where insecticide-resistant mosquito vectors of disease are present, or where a vector species is present that has been eradicated in the area where the airport of destination of the aircraft is situated, shall be disinsected in accordance with Article 26 using the methods recommended by the Organization. States concerned shall accept disinsecting of aircraft by the approved vapour disinsecting system carried out in flight. Every ship leaving a port in the situation referred to above shall be kept free from the immature and adult stages of the mosquito concerned.

2. On arrival at an airport in an area where malaria or other mosquito-borne disease could develop from imported vectors, or where a vector species has been eradicated that is present in the area in which the airport of origin is located, the aircraft mentioned in paragraph 1 of this Article may be disinfected in accordance with Article 26 if the health authority is not provided with satisfactory evidence that disinsecting has been carried out in accordance with paragraph 1 of this Article. Every ship arriving in a port in the situation referred to above should be treated and freed, under the control of the health authority, from the immature and adult stages of the mosquito concerned.

3. As far as practicable, and where appropriate, a train, road vehicle, other means of transport, container, or boat used for international coastal traffic, or for international traffic on inland waterways shall be kept free of insect vectors of human disease.
### Appendix 1

**DERATING CERTIFICATE** (a) — **CERTIFICAT DE DÉRATISATION** (b)

**DERATING EXEMPTION CERTIFICATE** (c) — **CERTIFICAT D’EXEMPTION DE LA DÉRATISATION** (d)

Issued in accordance with Article 54 of the International Health Regulations. — délivré conformément à l’article 54 du Règlement sanitaire international (1969)

(Not to be taken away by Port Authorities.) — (Ce certificat ne doit pas être retiré par les autorités portuaires.)

**PORT OF** — **PORT DE**

**Date** — **Date**

**THIS CERTIFICATE** records the inspection and (derating) (exemption) (e) at this port and on the above date

**LE PRÉSENT CERTIFICAT** atteste l’inspection et (dératation) (exemption) (f) en ce port et à la date ci-dessus

of the (i) **ship** (ii) **inland navigation vessel** (g) of

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(a) Strike out the unnecessary indications. — Rayer les mentions inutiles.

(b) In case any of the compartments enumerated do not exist on the ship or inland navigation vessel, this fact must be mentioned. — Lorsqu’un des compartiments énumérés n’existe pas sur le navire, on devra le mentionner expressément.

(c) Old or recent evidence of excreta, runs, or gnawing. — Traces anciennes ou récentes d'excréments, de passages ou de rongements.

(d) None, small, moderate, or large. — Néant, peu, passablement ou beaucoup.

(e) State the weight of sulphur or of cyanide salts or quantity of HCN acid used. — Indiquer les poids de soufre ou de cyanure ou la proportion d’acide cyanhydrique.

(f) Specify whether applies to metric displacement or any other method of determining the tonnage. — Spécifier s’il s’agit de déplacement métrique ou, sinon, de quel autre tonnage il s’agit.

### OBSERVATIONS.

In the care of exemption, state here the measures taken for maintaining the ship or inland navigation vessel in such a condition that it is free of rodents and the plague vector. — Dans le cas d’exemption, indiquer ici les mesures prises pour que le navire soit maintenu dans des conditions telles qu’il n’y ait ni rongeurs, ni vecteurs de la peste.

Seal, name, qualification, and signature of the inspector. — Cachet, nom, qualité et signature de l’inspecteur.
DISINSECTING PROCEDURES *

Disinsecting before take-off; "blocks away" disinsecting

(i) Disinsecting of the passenger cabin and all other accessible interior spaces of the aircraft, except the flight deck, shall be done after the doors have been locked following embarkation and before take-off, this operation to be referred to as "blocks away" disinsecting. Single-use hand-operated aerosol dispensers shall be used. The dispensers shall be serially numbered. The serial number(s) of the dispensers used for the disinsecting of the aircraft shall be entered on the Health Part of the Aircraft General Declaration. The empty dispenser(s) shall be suitably stored in the aircraft, and upon arrival at destination they shall serve, together with the entries on the Health Part of the Aircraft General Declaration, as evidence of disinsecting. All possible mosquito sheltering places inside the aircraft shall be treated, including cupboards, chests and compartments for clothes, luggage and freight. Foodstuffs and utensils inside the aircraft shall be protected from contamination.

(ii) The flight deck shall be treated at a suitable time prior to expected occupancy by the flight crew, the door or curtains of this compartment being then closed and kept closed, except when opened momentarily to permit the passage of the crew members, until the "blocks-away" treatment and the take-off of the aircraft are completed. The ventilation system must be closed during the spraying and for a period of not less than five minutes following spraying.

(iii) All parts of the aircraft accessible only from the outside and in which insects can find shelter, such as cargo holds and wheel wells, are to be disinsected as nearly as possible to the time the aircraft leaves the apron.

(iv) For the disinsecting of aircraft, an aerosol of pyrethrins and DDT as specified above shall be dispensed uniformly throughout the treated spaces at the rate of 35 g of the formulation per 100 m² (10 g per 1000 cu. ft) of enclosed space.

Disinsecting on the ground on arrival

(i) Disinsecting shall be carried out by the health authority upon landing before the disembarkation of passengers or unloading of luggage and/or freight. All possible mosquito sheltering places inside the aircraft shall be sprayed, including cupboards, chests and compartments for clothes, luggage and freight. Particular attention shall be given to spaces under seats and behind crates and luggage, where diffusion of the insecticide would otherwise be slow. Foodstuffs and utensils which may be inside the aircraft shall be protected from gross contamination with the insecticidal spray.

(ii) The passenger, crew and freight compartments, the ventilators and all external apertures of the aircraft must be kept tightly closed during the spraying and for a period of not less than five minutes following the operation.

(iii) The recesses provided for the landing-gear, and all parts of the aircraft accessible only from the outside and in which insects can find shelter, are to be disinsected.

(iv) For the disinsecting of the interior of the aircraft and any exterior parts which might constitute shelter for insects, an aerosol of pyrethrins and DDT as specified above shall be dispensed uniformly through these spaces at the rate of 35 g of the formulation per 100 m² (10 g per 1000 cu. ft) of enclosed space.

* Extract from Annex VI to the International Health Regulations: recommendations on the disinsecting of aircraft.
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IN INTERNATIONAL HEALTH

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(1969)

Adopted by the Twenty-Second World Health Assembly

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Insecticides, Rodenticides, Molluscicides, Herbicides, Repellents, Laboratory Methods

Third edition, 1967†; 300 pages, illustrated
(Clothbound) £2 $6.75 Sw. fr. 20.—

The third edition of this manual differs in several important respects from the first two editions. Many pesticides for which specifications were included in the second edition are no longer in use on a large scale. For these substances, no specifications are given in the third edition, but those in the second edition will retain their validity. For some other pesticides important modifications have been made in the specifications, notably in the susceptibility requirements for water-dispersible powders. Tentative specifications have been added for several newer pesticides that are likely to find wide application in public health programmes. The manual no longer contains a section on spraying and dusting apparatus, as this is now dealt with in the companion volume Equipment for Vector Control (see below). It should be noted that, as indicated by the expanded title of the manual, the specifications are not applicable to pesticides used for agricultural purposes.

EQUIPMENT FOR VECTOR CONTROL

Guide to Major Items, Specifications, Use Descriptions, and Field Tests

1964‡; 200 pages, illustrated
(Clothbound) £1.60 $5.25 Sw. fr. 16.—

This manual, prepared by the WHO Expert Committee on Insecticides, is in five parts: a guide to the major items of equipment used for the application of pesticides; a series of charts showing the equipment recommended for control of the different vectors; specifications (five definitive specifications for sprayers and dusters and three provisional ones for aerosol dispensers); use descriptions of some twenty items for which it is not yet possible to establish specifications; and an outline of field tests for compression sprayers. The manual forms a companion volume to Specifications for Pesticides used in Public Health (see above).

† Although these publications were issued under the International Sanitary Regulations, 1951, the information contained therein remains valid under the 1969 Regulations.


Monograph Series

No. 38 INSECTICIDE RESISTANCE IN ARTHROPODS

by A.W. A. BROWN & R. PAL

Second edition, 1971; 491 pages, illustrated
£3 $10.00 Sw. fr. 30.—

The authors describe in detail the appearance, history and geographical distribution of insecticide resistance, its nature and the physiology underlying it, and they assess the importance of the phenomenon for each of the species of arthropod examined. They also discuss the genetics of resistance and methods for detection and measurement. In compiling this enlarged edition of the monograph, the authors have made a thorough survey of the world literature, both published and unpublished (over 1600 references are listed).

Technical Report Series

No. 174 EXPERT COMMITTEE ON HYGIENE AND SANITATION IN AVIATION

First Report

1959 ; 62 pages
20p $0.60 Sw. fr. 2.—

Five main groups of problems are discussed: water supply and distribution; food and milk sanitation; sewage and waste disposal; insect and rodent control; and refuse disposal. The report also considers the relationships which should exist at the national or local level between the airport and constituted health authorities, the organization of personnel for airport sanitation, and the role of WHO.

No. 206 AIRCRAFT DISINSECTION

Eleventh Report of the Expert Committee on Insecticides

1961 ; 26 pages
10p $0.30 Sw. fr. 1.—

A number of international airports do not comply with the International Health Regulations regarding the protection of airports from mosquito vectors, and the status of vector control at these airports has given rise to some concern. This report urges the setting-up of an effective vector control organization at each international airport, under the auspices of the national health authority. Technical advice is given on the choice of dissection method, and recommendations for further research are outlined.

No. 268 GENETICS OF VECTORS AND INSECTICIDE RESISTANCE

Report of a WHO Scientific Group

1964 ; 40 pages
20p $0.60 Sw. fr. 2.—

This report is intended to stimulate research on the genetics of vectors and on the application of genetic methods in vector control. It includes a review of the state of knowledge in this field in 1963, with detailed research proposals and recommendations as to the types of service needed to stimulate and co-ordinate the research.

No. 368 MOSQUITO ECOLOGY

Report of a WHO Scientific Group

1967 ; 22 pages
20p $0.60 Sw. fr. 2.—

This report emphasizes the importance of carrying out ecological studies that might permit changes in mosquito populations to be anticipated. It proposes the use of a life-table analysis for describing, in terms of absolute population size, the numbers of mosquitoes in each generation and stage. Present knowledge of mosquito ecology is reviewed, and attention drawn to areas in which further research is necessary. Techniques for the study of mosquito populations are also described, and it is suggested that a number of methods commonly used to study the ecology of higher animals could profitably be applied to research in mosquito ecology.

No. 398 CYTOGENETICS OF VECTORS OF DISEASE OF MAN

Report of a WHO Scientific Group

1968 ; 41 pages
30p $1.00 Sw. fr. 3.—

Reviews knowledge of cytogenetics and outlines the importance of vector cytogenetic studies in public health, with particular attention to studies of chromosomes, including their number and morphology, salivary gland chromosomes, and the preparation of linkage maps. The formation of species complexes by vectors and the determination of the DNA content of cells are also discussed. The use of sterile insects in control programmes is reviewed. Information on the cytology, cytogenetics, and genetics of Aedes aegypti and Anopheles gambiae is summarized in annexes.
This report presents a synoptic review of the status of resistance and summarizes reports of vector resistance to the main insecticides. Reference is also made to resistance of insects to chemosterilants and bacterial toxins, resistance of non-target organisms to insecticides, and resistance of rodents to rodenticides. The effect of resistance on the control of the various arthropods of medical importance is outlined. The report also reviews progress in research on insecticide resistance and developments in vector control. Annexed to the report are revised standard test methods for the detection and measurement of resistance, and suggested chemical methods for the control of vectors and pests of public health importance.

Summary contents:

Summary contents: Use of pesticide formulations in public health programmes — Collaboration with other organizations — Establishment of specifications: comments on specifications in which no changes were recommended; specifications in which changes were recommended; new specifications — Deletions of specifications — Changes in methods — Development of specifications for new pesticides — Recommendations.


This survey is not intended to provide an exhaustive coverage of world legislation on pesticide control but to illustrate, on the basis of the policies adopted in 11 countries, the diverse patterns such legislation has taken. The introductory section contains a comparative analysis of the way in which the various countries have dealt with the more important aspects of the subject (registration of pesticides, control of manufacture, supply and application, labelling, occupational health, aerial application, residues in foodstuffs, etc.). This is followed by a detailed account of the legislation in each of the countries covered.
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