WHO/CDS/NTD/WHOPES/GCDPP/2006.1

PESTICIDES AND THEIR APPLICATION

For the control of vectors and pests of public health importance

World Health Organization

Sixth edition

WHO/CDS/NTD/WHOPES/GCDPP/2006.1

PESTICIDES AND THEIR APPLICATION

For the control of vectors and pests of public health importance

Sixth edition

World Health Organization

Department of Control of Neglected Tropical Diseases
WHO Pesticide evaluation scheme (WHOPES)

© World Health Organization 2006

All rights reserved.

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

All reasonable precautions have been taken by the World Health Organization to verify the information contained in this publication. However, the published material is being distributed without warranty of any kind, either express or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall the World Health Organization be liable for damages arising from its use.

Contents

Contents

Contents

Contents

Acknowledgements

The Department of Control of Neglected Tropical Diseases (NTD) wishes to thank Professor C.F. Curtis, London School of Hygiene and Tropical Medicine, UK, for drafting this document. NTD also wishes to thank the following for critical review of this publication and for their valuable comments and suggestions:

- K.M. Allam, Research Institute of Medical Entomology, Cairo, Egypt
- A. Akin, Crompton Europe, Izmir, Turkey
- S. Barlow, Brighton, East Sussex, United Kingdom
- M. Birchmore, Syngenta, Basel, Switzerland
- N. Besbelli, World Health Organization, Geneva, Switzerland
- C. Boase, Haverhill, Suffolk, United Kingdom
- R. Bos, World Health Organization, Geneva, Switzerland
- A. Buckle, Fernhurst, Haslemere, Surrey, United Kingdom
- I. Burgess, Insect Research and Development, Cambridge, United Kingdom
- M.M. Cameron, London School of Hygiene and Tropical Medicine, London, United Kingdom
- A. Chiri, Office of Pesticide Programs, US Environmental Protection Agency, Washington DC, United States of America
- D.G. Cochran, Hamstead, North Carolina, United States of America
- C.R. Davies, London School of Hygiene and Tropical Medicine, London, United Kingdom
- P. Desjeux, Institute for OneWorld Health, Divonne, France
- M. Faust, Bayer CropScience, Monheim, Germany
- P. Guillet, WHO Regional Office for Africa, Harare, Zimbabwe
- G. Hesse, Bayer Environmental Science, Lyon, France
- A. Hill, Huntington, York, United Kingdom
- N.Hill, London School of Hygiene and Tropical Medicine, London, United Kingdom
- K. Horn, Bayer Environmental Science, Monheim, Germany
- T. Itoh, Sumitomo Chemical, Osaka, Japan
- Z. Jaal, Vector Control Research Unit, University of Sains Malaysia, Penang, Malaysia
- W. Jacobs, Office of Pesticide Programs, US Environmental Protection Agency, Washington DC, United States of America
- J. Jannin, World Health Organization, Geneva, Switzerland
- A.M. Jordan, Wedmore, Somerset, United Kingdom
- D. Kelili, Dow AgroSciences, Sophia Antipolis, France
- S. Krause, Valent BioSciences, Chicago, Illinois, United States of America
- H.L. Lee, Infectious Disease Research Centre, Institute for Medical Research, Kuala Lumpur, Malaysia

Acknowledgements

- G. Matthews, International Pesticide Application Research Centre, Imperial College, Ascot, Berkshire, United Kingdom
- P.S. Mellor, Institute for Animal Health, Surrey, United Kingdom
- M. Nathan, World Health Organization, Geneva, Switzerland
- H. Pijst, Crompton Uniroyal Chemical, Amsterdam, Netherlands
- C.V. Prescott. University of Reading, Reading, Berkshire, United Kingdom
- C. Schofield, Pregnins, St Genis Pouilly, France
- A. Smith, University of Leicester, Leicester, Leicestershire, United Kingdom
- N. Spiller, Sumitomo Chemical, London, United Kingdom
- J.R. Stothard, Natural History Museum, London, United Kingdom
- T. Tanaka, Mitsui Chemicals, Tokyo, Japan
- A. Walker, University of Edinburgh, Edinburgh, Scotland, United Kingdom
- D. Warrell, University of Oxford, Oxford, Oxfordshire, United Kingdom
- G.B. White, Department of Entomology and Nematology, . University of Florida, Gainesville, Florida, United States of America
- M. Zaim, World Health Organization, Geneva, Switzerland

This publication was funded by the Global Collaboration for Development of Pesticides for Public Health.

1. General considerations

1.1 Introduction

Every year, hundreds of millions of cases of insect-, snail- and rodent-borne diseases occur, representing a major threat to global public health. Vector-borne diseases account for around 17% of the estimated global burden of infectious diseases. Operational, financial and managerial problems, together with environmental change, pesticide resistance and increasing population mobility have contributed to increases in the prevalence of many of these diseases in recent decades. Diseases that are usually transmitted via vectors or intermediate hosts include dengue, filariasis, Japanese encephalitis, leishmaniasis, malaria, onchocerciasis, schistosomiasis and trypanosomiasis. In addition, it has recently been confirmed that domestic flies play a significant role in the mechanical transmission of diarrhoeal diseases and trachoma. Although these two diseases are also transmitted by other routes, they are such important causes of child death and blindness that domestic flies should be considered of major significance as disease vectors.

Vector control is an important component of many vector-borne disease control programmes. Its implementation includes targeted, site-specific use of the available methods, predicated on technical and operational feasibility, resources and infrastructure. They should be applied in accordance with the principles of integrated vector management[1], an evidence-based decision-making process adapted to local settings, which rationalizes the use of vector control methods and resources and emphasizes the involvement of communities.

This is the sixth edition[2] of a guide to the use of chemical methods for control of vectors and pests of public health importance. It provides staff involved in operational vector control programmes with practical information on the safe and effective use of pesticides as well as information on the use of chemicals for individual and household protection from insect and rodent pests.

In many countries with endemic infestation with pests, vector control strategies have evolved from large, centrally organized vertical programmes to decentralized programmes integrated into general health services. The dwindling arsenal of safe, cost-effective pesticides for public health use, increasing concern about the environmental and safety implications of the widespread use of chemicals and the need to use more and more limited health sector funds to the maximum benefit has resulted in greater emphasis on the judicious use of pesticides. Thus, non-chemical measures are the first option, and use of chemical interventions is considered only when necessary. The selection and use of different chemical and non-chemical methods for vector and pest control should be based on their efficacy, sustainability and cost-effectiveness. It is beyond the scope of this manual to judge the cost-effectiveness of all the vector control strategies used in a

[1] *Global strategic framework for integrated vector management*. Geneva, World Health Organization (unpublished document WHO/CDS/PVC/2004.10; available on request from the Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

[2] This revision was edited by Professor C.F. Curtis (London School of Hygiene and Tropical Medicine). The original version and the first, second and third revisions appeared, respectively, in the eighth, tenth and thirteenth reports of the WHO Expert Committee on Insecticides. The fourth revision was prepared by Dr C.Y. Chow, Dr R. Le Berre, Dr M. Vandekar, Dr D.E. Weidhaas and Dr A. Smith. The fifth edition was edited by Dr D.C. Chavasse and Dr H.H. Yap.

wide range of settings, and this subject is addressed elsewhere[3]. Despite the growing contribution of alternative measures, chemical control will continue to play a vital role in vector-borne disease control, particularly when rapid, effective control is essential, such as during disease epidemics.

Community-based vector-borne disease control has received greater emphasis in recent years. Notably, the demonstration that insecticide-treated mosquito nets can reduce mortality and morbidity due to malaria (see chapter 2) led to the promotion of net use in many malarial areas. Greater attention has also been paid to personal and household protection from insect vectors and intermediate rodent hosts (see chapters 14 and 15), and to community participation in eliminating vector breeding sites. The provision of information on simple, effective, acceptable methods for reducing the sources of vectors and for personal protection at a reasonable cost is an important part of vector control programmes.

Four classes of chemical insecticides—the organochlorines, the organophosphates, the carbamates and the pyrethroids—are still the mainstay of vector control programmes. Use of pyrethroid insecticides has, however, increased, and that of the organochlorines and some of the more toxic organophosphate compounds has decreased in recent years. The continued use of DDT for disease vector control is conditionally approved under the Stockholm Convention on Persistent Organic Pollutants[4], in accordance with WHO recommendations and guidelines, and when locally safe, effective and affordable alternatives are not available.

Use of the bacterial insecticides, *Bacillus thuringiensis israelensis* (serotype H-14) and *B. sphaericus* has increased in response to the demand for safe, pest-specific compounds. Although these materials are considered to be biopesticides, they are included in this manual with chemical insecticides as larvicides for control of mosquitoes and blackflies.

Insect growth regulators have also become more widely used in recent years. These compounds can be divided into juvenile hormone analogues (juvenoids), such as methoprene and pyriproxyfen, and chitin synthesis inhibitors, such as diflubenzuron, triflumuron and novaluron. Juvenoids interfere with transformation of the immature stage to the adult, while chitin synthesis inhibitors inhibit cuticle formation. In general, juvenoids that act during a narrow period of susceptibility are less active against asynchronous larval populations, whereas chitin synthesis inhibitors that act during ecdysal changes are equally effective against synchronous and asynchronous populations. Insect growth regulators have been most widely used against mosquito vectors, although they are active against a wide range of public health pests. In general, these compounds have a high margin of safety for fish, birds, mammals and most aquatic non-target organisms. They also show extremely little toxicity to humans. Some insect growth regulators do, however, adversely affect aquatic crustaceans and species closely related to mosquitoes which share the same habitats, some of which may be predators for mosquito larvae, thus keeping vector populations down in a naturally balanced situation.

[3] *Guidelines for cost-effectiveness analysis of vector control.* Joint WHO/FAO/UNEP/UNCHS Panel of Experts on Environmental Management for Vector Control. Geneva, World Health Organization, 1993.

[4] http://www.pops.int/

1.2 Scope and layout of the manual

As in the fifth edition, each pest group is covered in its own chapter. Each chapter contains a brief introduction to the pest species, its medical importance and the role of chemicals in integrated vector and pest management. This is usually followed by sections on the various chemical approaches to control under the headings listed below.

Target area. This term refers to the main target site for pesticide treatment and covers the breeding areas of the immature stages and the resting and feeding sites of the adult vector or pest.

Insecticides. While reference is made to many insecticides in general use, this document does not provide a comprehensive list of all insecticides used in vector control. As far as possible, the names approved by the International Organization for Standardisation (ISO) are used. *The presence or absence of the name of a pesticide in a list in no way constitutes a recommendation for or against its use by the World Health Organization*. The decision to use a compound rests with national health authorities or individual vector control personnel. No proprietary names are given, as there are too many to mention individually, and the active ingredients of these products are changed from time to time. It is therefore important to consult the label on the container of every pesticide to check the identity of the active ingredients, recommended dose and safety measures before use.

Application procedure. As all possible methods of application cannot be described in detail, only those most commonly used are presented.

Treatment cycle. Pesticide application and the frequency of re-treatment depend on the species of vector and its bionomics, the pesticide selected and its formulation, the effectiveness of the dosage used, the types of site to be treated, local climatic conditions, the disease transmission period and the target level to which disease transmission is intended to be reduced. As treatment cycles can vary greatly from one geographical area to another, those indicated in this manual constitute only a basic guideline.

Precautions. Close attention should be paid to chapter 2, 'Safe use of pesticides'. The health risk of a compound is directly related to the way in which it is handled and used. Some pesticides present an unacceptable risk to sprayers, house occupants and the environment and should not be used. Only those that are approved for a particular use by the relevant national authority should be considered. Before applying a pesticide, the user should read the label carefully to determine any handling precautions, restrictions on people handling it and any hazard to non-target organisms. It is the responsibility of the vector control programme director to ensure that pesticides are used in such a way that injury, harm or damage is avoided.

WHO specifications are intended for quality assurance and risk management. Active ingredients and formulated pesticide products must conform to WHO specifications, when available. The WHO specifications for pesticides for public health use are available on the WHO web site at www.who.int/whopes/quality.

1.3 Selecting an appropriate chemical control strategy

Effective control measures must be based on a clear understanding of the bionomics and behaviour of the target species. Effective vector and pest control also requires careful training, supervision of control operations and periodic evaluation of the impact of the control measures on the targeted vectors or pests and on disease incidence or prevalence. Chemical measures should be considered only as a complementary addition to basic sanitation, as far as possible.

In selecting a pesticide and the appropriate formulation, consideration should be given to its biological effectiveness (including residual activity where appropriate) against the pest concerned, the susceptibility of the target organism, the methods of application, its safety to humans, its toxicity to non-target organisms, the registration status of the pesticide for the required use and its cost. If possible, small trials on the efficacy of a formulation and application method should be conducted under local conditions before a commitment is made to purchase large quantities. In choosing a pesticide, consideration should also be given to ease of handling and application, the availability of application equipment as well as transport requirements. The dose of active ingredient per unit area and the concentration of the active ingredient in the formulation must be known for determining the quantities of pesticide formulation required. Due regard should also be given to the impact of the compounds on the environment, including fish, birds and beneficial invertebrates. The cost should be determined on the basis of that of the material as applied (cost of application to treat a unit area that is effective for a given period of time) and not only on the purchase price of the chemical. These aspects should be discussed with the representatives of potential suppliers so that informed choices can be made on the most appropriate pesticide for the local context. WHO guidelines for the purchase of pesticides for public health use provide general guidance on selection of appropriate, good quality pesticides and formulations[5].

1.4 Pesticide formulations

Pesticides are rarely used in pure or technical-grade form. Usually, the technical-grade material (active ingredient) is mixed with various non-pesticidal ingredients to create a pesticide formulation. These ingredients are often known as ‘inerts’ (although the term is potentially misleading) and serve a variety of functions. The principal function is to facilitate delivery of the pesticide to the intended target; they may also enhance stability, improve safety, improve efficacy or facilitate handling of the product. The type of pesticide formulation, and in some cases the choice of product of the same formulation type, can markedly affect the results obtained in practical use. When absorbent surfaces such as mud are sprayed, suspensions of water-dispersible powders, water-dispersible granules or diluted suspension concentrates often have a longer residual effect than emulsions or solutions, which tend to be absorbed below the surface. While more effective, they may, however, leave an unpleasant deposit on treated surfaces. Microencapsulated products tend to provide long-term control and are more effective in exposed environments, such as outdoors. Safety, efficacy, residual life, cost, availability and ease of use must all be considered in selecting a formulation. Commonly used formulations are described briefly below.

[5] *Guidelines for the purchase of public health pesticides.* Geneva, World Health Organization (unpublished document WHO/CDS/WHOPES/2000.1; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://whqlibdoc.who.int/hq/2000/WHO_CDS_WHOPES_2000.1.pdf).

- *Bait (ready-for-use)*: a formulation designed to attract and be eaten by the target pest.
- *Capsule suspension (slow- or controlled-release)*: a suspension of capsules in a fluid, usually intended for dilution with water before use. The active ingredient in these products is encased in microscopic polymer capsules, which release the insecticide slowly, extending the compound's residual life. They ensure that an excessive surface concentration is not produced at the time of application and are relatively easily washed from the skin if accidental contamination occurs during application. The capsules are not readily absorbed by porous surfaces, and they adhere easily to insects, increasing insect–insecticide contact. They have little odour and a good residual effect, as the active ingredient is protected from sunlight and air. The diluted product might require agitation during application
- *Dustable powder:* a free-flowing powder suitable for dusting. This type of formulation is used mainly to control lice and fleas.
- *Emulsifiable concentrate*: a solution of active ingredient and surfactants in a water-immiscible solvent, which forms a stable emulsion after dilution with water (or with diesel oil or kerosene). This is an economical form in which to ship high concentrations of non-polar insecticides. Emulsifiable concentrates are easy to mix with water to form an emulsion, instantly, which then requires only a little agitation to maintain a formulation suitable for application. These emulsions leave few visible deposits on the treated surface; however, diluted emulsifiable concentrates can have a strong smell and are absorbed by porous surfaces. The organic solvents and emulsifiers can burn plant foliage and facilitate absorption of the active ingredient through the skin, thereby increasing the risk of operators. Another use of emulsifiable concentrates is for space spraying.
- *Emulsion, oil-in-water*: This formulation consists of an active ingredient dissolved in a water-immiscible solvent, which, in the presence of surfactants, is dispersed as fine oil-phase droplets in water. An oil-in-water emulsion is similar to a diluted emulsifiable concentrate but is usually stable for longer and contains lower concentrations of solvent and surfactants. The concentration of water-immiscible liquid active ingredients can be as high as 500 g/l. The formulation can be diluted only with water for application.
- *Granules*: a free-flowing solid formulation of a defined granule size range, ready for use. Granules are made by impregnating, extruding or coating coarse inert carrier particles with, usually 10–100 g of the active ingredient per kilogram (1–10%). When used to control mosquito larvae, better penetration of vegetation is obtained with granules than with liquid formulations, and the persistence of the active ingredient in the target area may be improved. In many instances, granules can be distributed by hand (suitable gloves must be used and properly disposed of after application), obviating the need for applicators.
- *Suspension concentrate (flowable concentrate)*: a suspension of active ingredient in water, intended for dilution with water before use. These formulations are similar to wettable powders or water-dispersible granules dispersed in water, in that the active ingredient is in the form of crystalline particles, but the particles are smaller. The particles are not absorbed into porous surfaces, the active ingredient does not penetrate the skin as readily as it would in a comparable emulsifiable concentrate, and they leave less visible residues than wettable powders, as the particles are tiny.

- *Technical grade*: The active ingredient in its purest commercial form, used for making formulations.
- *Ultra-low-volume liquid*: a solution, usually in a water-immiscible solvent, for use with cold fogging (ultra-low-volume) equipment for space spraying. These can be ready-to-use formulations or prepared for dilution with oil or kerosene.
- *Water-dispersible granules*: a formulation consisting of granules to be applied by spraying after disintegration and dispersion in water. The particulates in suspension can consist of the active ingredient or of inerts bearing the active ingredient. There is less risk of inhalation of airborne particles from water-dispersible granules than from wettable powders or water-dispersible powders. Some water-dispersible granules are available in high concentrations, thus reducing the costs of transport and storage.
- *Water-dispersible tablets*: tablet formulations used individually to form a dispersion of the active ingredient after disintegration in water. The tablets can be effervescent, to aid dispersion. They are as easy to use as water-dispersible granules, because the formulation does not have to be measured out, and the risk of exposure by inhalation is generally lower. This formulation has been used for treatment of mosquito nets by dipping.
- *Wettable powders and water-dispersible powders*: formulations that contain active ingredient plus wetting agent plus inert carrier, used to prepare water-based suspensions. For public health use, the powders usually contain the active ingredient at a concentration of 100–500 g/l (10–50%). They have been widely used for indoor residual spraying; however, the particles in suspensions made from wettable and water-dispersible powders are larger than those in suspension concentrates. As a result, visible residues may be left on sprayed surfaces.Furthermore, there is a risk of exposure during mixing, as the dry particles can become airborne and be inhaled. Masks should therefore be worn during mixing. When available, water-soluble sachets should be placeddirectly in the spray tank, thus preventing the release of airborne particles.

1.5 Pesticide application equipment

The selection of properly designed application equipment for the recommended method of control is an important part of vector control planning. Most programmes continue to rely on hand-operated equipment, compression sprayers being used most commonly for operations such as residual treatment and application of larvicides and molluscicides. The maintenance of compression sprayers is relatively simple, but it is important that at least one member of each field team knows how to replace worn-out nozzles, gaskets and pump washers, for instance. The operation and maintenance of motorized equipment require additional skills, and problems will arise unless supervision by trained personnel is guaranteed. A range of application equipment for delivering pesticides to the target site is referred to in this manual. Brief descriptions of commonly used equipment are given below[6].

Hand-operated compression sprayer

These sprayers are designed for applying pesticides onto surfaces with which the vector or pest will come in contact or to breeding sites. A pesticide and water mix is either

[6] See: *Equipment for vector control*. Geneva, World Health Organization. 3rd edition, 1990.

added to the tank or mixed within it. The tank is then pressurized by forcing air into it with a hand-operated plunger. A lever on the sprayer arm controls the release of spray through the nozzle. Filtering the water while filling the sprayer, regular maintenance and prompt replacement of damaged nozzle tips are essential to the sprayers' effectiveness; otherwise, abrasion from particles in the water can cause deterioration, resulting in an excessive increase in discharge rate. A disadvantage of this sprayer is that the pressure decreases as the tank is emptied, with an accompanying reduction in the rate of delivery. To counteract this, it is important to provide a pressure control valve at the nozzle. Bearing in mind the cost of insecticides and the dose required to control the target organism, it is important to maintain nozzle tips in good condition and to check the calibration of this equipment to ensure the correct rate of application. Most problems encountered with these sprayers in the field are due to inadequate cleaning at the end of each day. Regular inspection and checking of parts by trained personnel are essential.

Mist blowers (power-operated)

This equipment can be either portable or vehicle-mounted. Portable knapsack mist blowers are powered by a two-stroke engine, producing a high-velocity air stream, which blows out a low volume of insecticide as a fine mist. The engine must have a guard to prevent anyone touching the hot exhaust. The volume emitted can be regulated through restrictors, but large droplets are produced at high flow rates. Large droplets deposit insecticide onto surfaces, whereas smaller droplets remain airborne longer to affect insects either in flight or at rest. Although water is added to the insecticide formulation, the overall volumes applied with mist blowers are relatively small. Ultra-low-volume sprays can be applied with the smallest restrictors. Knapsack mist blowers can cover a large area in a relatively short time and can be operated in areas through which vehicle-mounted equipment cannot pass, such as narrow streets. Difficulties occur most frequently in starting these machines, because the fuel mixture (oil and petrol) left in the engine after use evaporates, leaving an oily residue over the spark-plug. This can be avoided if the method used to stop the machine at the end of spraying is to switch off the fuel, resulting in combustion of all the fuel in the carburettor, with none left in contact with the spark-plug overnight. Air, fuel filters and nozzles should be cleaned regularly, and the water used in the insecticide mix should be clean or filtered, as blades of grass or dirt can easily block the nozzle aperture. The disadvantages of the knapsack mist blower are the risk of burns from the engine and the discomfort caused by heat, vibration and noise.

Aerosol generators (power-operated)

Cold fogging equipment is used to apply insecticides, either in their technical-grade form or, more usually, diluted in oil or water, as space treatments, often at ultra-low volume. The machines can be hand-held, but larger versions are truck-mounted. As the volume sprayed per unit area is much smaller than that with thermal foggers (see below), they can cover larger areas more quickly. Portable ultra-low-volume aerosol generators are more efficient when access by road is difficult or when indoor spraying is required. The large truck-mounted machines can cover extensive urban areas where road access is reasonable. The most important consideration in use of ultra-low-volume cold foggers is the calibration and accuracy of droplet size. For flies and mosquitoes, this should be 15–25 µm. Factors that should be considered in choosing a method for ground application of aerosols include the behaviour and activity times of the target organisms, the availability of trained staff for supervision and maintenance, cost–effectiveness and safety of operation. Only insecticide formulations recommended for ultra-low-volume use by the manufacturer should be used in ultra-low-volume application equipment.

Thermal foggers (power-operated)

These machines, which can be either portable or vehicle-mounted, are preferred in many vector control programmes, despite the extra cost of application due to the use of diesel fuel as a diluent. Most of the droplets are less than 20 µm, but the droplet size is far less closely controlled than with cold fogging equipment. When using thermal foggers, consideration should be given to increasing the concentration of insecticide and decreasing the flow rate proportionally to reduce costs. Thermal foggers carry a potential fire hazard, especially when pulse-jet foggers are carried indoors. It is important that only well-trained personnel, using appropriate insecticide formulations and with access to a fire extinguisher, be entrusted with their operation. The advantage of pulse-jet foggers is their simple design and construction, as there are no rotating parts, and no lubrication is required. Nevertheless, their loud noise can be objectionable, and operators should wear ear protection.

Aerial spraying equipment

Large-scale and emergency vector control programmes often involve the use of aircraft to apply chemicals. Aircraft are especially well suited for rapid treatment of large areas or of areas where wet soil, water, rough terrain, dense woody vegetation or a dense urban population (during emergencies) prohibit the use of ground or hand-held equipment. Aerial spraying can be used both for adulticiding and for applying coarse larvicidal sprays. Accurate placement of sprayed chemicals is usually more difficult from aircraft than with ground application equipment, as many factors affect the trajectory of particles after they are released. Good-quality atomizers are needed to achieve the appropriate droplet spectra. The droplets must be larger than for ground application to compensate for evaporation on their descent. Ideally, by the time a droplet reaches ground level, it should be 15–25 µm. Therefore, use of aerial spraying should be thought out carefully, particularly with regard to safety when spraying populated areas. Aerial spraying should not be considered if buildings preclude low-level flying, as experience has shown that spraying from heights greater than 75 m is ineffective. Political pressure for immediate action has sometimes resulted in inappropriate, and consequently ineffective, use of aircraft to attempt vector control. Although rapid action might be required, several factors should first be considered, including safety, timeliness, cost, meteorological conditions, vector habitat, biological effectiveness and the availability of equipment, operational sites and trained crews.

Dusters

Dusters are most commonly used to apply dust to control human lice or rodent fleas for preventing epidemics of typhus or plague. The hand-activated, plunger-type duster is designed for control of arthropod pests on individuals and is appropriate for treating small numbers of people, as the dust can easily be blown into sleeves and other garment openings. Dusters can also be used to apply dusts to rodent burrows for flea control. Powered equipment for mass dusting of human populations tends to be unreliable, as the quantity and direction of dust flow are difficult to regulate and blockages are apt to occur. Although dusts contain only a small proportion of active ingredient, the main concern in the field is the risk of inhalation of pesticide particles smaller than 10 µm in diameter. This problem is accentuated if the operator walks into a cloud of dust without an appropriate face mask or respirator.

[7] *Vector resistance to pesticides*. Geneva, World Health organization, 1992 (WHO Technical Report Series, Nº. 818).

1.6 Pesticide resistance

Pesticides have been the cornerstone of vector-borne disease control for the past 50 years; however, use of chemicals on a vast and increasing scale has led to the widespread development of resistance as a result of selection for certain genes. The number of insecticide-resistant arthropods of public health importance rose from 2 in 1946 to 150 in 1980 and 198 in 1990. Some species have become resistant to multiple insecticides, making their control by chemical methods extremely difficult and expensive. Among the vectors of public health importance, tsetse flies, triatomine bugs, trombiculid mites and snail hosts of human schistosomiasis are the only ones in which resistance does not present a problem for control. The status of resistance of major vectors to pesticides in various geographical areas was last reviewed by WHO in 1992[7].

Monitoring of vector resistance to pesticides should be an integral component of the planning and evaluation of vector-bone disease and pest control programmes. Such monitoring should be standardized to ensure the comparability of data from different sources. The use of standard test kits and procedures, including 'discriminating concentrations', is therefore recommended. Discriminating concentrations (dosages) of pesticides are established under standardized laboratory conditions, with strains or populations of a range of vector and pest species known to be 'susceptible'. Discriminating concentrations are not intended to mimic the doses applied in the field but are the concentrations found reliably to kill strains that have never encountered pesticides and are therefore assumed to be susceptible. The discriminating concentrations of commonly used insecticides against a wide range of pest species are listed in the WHO report referred to above and updated on the WHOPES web site[8].

Reported resistance of a particular vector species in a particular area does not in itself justify an immediate change in policy for control programmes in that area. Planning for alternative strategies and pesticides should, however, begin. If current measures are inadequate to control disease to the required level, the strategy or pesticide should immediately be adjusted. Nevertheless, even in the presence of resistance, the pesticide might be sufficient to suppress transmission, either because the level of resistance of the vector is not sufficiently high or because the pesticide has some effect, such as reducing human–vector contact, which is not modified by resistance, or the resistance gene reduces the irritability due to the insecticide deposit so that the insects remain in contact long enough to acquire a lethal dose. In an important recent example, a high level of resistance to pyrethroids was detected by susceptibility testing of *Anopheles gambiae* Savannah in Côte d'Ivoire and Benin, and molecular tests showed the presence of the *kdr* gene at very high frequency. Data from experimental huts showed, however, that pyrethroid-treated mosquito nets were continuing to kill wild mosquitoes, and, in villages where there was widespread use of treated nets, malaria incidence continued to be dramatically reduced. This underlines the need to document resistance and its impact on the efficacy of interventions carefully before adopting corrective measures.

Resistance monitoring should be an integral part of vector control programmes. The susceptibility of vectors should be ascertained before selection of an insecticide and to provide baseline data for further resistance monitoring. Surveillance throughout a programme will allow early detection, so that resistance management strategies can be implemented, or, in the case of late detection, evidence of control failure can justify replacement of the pesticide. Resistance can be monitored easily by using the standard

[8] http://www.who.int/whopes/resistance/en/.

WHO test kits, which are available from the Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland. Procedures for procurement of the test kits are described on the WHOPES web site at: http://www.who.int/whopes/resistance/en/WHO_CDS_CPE_PVC _2001.2.pdf.

Resistance management consists of preventing, or delaying as long as possible, the development of resistance to a pesticide while at the same time maintaining an effective level of disease control. It requires a reliable system for disease surveillance and resistance monitoring. It is important to recognize that very few pesticides are available for use in public health programmes. Thus, the susceptibility of vectors and pests to those that are effective should be considered a valuable resource that must be preserved as long as possible. The following suggestions might be considered in managing resistance and indeed in managing vector control with optimal cost–effectiveness:

- use of non-chemical control methods, either alone or as a supplementary measure, in the seasons or areas in which they are applicable and cost-effective;
- limitation of pesticide use to areas with high levels of disease transmission;
- use of adulticides, which kill only adult females, rather than larvicides, which kill both sexes, resulting in approximately half the selection pressure for resistance;
- rotation among unrelated insecticides according to a pre-arranged plan based on knowledge of the likelihood of resistance developing to each compound;
- choice of a compound that has been found by experience to select for a narrow spectrum of resistance rather than a broad one; and
- use of mixtures or mosaic treatments with unrelated compounds, so that individuals resistant to only one of the components are killed by the other. This principle is used routinely in therapy of tuberculosis, HIV infection and leprosy to avoid the induction of drug resistance and should be more thoroughly investigated for insecticides.

So far, switching among unrelated insecticides in response to detection of resistance has been the main method used. It is very important that: (1) safe, effective alternatives are prepared before the detection of serious resistance; and (2) resistance management is implemented preventively to preserve the efficacy of the few insecticides available for public health purposes.

2. Safe use of pesticides

The following recommendations are intended as a guide to those responsible for the safe use of pesticides in vector and public health pest control programmes.

2.1 General principles of safety measures

All pesticides are toxic to humans to some degree; however, the doses that are acutely toxic to humans are usually far higher than those required for killing vectors and pests. The key to safe use of pesticides is to reduce to a minimum the possibilities of unsafe exposure during handling of hazardous chemicals. Therefore, care in handling pesticides, particularly by spraying staff and persons living in sprayed houses, should be a routine practice and form an integral part of any programme involving the application of pesticides. The general principles on which safety measures are based are discussed below, with special consideration to indoor use of residual sprays.

2.1.1 *Toxicity and hazard*

In recommending safety measures, both the nature of the pesticide, including its formulation, and the proposed method of application must be taken into account. One measure of the potential toxicity of pesticides to humans and other mammals is the acute LD_{50} value after oral or dermal application[9], which provide an estimate of the number of milligrams of active ingredient per kilogram of body weight required to kill 50% of a large population of test animals. For new pesticides, this measure has been replaced by one requiring use of considerably fewer test animals. While these figures represent the relative acute toxicity of various compounds to test animals, they do not represent the actual hazard involved when a pesticide is used in the field. Furthermore, the effects of long-term exposure to low doses are not measured in tests for acute toxicity. Factors that influence toxicity are: type of formulation, type of packaging, concentration of pesticide in the finished formulation, method of application, surface or area to be treated, dosage required, contact of human or animal populations with treated surface or area, and the species of animals exposed, their age, sex and condition. In selecting pesticide formulations, the oral and dermal acute toxicity for rats should be checked, because the values for the available formulations might differ markedly from those for the active ingredient, which are quoted in the tables of this guide.

Because of concern about the toxicity and persistence of long-term exposure to low doses of organochlorine insecticides and even organophosphates, use of pyrethroid insecticides has increased over the past two decades. Although the LD_{50} values for pyrethroids after oral administration to rats are relatively low, indicating a relatively high intrinsic toxicity, they are in fact less hazardous insecticides. As they are effective against insects at extremely low doses, the ratio of insect:mammalian toxicity is high. Even with frequent exposure to low concentrations (e.g. during handling of treated mosquito nets), the risk of toxicity is remote because any pyrethroid that reaches the systemic circulation is metabolized rapidly to less toxic metabolites. Therefore, field use of pyrethroids, at

[9] The WHO recommended classification of pesticides by hazard and guidelines to classification. 2000–2002 (unpublished document WHO/PCS/101.5; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://www.who.int/pcs/docs/Classif_Pestic_2000-02.pdf.

recommended concentrations and with the precautions necessary for the application of any chemical, poses little hazard to applicators. In order to avoid discomfort, however, skin should be protected while handling pyrethroid concentrates. A fuller description of pyrethroids can be found in section 2.2.2.

Hazard is the inherent property to cause a harmful effect. Risk is the likelihood that a harmful effect might result from exposure to a particular hazard. For toxicity to occur, there must be exposure to a hazardous chemical. Hazard is not the same as risk, which depends on the amount and route of exposure. Most occupational exposure to pesticides involves direct contact with skin, eyes or the respiratory tract, mainly in airborne particles or aerosols, which can also be ingested. Thus, attention must be paid to equipment and to training to minimize the exposure of pesticide workers.

2.1.2 *Supplies and equipment*

The planning of a vector control campaign must include provision for the safe transport and secure storage of pesticide concentrates. These should not be stored in rooms in which people live or in which food is kept. They should be stored out of direct sunlight and protected from rain and flooding. Protection against theft, misuse and access by children must be ensured. Persons in charge of programmes in which pesticides are used must ensure that suitably qualified people take full responsibility for the custody of stocks and for the disposal or treatment of empty or nearly empty containers (see section 2.1.8).

Pesticides that have satisfactorily completed the WHOPES[10] and for which either an interim or final specification has been recommended should be used in preference to compounds that have not been assessed within this scheme.

All pesticide containers should be adequately labelled to identify the contents and show, in a form understandable by the operator, the nature of the material and the precautions to be taken. Labels should always be printed in the local language. All equipment used to distribute the pesticides should conform to the general and specific recommendations on design and maintenance published by WHO[11]. All valves, gaskets or hoses must be inspected regularly and systematically to ensure that there is no leakage.

2.1.3 *Responsibility for safety*

The authority that approves use of a pesticide, including substitution of a new material for one already in use, must ensure that it is applied under appropriate supervision. Consultants or technical experts might have to be recruited to provide specialized training and advice, for instance, to inform local medical and other staff in public health programmes about the proper training of spray teams, setting up any diagnostic measures and organizing facilities for treatment, including the provision of antidotes in case of accidental poisoning. While the ultimate responsibility for the health of spraying staff and persons living in treated premises must rest with a medical officer, the day-to-day responsibility for ensuring that sound, safe application techniques are practised can be given to any competent field operator. The leader of the field team and other operators should receive instructions about the rates of application that will ensure correct dosages.

[10] http://www.who.int/whopes/

[11] http://www.who.int/whopes/equipment

2.1.4 *Safety training*

Training in the safe use of pesticides should be provided: (1) for medical specialists, entomologists, engineers and safety supervisors on the mode of action of the pesticide, the significance of diagnostic measures, recognition of the signs and symptoms of toxic effects, and the facilities required for treatment of cases of poisoning; and (2) for field team leaders and other operators in spraying techniques, safety precautions, protective equipment, recognition of early signs and symptoms of poisoning and first-aid measures, including resuscitation (see section 2.3.2). Handbooks on managing poisoning cases are available for primary health care workers and doctors.[12]

Staff must be organized into squads, in which each person knows precisely what his or her duties and responsibilities are. Training is essential before toxic materials are used, during which time the staff should work in the required protective clothing, to ensure that it is acceptable and that they can work properly while wearing it. All workers should know the hazard of the work they are required to carry out. They should understand the real risks involved and should not be led astray by erroneous preconceptions.

2.1.5 *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 health authorities. A watch should be kept for subtle neurological effects, such as loss of ability to understand written material and to concentrate. Apart from clinical surveillance, quantitative biochemical tests can be carried out to assess the degree of exposure. The significance and importance of regular determinations of blood cholinesterase activity when organophosphates are used are discussed in section 2.2.2. Measurements of the exposure of spray operators have been described.[13]

2.1.6 *Protective equipment*

The items of protective clothing that might have to be used are:

- *Hats*. These should be of impervious material with a broad brim to protect the face and neck and should be able to withstand regular cleaning or be replaced regularly.
- *Veils and visors*. A plastic mesh net will protect the face from larger spray droplets and permit adequate visibility. Alternatively, a transparent plastic visor can be used.
- Capes. Short capes of light plastic can be suspended from the hat to protect the shoulders.
- *Overalls*. These should be of light, durable cotton fabric. They must be washed regularly, the frequency depending on the pesticide being used. Washing with soap, detergent or washing soda is adequate for organophosphate and carbamate

[12] United Kingdom Department of Health (1996) *Pesticide poisoning: notes for the guidance of medical practitioners*, London, H.M. Stationery Office; Waxman MF (1998) *Agrochemical and pesticide safety handbook*, Boca Raton, Florida, Lewis Publishers.

[13] *Field surveys of exposure to pesticides - Standard protocol*. Geneva, World Health Organization, 1982 (unpublished document VBC/82.1); available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

compounds. A rinse in light kerosene might be needed for organochlorine compounds, followed by washing.

- *Aprons*. Rubber or polyvinyl chloride (PVC) aprons will protect from spills of liquid concentrates.
- *Rubber boots*. These will complete the protection afforded by the apron.
- *Gloves*. PVC or rubber gloves or gauntlets should be used when handling concentrates.PVC gloves should not be used to handle pyrethroids, which can be absorbed by PVC; rubber gloves should be used to handle concentrates with an organic solvent base. Impervious gloves must be cleaned regularly, inside and out.
- *Face masks*. Masks of gauze or similar material can filter the particles from a water-dispersible powder spray and can be worn to reduce inhalation of the spray and dermal exposure of the face, if such protection is considered desirable. They must be washed regularly; in some instances, fresh masks might need to be used for the second half of a day's spraying, so that the face is not contaminated.
- *Respirators* (masks with cartridge or canister). These are designed to protect operators who do fogging with very toxic powder formulations. The cartridge or canister must be renewed regularly, according to usage. To be effective, the respirator must fit the face closely and must be cleaned regularly. Respirators are not usually required for vector control.

2.1.7 *Personal hygiene*

Scrupulous attention to personal hygiene is an essential component of the safe use of pesticides. For professional spraying staff operating in the tropics, the safety precautions might depend largely on personal hygiene, including washing and changing clothes. A drill for carrying out and supervising personal hygiene, regular washing of protective clothes and cleaning of equipment should be organized along the following lines:

- Spraying staff should be provided with at least two uniforms to allow for frequent changes.
- Washing facilities with sufficient water and soap should be made available in the field at appropriate locations.
- All working clothes must be removed at the end of each day's operations and a shower or bath taken.
- Working clothes must be washed regularly, the frequency depending on the toxicity of the formulation used.
- Particular attention should be given to washing gloves, as wearing contaminated gloves can be more dangerous than not wearing gloves at all.
- Spray operators must wash before eating.
- Eating, drinking and smoking during work must be strictly forbidden.
- When work involves insecticides of relatively high toxicity, the hours of work must be arranged so that exposure to the material is not excessive; transport should be arranged so that there is not a long delay between the end of the day's operations and return to base for washing.

For some of the older pesticides, washing with soap can increase dermal absorption from contaminated skin. This underlines the importance of avoiding exposure.

2.1.8 *Disposal of empty or nearly empty containers*

Safe disposal of empty or nearly empty containers must be ensured. They must not be removed by unauthorized people who might use them as containers for food or drinking-water, especially in areas where such containers are scarce. Such re-use has, in the past, been the cause of poisonings by pesticides. As it is inevitable, however, that some pesticide containers will be re-used, it is important to ensure that the risk for poisoning is minimized. Used containers can be effectively decontaminated by rinsing them two or three times with water and scrubbing the insides thoroughly with a household detergent. Drums that contained an organophosphate should be given an additional rinse with washing soda at 50 g/l (5%), and the solution should be allowed to remain in the container overnight. Rubber gauntlets should be worn during this work, and a soakage pit should be provided for rinsing. All containers should be indelibly marked 'not for storage of food or water for human or animal consumption'.

2.2 Operational procedures

2.2.1 *Preparation of spray materials*

As the heaviest exposure occurs during handling of pesticide concentrates, appropriate facilities must be provided. When compounds of relatively high mammalian toxicity are to be used by non-commercial operators, the compounds should be supplied in diluted form. Concentrates of water-dispersible powders should be prepared in deep mixing vessels with long-handled mixers, to protect the operator from splashing and to permit stirring from a standing position.

Power appliances are most appropriate for the dilution of solid pastes and permit preparation of the dilution in a closed vessel. When such appliances are not available, long-handled mixers and tall vessels should be provided. No vessel should be filled to a level at which the operator risks being splashed. Long-handled dippers or scoops should be used to transfer insecticide from one vessel to another. Concentrates can be partitioned into bags or small containers suitable for safe mixing by spraying staff in the field. All smaller containers should be secured and packed to withstand transport in the area of application. Adequate protective clothing (see section 2.1.6) should be available for persons handling concentrates, and adequate washing facilities must be immediately accessible so that spills on the skin can be quickly removed.

2.2.2 *House treatment with residual sprays*

Spraying staff will inevitably be exposed to insecticide spray, and 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.

Inhabitants of houses that are to be sprayed should be informed of the purpose and the times of insecticide applications and should be given clear instructions as to what to do before and after their houses have been treated: e.g. remove all foodstuffs and cooking

utensils, stay out of the house during spraying, prevent children from re-entering the house until the floors have been swept or washed.

Appropriate facilities must be provided for handling pesticide concentrates, both as water-dispersible powders and as emulsifiable concentrates. Workers must use protective clothing and equipment as indicated below. When workers are weighing insecticide powder and preparing the suspension, they should avoid contact with the powder and should stand in such a position that the wind blows the dust away from them and not onto other workers. If the concentrate comes into contact with skin, it should be washed off at once. Work should be performed away from food and cooking utensils.

Any spillage of insecticide onto the ground during mixing should be removed, in particular for the protection of chickens and domestic animals. Concrete surfaces should be washed. To clean earth surfaces, damp earth should be scooped up and then buried. Large numbers of insects, such as flies, moths and bedbugs, might be killed and fall on the floor during indoor spraying operations, presenting a hazard, particularly to chickens. Floors should therefore be carefully swept and the sweepings safely disposed of.

In applying the *organochlorine* insecticides that are still authorized, such as DDT, operators should wear protective clothing and some form of head covering. After completing the day's work, they should wash and change into their ordinary clothes. Staff spraying organophosphates should wear clean, regularly washed overalls, broad-brimmed hats and shoes or boots (not sandals) while spraying. Mixers and baggers and any other personnel handling the concentrate should also wear protective clothing and rubber gloves while working. They should wash, preferably under a shower, at the end of a day's work.

In applying *fenitrothion* and *diazinon*, strict precautionary measures should be observed, including daily washing of overalls and use of cloth face masks, broad-brimmed hats and shoes or boots. Mixers and baggers handling the concentrate should also wear rubber boots, gloves and aprons. Any concentrate that gets onto the skin should be washed off at once. Clothes that are wetted with the insecticide should be changed immediately. Operators should not be exposed to the insecticide for longer than the predetermined working hours (usually 5–6 h). Transport should be arranged to minimize delays between the end of a day's operations and return to base for showering, which should be mandatory. Once a week, all personnel exposed to the insecticide should be examinedand their cholinesterase activity determined. Operators should be withdrawn from exposure if their cholinesterase activity decreases to 50% or more of that before exposure. The simple tintometric method is suitable for determining blood cholinesterase activity, and the commercially available field kit[14] contains an instruction sheet.

With respect to the *carbamate* insecticides, ordinary precautionary measures should be taken in applying carbaryl, but stricter precautions are required for propoxur. Spraying staff should wear clean overalls, cloth face masks, broad-brimmed hats and shoes or boots. Mixers and baggers should wear the protective clothing described above as well as rubber gloves and aprons. Emphasis should be placed on hygiene, with all the precautionary measures mentioned above, except for determination of cholinesterase activity, since when the enzyme is inhibited by a carbamate it reactivates too rapidly for this technique to be of operational use. For bendiocarb, the same precautions are to be taken as for propoxur except that the insecticide should be mixed in the sprayer: the outer sachet is opened, the inner soluble sachet is added to the sprayer containing the

[14] Produced by Tintometer Ltd, The Colour Laboratory, Waterloo Road, Salisbury SP1 2JY, United Kingdom. http://www.tintometer.com/AF267.HTM.

required amount of water, and the sprayer is then closed, pressurized and shaken well. The empty outer sachet should be returned to the supervisor for disposal.

For the *pyrethroid* insecticides, ordinary precautionary measures, such as wearing clean overalls, canvas shoes or rubber boots and hats, and washing the body and changing clothing after a day's work, should be observed. The wearing of disposable face masks is also recommended. For the more irritating pyrethroids, visors might be necessary. Whenever feasible, exposure should be limited to fewer than seven pump charges per day, and operators should comply strictly with the hygiene regimen (washing the hands and face after spraying a pump charge). As pyrethroids applied to mosquito nets are now an important part of pesticide use for vector control worldwide, a more detailed description is given below (15.2.9).

2.2.3 *Larvicide treatments*

Persons applying larvicides are generally much less exposed than staff engaged in indoor house treatment, and exposure is confined mainly to the hands and arms.

For the majority of larvicides, care must be taken to avoid contamination of drinking-water and waters inhabited by non-target organisms of value, such as fish and crustaceans. Temephos, methoprene, *Bacillus thuringiensis* H-14 (*Bacillus thuringiensis israelensis*), pyriproxyfen and permethrin can be used to control mosquitoes that breed in drinking-water containers (see section 3.2.1). Such treatment should always be made with pesticide formulations that ensure accurate and reliable dosing.

2.2.4 *Rodenticide treatments*

Compounds that are toxic to rodents are usually also toxic to non-target mammals, including humans. The ratio of pest:human toxicity is usually lower for rodenticides than for insecticides. When handling rodenticides, gloves should be worn and the hands should be thoroughly washed afterwards. In enclosed areas, the bait should be placed on trays or plates, while, in open areas, tamper-resistant bait stations (such as wooden boxes or tubes) should be used. Rodenticides that rapidly break down in the bodies of rodents should be used when possible to prevent secondary toxicity to animals scavenging the dead rodents. When rodenticides are applied in the domestic environment, specific antidotes should ideally be available for accidental poisoning of humans and non-target animals. Unfortunately, few of the acute rodenticides have a specific antidote, and, owing to their rapid action, there would seldom be sufficient time to administer one. The slow mode of action of the anticoagulants is thus advantageous for safety reasons, as the symptoms of poisoning can be recognized and the antidote, vitamin K_1, given.

Thus, in order to reduce the risk of unintentional poisoning, anticoagulants should be used in preference to acute rodenticides. Toxic compounds should be stored safely and applied in a manner that reduces access by non-target animals. For instance, placing the rodenticide tray under a weighted wooden crate with small openings will help prevent access by animals larger than rats.

Fumigants are used for indoor fumigation of agricultural food commodities, animal feed, processed food commodities, greenhouses, ships and transport vehicles and for outdoor fumigation of burrowing rodents and moles. Fumigants have a remarkable capacity for diffusion, and some readily penetrate rubber and neoprene personal protective gear, as well as human skin, from which they are rapidly absorbed across the pulmonary

membrane and gut. Special adsorbents are required in respiratory canisters to protect exposed workers from airborne fumigant gases, but even these might not provide complete protection when the air concentration of fumigant is high.

2.2.5 *Application by motorized equipment and aircraft*

The persons mainly exposed to the hazards of motorized and aerial application are those who handle bulk concentrates while loading the machines and pilots, operators and ground staff. Special equipment, including pumps and pouring devices for transferring liquids, must be available. The machines, hoses and connections should be carefully cleaned and maintained to ensure that mechanics do not accidentally contaminate themselves with concentrates during routine maintenance. Washing facilities to deal with large spillages of concentrate must be available at loading points.

Aircraft and machinery must be properly designed for the purposes for which they will be used, and pilots must be given specific training in the use of toxic pesticides. When large tracts of land and urban areas are to be treated, the health authorities responsible for the residents and for the food and water supplies in the areas must be consulted before spraying. Any limits they lay down must be strictly adhered to. Residents should be informed of the purpose and times of pesticide application. Any drift from the agreed areas must be reported immediately.

2.2.6 *Application to people*

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

2.2.7 *Special devices*

In operations involving use of vapour-release devices, baits and impregnated cords and cloth, the materials are usually commercially available and are prepared by mixing pesticide concentrates with appropriate food for the pest. Such baits should not be prepared or used inside dwellings and should be freshly prepared for each application or stored in clearly labelled containers, out of reach of children and animals.

2.2.8 *Insecticide treatment of mosquito nets*

Pyrethroids are the only insecticides currently recommended for treatment of mosquito nets (chapters 3 and 15). Symptoms of poisoning due to treatment or use of mosquito nets are rare, apart from transient numbness or tingling if there has been significant dermal contact. Depending on the frequency of washing, mosquito nets might require re-treatment every 6–12 months.

When the mosquito nets of whole communities are treated, the protective clothing described in section 2.2.2 should be worn. One or a few mosquito nets can be treated by the persons using them, with kits available for home use. As untrained adults and children might conduct the treatment, such kits are usually designed for treating a single net and for minimizing exposure to insecticide; for instance, insecticide concentrates might be in the form of dry tablets, which are generally safer to use than liquid formulations. The pictorial or written instructions in the kit should be followed carefully. If disposable gloves are supplied with the kit, they should be worn for the entire operation of diluting

and mixing concentrated insecticide in water, dipping the net, putting it out to dry and disposing of any unused insecticide. After use, disposable gloves should be discarded. If no gloves are supplied, the insecticide concentrates should be mixed with a stick or tool rather than with the hands. No special protective clothing other than gloves need be worn, but splashes on the skin should be avoided. Any splashes of concentrate should be washed off immediately. Splashes of dilute insecticide should be washed off as soon as net treatment has been completed. Care should be taken in disposing of any unused insecticide, as pyrethroids are toxic to aquatic life. Insecticide concentrates and unused kits should be stored out of reach of young children.

WHO has published a generic risk assessment model for insecticide treatment and subsequent use of mosquito nets, which can be used to predict the risks due to exposure to any insecticide during treatment of nets or resulting from use of the nets by adults, children and infants[15]. A detailed risk assessment of the use of the pyrethroid deltamethrin on mosquito nets has also been published[16], which is generally reassuring about the absence of risk for persons treating nets with 'do-it-yourself' kits or using such nets.

2.3 Diagnosis and treatment of pesticide poisoning

2.3.1 *Symptoms of poisoning*

The signs and symptoms of organochlorine poisoning are due to excitation of the nervous system. Initially, the victim complains of headache and dizziness and might appear worried and excited. Later, he or she may vomit and show weakness in the arms and legs, and the hands might shake. The victim can become disoriented in time and space, and fits can follow.

The symptoms after exposure to organophosphate and carbamate insecticides are similar, but the signs of poisoning appear more rapidly with the latter. The signs that appear after exposure to organoposphates might therefore not appear until after the person has left work and therefore might not immediately be associated with occupation. The early symptoms of poisoning include excessive sweating, headache, blurred vision, narrowed pupils, weakness, dizziness, nausea, excessive salivation or bronchial secretion, vomiting, stomach pains, slurred speech and muscle twitching. Later, there may be diarrhoea, loss of reflexes and sphincter control, convulsions and coma.

The symptoms of pyrethroid poisoning can include paraesthesia (a burning sensation of the skin), particularly on the face and hands, irritation of the upper respiratory tract, salivation and, occasionally, allergic reactions (see section 2.3.2). If pyrethroids are ingested, prominent digestive symptoms can occur, such as nausea, vomiting and epigastric pain. In severe poisoning, patients can have fits and become unconscious. Death is due to respiratory paralysis.

Two or three days after a single large dose or after repeated ingestion of small doses of an anticoagulant rodenticide over a few weeks, bleeding gums, pale skin, swelling and

[15] A generic risk assessment model for insecticide treatment and subsequent use of mosquito nets. Geneva, World Health Organization, 2004 (unpublished documents WHO/CDS/WHOPES/GCDPP/2004.6, WHO/PCS/04.1; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://www.who.int/ctd/whopes/docs/Risk_assessment_model.pdf

[16] Barlow SM, Sullivan FM, Lines J. Risk assessment of the use of deltamethrin on mosquito nets for the prevention of malaria. Food and Chemical Toxicology, 2001, 39:407–422.

tenderness of the joints, bruising, blood in urine and faeces and abdominal pains may occur. Severe cases can lead to death.

The signs and symptoms of fumigant poisoning are highly variable, depending on the agent. Carbon disulfide, chloroform, hydrogen cyanide and naphthalene can have serious effects on the central nervous system. Methyl bromide and aluminium phosphide cause pulmonary oedema, and hydrogen cyanide causes severe hypoxia without cyanosis in the early stages.

2.3.2 *First aid and decontamination*

Once poisoning has been diagnosed, the following information should be collected for a doctor or medical officer: the name of the toxic substance (on packaging), the amount and route of exposure (e.g. skin, mouth) if known, the time of poisoning, the reason for poisoning (intentional, accidental, overexposure while spraying) and any other information about the circumstances.

If the person providing first aid knows the type of chemical in the pesticide, treatment can be started for some types of poisoning. Otherwise, the general rules for treatment based on signs and symptoms should be applied. First, respiration and pulse should be checked. If either is absent, resuscitation should be started. If the person is unconscious, the airways should be freed by pulling the chin upwards and backwards. False teeth should be removed. The person should lie on his or her side or front downwards, with the head turned to one side. This posture should be used if the person is to be transported, in order to prevent vomitus from entering the lungs. Nothing should be given by mouth to an unconscious patient.

The person administering first aid must be protected from the solvents and active ingredient by wearing gloves; if mouth-to-mouth respiration is required, all vomit and saliva should be removed from the patient's mouth and a clean handkerchief placed between the mouth of the patient and the mouth of the person giving first aid. At the onset of symptoms, all contaminated clothing should be removed to prevent further absorbtion. Affected skin should then be washed with soap and flushed with large quantities of water. If the eyes are contaminated, the lids should be opened with the fingers and the insides (conjunctivae) should be washed with running water for several minutes.

The patient should be transported as soon as possible to a doctor to receive an antidote. After exposure to massive doses, acute respiratory failure may occur. Oxygen should be administered early if necessary. The patient must be watched constantly, and respiratory support should be instituted if necessary. In cases of ingestion, gastric lavage should be performed within 1 h. Activated charcoal can be effective for treating poisoning with organophosphorus pesticides.

For organophosphate and carbamate poisoning, 1–2 mg of atropine should be given intravenously every 5–10 min until signs of atropinization (dilated, fixed pupils, heart rate > 140 beats/min, reddening of the face, loss of salivation and bronchial hypersecretion) appear. If intravenous administration is not possible, atropine can be given intramuscularly. In severe cases, tachycardia and mydriasis are unreliable features, as they can result from nicotinic stimulation. Oximes such as obidoxime chloride (Toxogonin) or pralidoxime chloride (Protapam, 2-PAM) must not be given in cases of carbamate

poisoning. Automatic injectors are available for administration of atropine[17], and it is recommended that these devices be at hand where organophosphate or carbamate insecticides are being applied. They should not be issued to the operators, but field supervisors should be trained in emergency treatment of insecticide poisoning (including atropine injection) and resuscitation where a doctor or medical officer is not available,.

There is no specific antidote for pyrethroid poisoning. Treatment is essentially symptomatic and supportive after decontamination to prevent further absorbtion. Vitamin E oil preparations can be given for prolonged paraesthesia.

There is no specific antidote for organochlorine poisoning. The aim of treatment is symptomatic and supportive to maintain ventilation and control hyperactivity and convulsions. If the compound has been ingested recently, gastric lavage and use of activated charcoal can be considered. If the compound has been absorbed through the skin, washing of the skin with soap and water should be thorough. To control or prevent convulsions, diazepam should be given intravenously at a dosage of 5–10 mg for adults and 0.3 mg/kg for children.

Few acute rodenticides have a specific antidote and, owing to their rapid action, there would seldom be sufficient time to administer one. Persons who have ingested an anticoagulant rodenticide should be referred to a medical doctor, as a blood test is necessary for diagnosis. The doctor can use clinical judgement to decide whether to give a specific antidote, vitamin K_1, orally as a reasonable precaution at a dose of 10 mg/kg body weight for adults and 0.25 mg/kg body weight for children.

Decontamination of the skin and eyes must be immediate and thorough after exposure to a fumigant. The skin and eyes should be washed with copious amounts of water for at least 15 min. Special medical treatment should be sought promptly after decontamination. Specific measures are needed for different agents.

[17] For example, 'Atropen' auto-injector containing 2 mg atropine in solution, produced by Duphar, PO Box 7005, Amsterdam, Netherlands

3. Mosquitoes

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided, and with chapter 2, on safe use of pesticides.

Mosquitoes are responsible for transmitting the most important vector-borne diseases, above all malaria, but also lymphatic filariasis, Japanese encephalitis and dengue, as well as yellow fever, West Nile fever and other forms of encephalitis. In selecting a chemical control strategy, detailed knowledge of the biology of the target species is essential, as measures that are effective against one species might be inappropriate for another. Protection from mosquito bites can be achieved by the use of repellents or insecticide-treated mosquito nets (chapter 15). This chapter deals primarily with chemical control of mosquito vectors and does not address the control of some important nuisance species.

3.1 *Anopheles* spp.

Some species of *Anopheles* that are anthropophilic, i.e. which prefer to bite humans, are important vectors of malaria and, in some areas, of lymphatic filariasis as well. In areas where the vectors are strongly endophilic, i.e. where they tend to rest indoors, interior residual house spraying can effectively control transmission. Use of insecticide-treated mosquito nets is highly recommended to prevent bites by the important *Anopheles* malaria vector species, which feed indoors at the time such nets are used, even if they do not stay there after feeding. Vectors that are mainly exophilic but feed or rest indoors briefly can also be controlled effectively by indoor residual spraying, especially with insecticides that have a strong fumigant effect (**see Table 1**). In refugee camps, spraying the insides of tents with residual insecticides can reduce malaria transmission. In areas where the vectors are strongly exophilic or exophagic, i.e. which rest and bite outdoors, personal protection and other methods, such as space spraying or larval control, should be considered.

Many vector species have developed resistance to organochlorine compounds, and some are also resistant to organophosphate, carbamate and pyrethroid insecticides. An insecticide should be selected on the basis of an assessment of the susceptibility of the target vector. For long-term use, regular monitoring of resistance should be instituted (see section 1.6).

3.1.1 *Indoor residual spraying*

In view of the general applicability of this method and the relatively well-established standardization of the application techniques and equipment, indoor residual spraying continues to be the most widely used method for malaria vector control. Indoor residual spraying increases the risks for a mosquito each time it enters a house for a blood meal, which it typically does every 2–3 days, so that few will survive the approximately 12 days that are required for malaria parasites to complete part of their life cycle in the vector

mosquito. In practice, the effectiveness of house spraying for malaria control depends on adherence to the criteria specified for the insecticide and the application procedure, public acceptance of spraying, the availability of well-maintained equipment, adequately trained spraying personnel, efficient supervision and strong financial support. The size of the operational area depends on local circumstances and is influenced by the distribution of malaria and malaria vectors, the distance from important breeding sites, the flight range of the vectors and demographic features.

Table 1. WHO-recommended insecticides for indoor residual treatment against mosquito vectors

Insecticide	Chemical type	Dosage of ai (g/m^2)	Duration of effective action (months)	Insecticide action	WHO hazard classification of ai[a]
Bendiocarb	Carbamate	0.100–0.400	2–6	Contact & airborne	II
Propoxur	Carbamate	1–2	3–6	Contact & airborne	II
DDT	Organochlorine	1–2	> 6	Contact	II
Fenitrothion	Organophosphate	2	3–6	Contact & airborne	II
Malathion	Organophosphate	2	2–3	Contact	III
Pirimiphos-methyl	Organophosphate	1–2	2–3	Contact & airborne	II
á-Cypermethrin	Pyrethroid	0.020–0.030	4–6	Contact	II
Bifenthrin	Pyrethroid	0.025–0.050	3–6	Contact	II
Cyfluthrin	Pyrethroid	0.020–0.050	3–6	Contact	II
Deltamethrin	Pyrethroid	0.020–0.025	3–6	Contact	II
Etofenprox	Pyrethroid	0.100–0.300	3–6	Contact	U
λ-Cyhalothrin	Pyrethroid	0.020–0.030	3–6	Contact	II

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

(a) *Target area*

Generally, all the interior walls and ceilings of a house are treated. Not only permanent dwellings but also field huts in which people sleep during the planting or harvesting season and animal shelters might have to be sprayed, depending on local vector behaviour. Where, as is the case with *A. culicifacies*, the vector bites and rests both in human dwellings and in cattle sheds, both types of structure should be sprayed. On the basis of knowledge of the resting behaviour of the target species, treatment might be confined to the ceiling or the lower or upper half of the walls. In other cases, the undersides of furniture, outside eaves and porches might need to be treated. It should be noted that the residual effect of insecticides can be much shorter on some surfaces, such as porous mud walls, walls covered by cement or alkaline whitewash and surfaces exposed to sunlight.

(b) *Insecticides*

The factors that must be considered in selecting an insecticide for indoor spraying include availability, cost, residual effectiveness, safety, vector susceptibility and excito-repellency[17] (see section 1.3). Insecticides suitable for interior residual treatment are listed in Table 1. The use of DDT is discussed in section 1.1.

(c) *Application procedures*

Hand-operated compression sprayers fitted with a flat fan nozzle are widely used to apply insecticide and water mixtures evenly to walls and ceilings[18]. Water-dispersible powders are generally used, because they are cheaper and their residual effect is longer, particularly on porous surfaces. The advantages of other formulations, such as capsule suspensions, suspension concentrates and water-dispersible granules, are listed in chapter 1. Emulsifiable concentrate formulations are not recommended for indoor residual spraying because of their short persistence, especially on porous surfaces.

(d) *Treatment cycle*

The frequency of treatment depends on the duration of the residual effect of the insecticide at the dosage used, the type of surface sprayed, vector bionomics, the malaria transmission season and climatic conditions. Houses should be sprayed just before periods of high malaria transmission. The average duration of effectiveness of the various insecticides is given in Table 1. Early re-treatment is required, however, if insecticide deposits are removed from surfaces by re-plastering, whitewashing, re-roofing or smoke deposits.

(e) *Precautions*

Care must be taken to protect sprayers, the public and domestic animals from unnecessary or prolonged exposure to or accidental ingestion of insecticides. Safety guidelines for protecting, monitoring and treating sprayers are discussed in chapter 2. Proper, regular maintenance of spraying equipment also contributes to protecting sprayers from unnecessary contamination (see section 1.5).

3.1.2 Insecticide-treated nets

As most important malaria vector species tend to bite late at night, mosquito nets would be expected to protect against them effectively. Mosquitoes can, however, enter through holes in torn nets or can bite human skin in contact with the netting. In order to avoid this problem, nets are treated with insecticides that are safe for humans in close contact. Nets treated with pyrethroids are fairly effective in preventing biting, even if they are torn. Furthermore, treated nets act like mosquito traps baited by the odour of the occupant; thus, when most people in a community are using treated nets, large numbers of mosquitoes are killed. As with indoor residual spraying, increasing the risk of mosquitoes when they enter a house to bite means that fewer will survive long enough to transmit malaria and the infective biting population is reduced. This 'bonus' effect of community-wide use of treated nets has been observed in many, but not all, trials of these nets.

[17] Najera JA, Zaim M. *Malaria vector control: Iinsecticides for indoor residual spraying*, Geneva, World Health Organization, 2001 (unpublished document WHO/CDS/WHOPES/2001.3; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://whqlibdoc.who.int/hq/2001/WHO_CDS_WHOPES_2001.3.pdf).

[18] *Manual for indoor residual spraying. Application of residual sprays for vector control*. Geneva, World Health Organization, 2000 (unpublished document WHO/CDS/WHOPES/GCDPP/2000.3 Rev. 1; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://whqlibdoc.who.int/hq/2000 WHO_CDS_WHOPES_GCDPP_2000.3.Rev.1.pdf).

(a) *Target populations*

Insecticide-treated mosquito nets are expected to be most effective against mosquitoes that bite indoors when people are sleeping. These conditions apply to the world's most important malaria vectors *A. gambiae* and *A. funestus* in Africa. Insecticide-treated nets have also been used successfully outdoors, in areas such as northern Ghana where people to sleep outside in hot weather. In areas highly endemic for malaria, where immunity to the disease is important, very young children and pregnant women are the most vulnerable because their immunity has not yet developed or is temporarily reduced. It has frequently been suggested that these vulnerable groups should be targeted for provision of insecticide-treated nets. Community-wide provision of nets, however, brings the 'bonus' of reduction of transmission. It has been suggested that the applicability of insecticide-treated mosquito nets varies in areas with intense and less intense transmission; however, in a comparison of a highland and a lowland area in the United Republic of Tanzania with a 15-fold difference in intensity of transmission, several measures of malaria morbidity in children were reduced by 60–80% from baseline levels in both areas. Concern has been expressed that reduced build up of immunity due to a prolonged reduction in intensity of transmission might postpone morbidity or mortality to a later period of childhood but not prevent it completely. Several recent studies, however, showed no such effect. It is now considered that insecticide-treated mosquito nets are effective in all malarial areas where mosquito biting patterns coincide with the time when most people are likely to be sleeping under a net.

(b) *Insecticides*

Because pyrethroids are safe for close contact and they have a rapid, persistent effect on mosquitoes at low doses, members of this group of insecticides are at present the only ones recommended for treatment of nets. Effective non-pyrethroid alternatives are, however, being sought because of the consequence that the emergence of strong resistance to pyrethroids would have on the effect of insecticide-treated mosquito nets.

WHO-recommended pyrethroid products for treatment of nets are listed in **Table 2**. Solid formulations, such as water-dispersible tablets, have many advantages, as they are easy to handle, transport and store and carry less risk of accidental spillage and contamination than liquids. Of the available liquid formulations, water-based products, i.e. capsule suspensions, oil-in-water emulsions and suspension concentrates, are preferred. These

Table 2. Amounts of insecticide formulation recommended for treating nets

Insecticide	Formulation	Dosage per mosquito net[a]
á-Cypermethrin	10% suspension concentrate[b]	6 ml
Cyfluthrin	5% emulsion, oil in water	15 ml
Deltamethrin	1% suspension concentrate	40 ml
Deltamethrin	25% water-dispersible tablet	One tablet
Etofenprox	10% emulsion, oil in water	30 ml
λ-Cyhalothrin	2.5% capsule suspension (microencapsulated)	10 ml
Permethrin	10% emulsifiable concentrate	75 ml

[a] Based on the highest WHO recommended concentration of active ingredient (ai) per square metre of netting (á-cypermethrin, 20–40 mg ai/m2; cyfluthrin, 50 mg ai/m2; deltamethrin, 15–25 mg ai/m2; etofenprox, 200 mg ai/m2; λ-cyhalotrhin, 10–15 mg ai/m2; and permethrin, 200–500 mg ai/m2) and for a family-sized net of 15 m2 and known uptake of liquid by polyester and cotton netting

[b] 10 ml with á-cypermethrin 6% suspension concentrate

are not inflammable, have less odour than emulsifiable concentrates and are less toxic if they are accidentally swallowed or splashed onto the skin or into the eyes. Permethrin is the only pyrethroid insecticide still used in emulsifiable concentrate formulations for insecticide-treated mosquito nets. Buying high-concentration permethrin (e.g. 50% emulsifiable concentrate) over the counter should be avoided.

(c) *Application procedures*

Rectangular nets are likely to offer better protection than conical ones, as it is difficult to avoid parts of the body touching conical nets, allowing mosquitoes to bite. Most nets are now made of polyester. The fibres should be at least 75 denier to resist tearing. Monofilament polyethylene is even more durable than polyester. Nets are generally treated by dipping them into an appropriate mixture of a pyrethroid formulation in water and drying them flat, preferably in the shade. To simplify calculation of the amount of insecticide formulation required, Table 2 shows the recommended volumes to be added to 0.5 or 2 l of water for treatment of a single polyester or cotton net, respectively. The values in the table are based on the highest WHO-recommended concentration per square metre of netting for a family-sized net of 15 m^2 and the known uptake of liquid by polyester and cotton netting.

For a single treatment, the net can be placed in a plastic bag and the correct amounts of water and insecticide needed to treat one net added. The bag is tightly closed and the contents thoroughly kneaded to ensure homogeneous treatment of the net. To treat several nets, mixtures based on those shown in Table 3 can be made up in a large bowl, and each net can be dipped and wrung out, the excess liquid being allowed to fall back into the bowl. When both polyester and cotton nets are being treated, separate mixtures should be made up for each type. The nets of different families should be dipped separately.

Re-treatment kits (offered as unit dose or pre-measured pack) are available in the form of tablets, sachets or small bottles, which contain enough insecticide to treat one net and are intended for application by households. The insecticide dose must be added to enough water to wet the net (see above), as indicated in the instructions accompanying the kit. It is important that these instructions be written accurately in a language that local householders will understand.

(d) *Treatment cycle*

Insecticidal activity on nets is lost mainly during washing. Different persistence has been reported in different areas; some of the factors responsible are frequency of washing, alkalinity of the soap used and intensity of scrubbing. Usually, nets should be re-treated after three washes or at least once a year[19]. In areas with perennial transmission, the nets might be treated twice a year, at the doses recommended by WHOPES (Table 2).

(e) *Precautions*

Strong rubber gloves should be worn during net dipping to avoid skin irritation. The gloves should be checked for holes, as damaged gloves would keep the hands wet with insecticide mixture throughout the working period. The wearing of goggles or other types of eye protection is recommended for persons who will be close to the dipping bowl. A wide, shallow dipping bowl is preferable to a tall, narrow one as vapour from the insecticide formulation can accumulate in the latter and cause unpleasant symptoms in people who have to dip many nets.

[19] *Instructions for treatment and use of insecticide-treated mosquito nets.* Geneva, World Health Organization, 2002 (unpublished documents WHO/CDS/RBM/2002.41; WHO/CDS/WHOPES/GCDPP/2002.4; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

Pyrethroids are toxic to fish. Therefore, any surplus insecticide should not be disposed of where it might enter a pond or stream. When poured into a pit latrine, it will kill fly or mosquito larvae; on dry soil, it will be harmlessly degraded. Empty insecticide containers and plastic bags should be destroyed so that they cannot be reused. After mass dippings, all empty containers should be returned to the supervisor for safe disposal.

(f) *Long-lasting insecticidal nets*

A long-lasting insecticidal net is a factory-treated mosquito net that is expected to retain its biological activity for a minimum number of standard WHO washes and a minimum time under field conditions. Currently, a long-lasting insecticidal net would be expected to retain biological activity for at least 20 standard WHO washes under laboratory conditions and 3 years of recommended use under field conditions, as defined in the WHO guidelines[20].

Two long-lasting insecticidal nets have been tested and evaluated by WHO[21,22]. One is made of polyethylene fibre into which permethrin is incorporated before the fibre is extruded. The insecticide inside the fibre provides a reservoir from which a bioavailable surface layer of insecticide is maintained, despite washing and normal domestic wear and tear. In other brands of long-lasting nets, the insecticide is bonded to the netting with a resin. Community-wide use of long-lasting insecticidal nets would avoid the need for visits by a re-treatment team, and teams would not have to try to persuading householders to buy insecticide to re-treat their own nets.

3.1.3 *Space treatment*

Space treatment for malaria control should be undertaken only in exceptional circumstances because the operational costs are high, the residual effect is low and other, more cost-effective approaches are usually available. Space spraying might be justified for control of certain exophilic, exophagic vectors and during malaria epidemics, especially in camps for internally displaced people, where infective mosquitoes must be eliminated rapidly.

(a) *Target area*

When vector density must be reduced as much as possible in order to control an epidemic, efforts should be concentrated in areas where the epidemic is most severe and the population density is highest. Vehicle-mounted sprayers can cover a large area rapidly.

Space spraying to reach the daytime resting-places of exophilic vectors should be considered only when the resting-places are not widely dispersed or when treatment of those closest to human dwellings has proved to be effective in reducing transmission. Mist blowers might be more suitable for this type of treatment than space fogs.

[20] *Guidelines for laboratory and field testing of long-lasting insecticidal mosquito nets*. Geneva, World Health Organization (unpublished document WHO/CDS/WHOPES/GCDPP/2005.11; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://whqlibdoc.who.int/hq/2005/WHO_CDS_WHOPES_GCDPP_2005.11.pdf.

[21] *Report of the Fifth WHOPES Working Group Meeting—review of Olyset nets and bifenthrin 10%WP, 30–31 October 2001*, Geneva, World Health Organization, 2001 (unpublished document WHO/CDS/WHOPES/2001.4; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://www.who.int/whopes/recommendations/wgm/en/).

[22] *Report of the Seventh WHOPES Working Group Meeting—Review of VectoBac WG, PermaNet and Gokilaht 5EC*, 2–4 December 2003, Geneva, World Health Organization, 2004 (unpublished document WHO/CDS/WHOPES/2004.8; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://www.who.int/whopes/recommendations/wgm/en/).

The target area must be defined precisely, for environmental and cost considerations, to avoid waste, increase efficiency and attain the required coverage in the minimum time.

(b) *Insecticide*

Insecticides used as cold aerosol sprays or as thermal fogs are listed in **Table 3**.

(c) *Application procedures*

Applications should coincide with the peak flying time of the local vector. Exterior spaces can be treated with vehicle-mounted fogging equipment or, in limited areas, with hand-held machines. The doors and windows of houses should be left open for maximum penetration of the insecticide. House-to-house indoor spraying with hand-carried space sprayers should be used in dwellings and areas not accessible to vehicle-mounted sprayers. Where aerial application is indicated, rotary atomizers can be mounted on suitable aircraft. Interiors and confined exterior environments can be treated with portable cold or thermal fogging equipment. The dosages applied with thermal fogs and cold aerosols are listed in Table 3. Further information about space spray application of insecticides is provided in the WHOPES guide[23].

Table 3. Insecticides used for cold aerosol or thermal fog application against mosquitoes

Insecticide	Chemical	Dosage of ai (g/ha)		WHO hazard classification of ai[b]
		Cold aerosols	Thermal fogs[a]	
Fenitrothion	Organophosphate	250–300	250–300	II
Malathion	Organophosphate	112–600	500–600	III
Pirimiphos-methyl	Organophosphate	230–330	180–200	III
Bioresmethrin	Pyrethroid	5	10	U
Cyfluthrin	Pyrethroid	1–2	1–2	II
Cypermethrin	Pyrethroid	1–3	–	II
Cyphenothrin	Pyrethroid	2–5	5–10	II
d,d-trans-Cyphenothrin	Pyrethroid	1–2	2.5–5	NA
Deltamethrin	Pyrethroid	0.5–1.0	0.5 – 1.0	II
D-Phenothrin	Pyrethroid	5–20	–	U
Etofenprox	Pyrethroid	10–20	10–20	U
λ-Cyhalothrin	Pyrethroid	1.0	1.0	II
Permethrin	Pyrethroid	5	10	II
Resmethrin	Pyrethroid	2–4	4	III

ai, active ingredient

[a] The strength of the finished formulation when applied depends on the performance of the spraying equipment used

[b] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use; NA, not available

(d) *Treatment cycle*

For control of malaria epidemics, daily re-treatment has the maximum impact on vector density, as no residual effect is associated with this application technique.

[23] *Space spray application of insecticides for vector and public health pest control.* Geneva, World Health Organization, 2003 (unpublished document WHO/CDS/WHOPES/GCDPP/2003.5; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://www.who.int/whopes/equipment/en/).

(e) *Precautions*

Sprayers should be well protected to avoid exposure of their skin to insecticide concentrates, and they should avoid inhaling insecticide droplets. Care should be taken to ensure that people and animals are not directly exposed to the spray.

3.1.4 *Larviciding*

Larviciding can be a useful method for malaria control, particularly in areas where breeding sites are accessible and relatively limited in number and size. These criteria are often met in urban areas, where larviciding in a central area can be combined with indoor residual spraying in a barrier zone of houses around the periphery of the town or city. As many vector breeding sites as possible should be eliminated through environmental management, to reduce the number to which larvicides need to be applied.

(a) *Target area*

Before undertaking larviciding, surveys should be carried out to estimate the relative importance of different types of vector breeding sites, which varies considerably, depending on the species and local environment. Targeting only the most important sites might improve operational cost–effectiveness.

(b) *Insecticides*

The insecticides listed in **Table 4** are suitable for larviciding. The period of effectiveness of chemical larvicides depends greatly on the nature of the breeding site and exposure to the sun; it can vary from months in clean water to only a few days in polluted water.

Table 4. WHO-recommended compounds and formulations for control of mosquito larvae

Insecticide	Chemical type	Dosage of ai (g/ha)	Formulation	WHO hazard classification of ai[a]
Fuel oil	–	[b]	Solution	–
B. thurigiensis israelensis	Biopesticide	[c]	Water-dispersible granule	–
Diflubenzuron	Insect growth regulator	25–100	Wettable powder	U
Methoprene	Insect growth regulator	20–40	Emulsifiable concentrate	U
Novaluron	Insect growth regulator	10–100	Emulsifiable concentrate	NA
Pyriproxyfen	Insect growth regulator	5–10	Granules	U
Chlorpyrifos	Organophosphate	11–25	Emulsifiable concentrate	II
Fenthion	Organophosphate	22–112	Emulsifiable concentrate, granules	II
Pirimphos-methyl	Organophosphate	50–500	Emulsifiable concentrate	III
Temephos	Organophosphate	56–112	Emulsifiable concentrate, granules	U

ai, active ingredient

[a] Class II = moderately hazardous; class III = slightly hazardous; class U = unlikely to pose an acute hazard in normal use; NA = not available.

[b] 142–190 l/ha, or 19–47 l/ha if a spreading agent is added

[c] To open bodies of water at dosages of 125–750 g of formulated product per hectare, or 1–5 mg/l for control of container-breeding mosquitoes

Higher dosages are usually recommended for polluted water. Organochlorines, such as DDT, are not recommended for larviciding because of their persistence in the environment. Likewise, insecticides that are highly toxic to mammals are not recommended. Although considered ecologically unacceptable in some situations, application of oils or fuel oil to breeding sites can be effective for limited periods. Pyrethroids are not usually recommended for use as larvicides because they affect a broad spectrum of non-target arthropods and their potency might potentiate larval selection for pyrethroid resistance.

Insect growth regulators (see section 1.1) and the microbial insecticides *Bacillus thuringiensis israelensis* (serotype H-14) and *B. sphaericus* are possible alternatives to common chemicals for larviciding. Insect growth regulators might, however, affect non-target organisms and should not be used in breeding sites with an abundance of arthropod species, unless an impact assessment has been carried out. *B. thuringiensis* H-14, which is more active than *B. sphaericus* against malaria vectors (with the possible exception of *A. gambiae*), is specific against mosquito larvae, but frequent re-treatment is necessary with the commonest formulations.

(c) *Application procedures*

Liquid formulations can usually be applied with the same equipment as used for indoor residual spraying, i.e. hand-operated compression sprayers fitted with a flat fan, cone-jet or adjustable cone-jet nozzle. In some breeding sites, application of granular formulations by hand might be more appropriate.

(d) *Treatment cycle*

The interval for re-treatment with chemical and bacterial larvicides is usually 7–10 days but can be longer for standing clear water or with higher dosages. Certain insect growth regulators can persist much longer.

(e) *Precautions*

Care must be taken not to exceed the recommended dosage of insecticides applied to water that might be used by humans or domestic animals or that contains wildlife of importance to the human environment.

3.2 *Aedes* spp.

The main vector of dengue and urban yellow fever is *Aedes aegypti*. *A. albopictus* is a secondary dengue vector in South-East Asia and the western Pacific. The epidemiological significance of the recent establishment of *A. albopictus* in parts of Africa, the Americas snd Europe remains unclear. *A. polynesiensis* and *A. pseudoscutellaris* are arboviral and filarial vectors present in the South Pacific. At least eight other Aedes species of the *Stegomyia* subgenus, including *A. africanus* and *A. simpsoni sensu lato*, and species of other subgenera such as *A. (Diceromyia) furcifer-taylori* are important vectors of yellow fever outside urban areas.

Except for one African form occurring in forest environments, *A. aegypti* lives in close association with humans, typically breeding in household water-storage containers and other artificial rain-filled containers in the domestic environment, including roof gutters, discarded tyres and food containers. In some towns and cities, underground catchment basins and storm drains are important larval habitats. *A. albopictus* uses both artificial

and natural breeding sites (domestic and peridomestic), whereas all the other important *Aedes* species prefer natural breeding sites, such as tree holes, plant axils and coconut husks. The domestic forms of *A. aegypti* feed indoors and outdoors, mainly in the early morning and the last 3–4 h of daylight and prefer to rest indoors in secluded places, e.g. under sinks, in curtain folds or in wardrobes. *A. albopictus* is less domestic than *A. aegypti* and tends to rest and feed outdoors, as do most of the other important vector species. It is generally accepted that *Aedes* species have a flight range of less than 400 m, although recent studies indicate that *A. aegypti* might disperse over much longer distances in search of oviposition sites.

An essential component of routine *A. aegypti* control is the removal or destruction of peri-domestic breeding sites, such as discarded tyres and discarded plastic, glass and metal food containers. Domestic water-storage containers should be covered appropriately to prevent mosquito access, emptied and scrubbed once a week or treated with insecticides considered safe for use in drinking-water (see section 3.2.1). Alternatively, biological control agents such as fish, e.g. *Poecilia* spp., or suitable local species of cyclopoid copepods can be added to water tanks, cisterns and metal drums. As community involvement is important for effective *A. aegypti* control, health education and social mobilization are integral parts of effective control programmes.

Chemical control of *A. aegypti* mosquitoes can include application of larvicides as part of a routine control strategy or, in the case of space spray treatment, in anticipation of or during epidemics of dengue or yellow fever. Indoor residual treatment can also be effective for control of *A. aegypti*. Insecticide resistance has been detected in many *A. aegypti* populations, and susceptibility testing coupled with assessment of the practical impact (if any) of cases of detected resistance is strongly recommended.

3.2.1 *Larviciding*

Larviciding should be considered as complementary to environmental management. It is feasible only against strictly domestic species such as *A. aegypti*; it is not usually practicable against species that breed in hard-to-reach natural sites such as leaf axils and tree holes. As *A. aegypti* often breeds in water-storage containers, the larvicides must have little toxicity to mammals and should not change the taste, odour or colour of the water significantly. The toxicology of the active ingredients methoprene, pyriproxyfen and temephos and those in *B. thuringiensis israelensis* has been assessed by the International Programme on Chemical Safety (IPCS) to determine their safety for use as mosquito larvicides in drinking-water at dosages that are effective against *Aedes* larvae. Nevertheless, the safety of the ingredients of the final formulation, which vary from one product to another, still requires study, though, as does possible microbiological contaminants in formulations of *B. thuringiensis israelensis*. The WHO *Guidelines for drinking-water quality*[24] provide authoritative guidance on the use of pesticides in drinking-water. In areas where *A. aegypti* breeds in septic tanks or soak-away pits, expanded polystyrene beads can be applied, as long as the sites are not subject to regular flooding.

(a) *Target area*

Surveys should be carried out to determine the main breeding places and how and when they should be treated. Breeding sites in, for instance, jars, discarded tyres, discarded containers, ant traps and plant containers should be treated only if removal or destruction is not feasible.

[24] http://www.who.int/water_sanitation_health/dwq/guidelines/en/index.html.

(b) *Insecticides*

Mosquito larvicides suitable for application to containers of non-potable water are listed in Table 4. For treatment of drinking-water, temephos and methoprene at dosages not exceeding 1 mg of active ingredient (ai) per litre (1 ppm), pyriproxyfen at dosages not exceeding 0.01 mg ai per litre (0.01 ppm) and *B. thuringiensis israelensis* can be used.

(c) *Application procedures*

Hand-operated compression sprayers are adequate for application of liquid insecticides to larger breeding sites. A syringe or pipette can be used for treating indoor flower vases and ant traps. Granule and certain other solid formulations are applied directly by (protected) hand to confined breeding sites. In treating containers of drinking-water, enough insecticide should be added for the volume of the container even if the container is not full of water (e.g. 1 g of 1% temephos granules for 10 l of container volume).

(d) *Treatment cycle*

The mosquito species, seasonality of transmission, rainfall patterns, residual property of the larvicide, and types of breeding site all affect the treatment cycle. In a few cases, two to three treatments per year, carefully spaced between periods of rainfall, might be sufficient. More frequent treatment might be required, depending on water quality and exposure to sun.

(e) *Precautions*

Extreme care must be taken when treating drinking-water to avoid dosages toxic to humans.

3.2.2 *Residual treatment*

Indoor residual treatment of houses has not been used widely for *Aedes aegypti* control. However such treatment can be effective, for example, the elimination of *A. aegypti* from the Mediterranean region was attributed to indoor residual house spraying with DDT for malaria eradication. Residual insecticides can also be used to treat potential breeding containers, whether they hold water or not, and for spraying surfaces up to 60 cm from each container. This results in a residue that can destroy existing and subsequent larval infestations as well as adult mosquitoes that frequent the sites. This approach is known as 'perifocal spraying', a term that is also sometimes used to describe insecticide application in an area around a reported case of dengue. Suitable insecticides (e.g. those listed in Table 1, excluding organochlorines) can be applied with hand-operated compression sprayers. Power sprayers can be used to treat large accumulations of discarded containers rapidly. Care must be taken not to treat containers used to store water for human or animal use.

3.2.3 *Space treatment*

There has been considerable controversy about the efficacy of aerosol insecticide applications during epidemics of dengue and yellow fever. Any control method that reduces the number of infective adult mosquitoes, even for a short time, should reduce virus transmission during that time, but it remains to be proven whether such a short-term impact is epidemiologically significant in the long run. Certainly, there is no well-documented example of this approach interrupting an epidemic. Nevertheless, if space spraying is used early in an epidemic, the intensity of transmission might be reduced, which would give time for larviciding and community-based source reduction for long-term results. Thus, if disease surveillance is sensitive enough to detect cases in the early

stages of an epidemic and if the resources are available, emergency space spraying can be initiated at the same time as source reduction measures and larviciding are intensified.

In addition to insecticide susceptibility, droplet size, application rate and indoor penetration of the insecticide are all crucial to the efficacy of this method. Indoor penetration of an insecticide depends on the house construction, whether doors and windows are left open during spraying and, in the case of vehicle-mounted application equipment, residential block configuration, the route of the spray vehicle and meteorological conditions.

Vector populations can be suppressed over large areas by the use of space sprays released from aircraft, especially over areas where access with ground equipment is difficult and extensive areas must be treated rapidly. In applying space sprays from the air, careful consideration must be given to meteorological factors, especially wind speed, at spray height and at ground level, and to the droplet size spectrum obtained at the flying speed of the aircraft. For all aerial spray operations, clearance must be obtained from the civil aviation authority. For safety reasons, populated areas must usually be sprayed from twin-engined aircraft. Modern aircraft are fitted with global positioning systems, so the exact position of the aircraft while the insecticide is being applied can be accurately recorded.

(a) *Target area*

As total coverage can rarely be achieved, the focus should be on areas where people congregate, e.g. high-density housing, schools, hospitals and areas where cases of disease or high vector densities have been recorded. Selective space treatment up to 400 m from houses in which cases have been diagnosed was practised in the past; in general, however, by the time a case is detected and a response mounted, the infection will have spread to a wider area. When space treatment is applied from outside, residents should be encouraged to leave windows and doors open during application to allow penetration of the insecticide. Application from the outside is less effective when houses have solid walls, glazed windows and high garden walls. In such cases, indoor space or residual treatment is likely to be more effective.

(b) *Insecticides*

Suitable insecticides for space spraying as cold aerosols or thermal fogs are listed in Table 3. The choice of insecticide formulation for space spraying in and around dwellings should be based on its immediate environmental impact and the compliance of the community.

Only insecticide products with high flash-points should be used for thermal fogging. Space-spraying formulations are usually oil-based, as the oil carrier inhibits evaporation of small fog droplets. Diesel fuel has been used as a carrier for thermal fogging agents, but it creates thick smoke and oily deposits, which may lead to community rejection. Water-based formulations have been made available recently, for environmental reasons; they may also contain substances that prevent rapid evaporation.

(c) *Application procedures*

Space sprays can be applied either as thermal fogs at about 10–50 l/ha or as ultra-low-volume applications of undiluted or partially diluted technical-grade insecticide in the form of a cold aerosol of droplets of controlled size (15–25 µm) at a rate of 0.5–2.0 l/ha. Portable or vehicle-mounted thermal or cold fog generators can be used for ground application. If the affected area is more than 1000 ha or if it cannot be covered by

ground equipment within 10 days, aerial cold fog application is sometimes used. The difficulties of ensuring penetration of insecticide droplets into the resting sites of the target species are similar to those for aerosols dispensed from road vehicles.

Application rates vary with the susceptibility of the target species and environmental considerations. Wind speed has a strong effect on droplet distribution and contact with insects. In most situations, a wind speed of 1–4 m/s (approximately 3.6–15 km/h) is needed to drift droplets downwind from the line of travel. Furthermore, space sprays should be applied when there are temperature inversions, i.e. colder air closer to the ground, which occur early in the morning or in the evening when the ground temperature begins to fall.

Space spray applications should correspond to the activity of the target species. *A. aegypti* and *A. albopictus* are active during the day, with peak flight activity in the morning and afternoon. For these species, a compromise is usually made by spraying outdoors in the early morning or late afternoon.

Indoor treatments with portable cold or thermal fog generators are particularly effective against *A. aegypti* because its resting behaviour is mainly indoors. They are the only choice where there is no access for vehicles. For application from vehicle-mounted equipment in areas with narrow roads and houses close to the roadside, the spray should be directed backwards from the vehicle. In areas with wide roads and buildings far from the roadside, the vehicle should be driven close to the roadside and the spray should be directed at a right angle (downwind) to the road rather than directly behind the vehicle. More detailed information on operational guidelines for space spraying is available in the WHO manual on this subject[25]. For cold fog applications from large aircraft, the speed at which applications are made would be 240 km/h, 60 m above the ground, with swath spacing of 180 m. Small fixed-wing aircraft are flown at 160 km/h, 30 m above the ground, with a swath width of 50–100 m. In emergencies, agricultural spraying aircraft, including helicopters, can be used. They should be fitted with rotary atomizers or other suitable nozzles calibrated for the insecticide, its formulation and the desired application rate.

(d) *Treatment cycle*

When a rapid reduction in vector density is essential, space treatment should be carried out every 2–3 days for 10 days. Further applications should then be made once or twice a week to sustain suppression of the adult vector population. Continuous entomological and epidemiological surveillance should be conducted, however, to determine the appropriate application schedule and the effectiveness of the control strategy adopted.

(e) *Precautions*

When house-to-house space treatment is carried out with portable equipment, operators should take special safety measures. In addition to normal protective clothing, they should wear face masks and should operate the equipment only for short periods. Ultra-low-volume aerial applications should be made only by highly skilled pilots trained to undertake spraying at the proper speeds and heights (see section 1.5). Clearance from the local civil aviation authority must be sought. Ground reconnaissance should be made before treatment and the public advised to safeguard non-target animals and beehives.

[25] *Space spray application of insecticides for vector and pest control—A practitioner's guide*. Geneva, World Health Organization, 2003 (unpublished document WHO/CDS/WHOPES/GCDPP/2003.5; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

Fogging in urban areas can be a traffic hazard, and spotted staining of vehicles may result, particularly when large droplets are used.

3.3 *Culex* spp.

3.3.1 Residual fumigation

Some species of *Culex* are important vectors of disease. *C. quinquefasciatus* is a vector of Bancroftian filariasis in parts of Asia, especially southern and eastern India, in urban areas of East Africa, in Haiti and in north-eastern Brazil. It is a pest in all tropical towns and cities. *C. pipiens* has been linked to the transmission of Bancroftian filariasis in Egypt and that of epidemic West Nile virus in Europe and the United States of America and to mechanical transmission of the virus causing Rift Valley fever in the Middle East. *C. tritaeniorhynchus* is the main vector responsible for transmitting Japanese encephalitis in South and East Asia; *C. tarsalis* is the vector of St Louis encephalitis in the United States and *C. annulirostris* transmits Murray Valley encephalitis and Ross River disease in Australia. The many other vectors and pest species of *Culex* are too numerous to mention.

Most *Culex* species rest outdoors, except for *C. quinquefasciatus*, which is a domestic mosquito, over 50% resting on non-sprayable surfaces in houses, such as mosquito nets, clothes, hangings and furniture. For this reason, indoor residual house spraying is of limited use, particularly when the insecticide used does not have volatile or fumigant properties. Furthermore, *C. quinquefasciatus* adults in many areas have developed high levels of resistance to insecticides (organochlorines, organophosphates, carbamates and pyrethroids). Insecticide-treated nets (chapter 15) give considerable relief from the nuisance of *C. quinquefasciatus* biting, which may be a major incentive for use of these nets. If use of treated nets was sustained for long enough, there would be a real effect on the incidence of filariasis. At present, larviciding is the principal method of chemical control of most species of *Culex*, especially in urban and semi-urban areas.

Environmental sanitation should be an integral part of effective *C. quinquefasciatus* control. This may involve unblocking drains to maintain water flow, draining areas of flooded land, filling in small collections of polluted water and repairing chipped or cracked concrete lids of septic tanks. In the special situations posed by pit latrines, which sometimes have a free water surface (i.e. not covered in scum), cesspits and septic tanks, all of which can produce vast numbers of *C. quinquefasciatus*, a 1-cm layer of expanded polystyrene beads can be applied to prevent breeding. Massive reductions in adult *C. quinquefasciatus* populations have been achieved in communities in Zanzibar and south India by concerted use of polystyrene beads. In both cases, this practice was shown to supplement the effects of mass administration of anti-filarial drugs in suppressing filarial infection. When a polystyrene-treated pit is eventually filled in, the beads persist and become mixed with soil. This is not environmentally harmful, as shown by the fact that polystyrene beads are routinely mixed with greenhouse soil to improve its aeration. Nevertheless, care should be taken to avoid unsightly scattering of the beads on the surface when treated sites are flooding or being emptied. The beads should not be used in unrestricted larval habitats or habitats prone to flushing or flooding.

3.3.2 *Space treatment*

Space treatment is conducted mainly to control outbreaks of arbovirus disease. The insecticides and application procedures used are the same as those for the control of *Aedes* mosquitoes (see section 3.2.3). For exophilic species, outdoor resting sites should be targeted for treatment.

3.3.3 *Larviciding*

(a) *Target area*

The breeding sites of *C. quinquefasciatus* are collections of polluted water, such as cesspools, drains, pit latrines and ditches, while *C. tritaeniorhynchus* breeds in clearer water such as that found in rice fields, swamps and marshes. *C. annulirostris* breeds in almost any type of groundwater, whereas *C. tarsalis* prefers sewage lagoons, pastures and irrigated croplands.

(b) *Insecticides*

Chemicals used as larvicides are listed in Table 4. Current practice is based chiefly on the use of organophosphates, despite increasing levels of resistance in some areas. For residual control, the dosage should be markedly increased for longer activity. Various insect growth regulators and *B. sphaericus* provide good control of *C. quinquefasciatus* in polluted breeding sites.

(c) *Application procedures*

Hand-operated compression sprayers can be used for application of liquid insecticide to localized breeding sites. It has been found practicable to express dosages of insecticides used in confined breeding places such as latrines (if polystyrene bead treatment is not feasible) as mg/l (ppm) rather than g/ha. The aim is to introduce into the breeding-place a specific amount of insecticide adapted to each situation by applying a precise volume of formulated compound (e.g. 240 ml of chlorpyrifos at 5 g/l (0.5%) per catch basin or 5 g of 100 g/kg (10%) granules per latrine). For extremely polluted sources, such as sewage-treatment plants, the insecticide can be introduced into the effluent by a drip technique. In contaminated ponds, floating booms have been used to confine heavy-oil larvicides to breeding areas on the perimeter. Where areas of flooded grassland are important breeding sites, granular formulations are suitable, as they can fall through the grass to the water below. Aerial application is useful for treating extensive breeding areas. Liquid formulations are applied at 5–10 l/ha to control *C. tritaeniorhynchus* in rice fields.

(d) *Treatment cycle*

Applications at intervals of 1–2 weeks are usually required for temporary treatment with light mineral oil alone or light mineral oil fortified with chemical larvicides. For control of susceptible *C. quinquefasciatus* breeding in polluted concrete drains and in pit latrines, organophosphates can remain effective for 2–8 weeks. Treatment with microbial insecticides prevents breeding for 1–2 weeks, and, depending on environmental conditions, insect growth regulators prevent emergence of viable adults for 2–20 weeks.

(e) *Precautions*

Larvicides that are suitable for use in polluted waters might not be suitable for use in ecologically sensitive areas where non-target organisms might be affected.

3.4 *Mansonia* spp.

Several species of *Mansonia* are important vectors of lymphatic filariasis *(Wuchereria bancrofti* and particularly *Brugia malayi*). *M. uniformis* is the most widely distributed of these species. The larvae of *Mansonia* attach themselves to the roots of aquatic plants such as *Pistia*, *Eichhornia*, *Salvinia* and *Scirpus* and to irrigated grasses. In situations in which removal or destruction of host plants is not practical but control of *Mansonia* is required, chemical or microbial larvicides can be used (Table 4). The adults are mainly exophilic, although considerable numbers of certain species remain in houses after feeding on humans. These can best be controlled by indoor residual house spraying, as for *Anopheles* control (see section 3.1).

4. Flies

This chapter should be considered in conjunction with chapter 1, in which general information on the selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

4.1 *Musca domestica* and other fly species closely associated with humans

Flies live in close association with humans. The most important include the housefly family, with the genera *Musca*, *Fannia* and *Muscina*; the biting flies, *Stomoxys* (family Muscidae); the blowflies, *Chrysomya*, *Calliphora* and *Lucilia*; and the flesh-flies, *Sarcophaga*. *Musca domestica*, the housefly, is the species found most commonly throughout the world and is the main focus of this section.

The breeding sites of flies are animal and human excreta and a wide variety of other organic matter, particularly domestic rubbish. Experimental and epidemiological studies have shown that, because of their filth-breeding and filth-feeding habits, some fly species closely associated with humans can be important vectors of the microorganisms that cause diseases, such as shigellosis and other diarrhoeal diseases (*M. domestica*) and trachoma (*M. sorbens*). These two diseases are such important causes of child deaths and blindness that domestic flies should be considered significant disease vectors. Epidemics of these diseases can be common where high human and fly population densities are associated with unsanitary conditions, as may be found in refugee camps. Flies are, however, rarely the sole transmitting agents in any disease epidemic.

Environmental sanitation is the fundamental measure for fly control. Proper processing and disposal of refuse, manure, compost and other organic waste is of prime importance in the elimination of fly breeding sites. As far as possible, flies should be kept away from young children. Cooking areas should be fly-proofed and stored food covered. In some countries, baited fly traps are used to reduce fly nuisance, and biological control is also an option for reducing fly density. Insecticides should be used only as a supplement to environmental management control methods, not as a substitute.

There are several chemical methods of fly control. Before one is adopted, the local fly population's breeding, feeding and resting habits and the insecticides to which the flies are resistant should be studied thoroughly. Given that insecticide resistance in various forms is widespread and given the limited range of available insecticides, it is strongly recommended that insecticides be used judiciously and backed up by effective resistance management.

4.1.1 *Residual treatment*

(a) *Target area*

Treatment should be directed against surfaces in and around animal shelters, fly-breeding sites and areas where flies congregate for feeding or resting. Night-time resting sites are

particularly important, as houseflies prefer edges of objects, strings, wires and thatch material under the roofs of houses and animal shelters. When average temperatures are high, many houseflies remain outside at night and rest on the exterior surfaces of buildings and on fences, trees and shrubs. Blowflies and flesh-flies normally rest outdoors.

(b) *Insecticides*

A preliminary assessment of susceptibility to insecticides should be undertaken before one is selected for control of any medically important insect. This is particularly important in the case of houseflies as resistance is so widespread. Housefly populations have developed resistance to DDT and related compounds in all parts of the world. Organophosphate resistance is also common and appears to be increasing worldwide in terms of the level, distribution and compounds involved. Resistance to carbamates and to pyrethroids is also becoming widespread. Resistance to insect growth regulators is not a problem if they are used for direct treatment of manure, although moderate resistance has been observed when they are mixed into animal feed. Compounds acceptable for use in dairies and poultry houses (subject to local regulations) are listed in **Table 5**. Although deposits of emulsifiable concentrates are less conspicous, suspension concentrates, wettable powders and capsule suspensions offer better residual efficacy. Addition of sugar to finished formulations at two to three times the concentration of the toxicant increases the effectiveness of treatment with some insecticides. This can, however, favour the development of mould in areas of extreme humidity.

As a rule, the speed and risk of development of resistance is greater with residual sprays than with other treatments against adult flies. For this reason, intensive use of pyrethroids as residual treatment is not recommended unless no alternative exists; in some countries, it is prohibited altogether in certain areas. The risk for developing resistance is also increased when the same active ingredient is used as both an adulticide and a larvicide. For this reason, fly breeding sites should ideally be treated with insecticides different from those used for treating adult fly resting sites.

(c) *Application procedures*

Hand compression or power-operated sprayers are used to apply the formulations. The spray volumes required vary with the nature of the surface to be treated: 40–80 ml/m^2 might suffice for smooth, non-absorbent surfaces, but volumes up to 250 ml/m^2 might be required for treatment of highly absorbent surfaces, such as refuse tips or refuse collection areas.

(d) *Treatment cycles*

Effectiveness can last from a few weeks to a few months, depending on the insecticide, dosage, surface treated, climate and resistance of local flies. When compounds are applied to shelters housing non-dairy animals, the dosage can be increased to the maximum, as given in Table 5, with corresponding extension of the residual effect.

(e) *Precautions*

Contamination of food, food preparation surfaces and drinking-water should be avoided. The product label and local regulations should be read and followed.

Table 5. Insecticides used for residual treatment for fly control

Insecticide	Chemical type[a]	Concentration of formulation as applied (g/l)	Dosage of ai (g/m2)	WHO hazard classification of ai[a]	Remarks
Bendiocarb	Carbamate	2–8	0.1–0.4	II	4
Azamethiphos	Organophosphate	10–50	1.0–2.0	III	1
Chlorpyrifos-methyl	Organophosphate	6–9	0.4–0.6	U	1&5
Diazinon	Organophosphate	10–20	0.4–0.8	II	1
Dimethoate	Organophosphate	10–25	0.046–0.5	II	2
Fenitrothion	Organophosphate	10–50	1.0–2.0	II	1
Malathion	Organophosphate	50	1.0–2.0	III	3
Naled	Organophosphate	10	0.4–0.8	II	4
Pirimphos-methyl	Organophosphate	12.5–25.0	1.0–2.0	III	1
α-Cypermethrin	Pyrethroid	0.3–0.6	0.015–0.03	II	1
β-Cypermethrin	Pyrethroid	1.0	0.05	II	1
Betacyfluthrin	Pyrethroid	0.15	0.0075	II	1
Bifenthrin	Pyrethroid	0.48–0.96	0.024–0.048	II	1
Cyfluthrin	Pyrethroid	1.25	0.03	II	1
Cypermethrin	Pyrethroid	2.5–10.0	0.025–0.1	II	1
Cyphenothrin	Pyrethroid	–	0.025–0.05	II	1
Deltamethrin	Pyrethroid	0.15–0.30	0.0075–0.015	II	1
Esfenvalerate	Pyrethroid	0.5–1.0	0.025–0.05	II	1
Etofenprox	Pyrethroid	2.5–5	0.1–0.2	U	1
Fenvalerate	Pyrethroid	10–50	1.0	II	2
λ-cyhalothrin	Pyrethroid	0.7	0.01–0.03	II	1
Permethrin	Pyrethroid	1.25	0.0625	II	1
D-Phenothrin	Pyrethroid	–	2.5	U	1

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

Remarks:

1. Can also be used in milk rooms, restaurants and food stores.
2. Animals must be removed during treatment; not to be used in milk rooms.
3. Only premium-grade malathion should be used in milk rooms and food-processing plants.
4. Not to be used in milk rooms; at strength of 2.5 g/l (0.25%) can be applied to chicken roosts, nests, etc., without removing the birds; animals must be removed.
5. In chicken houses, birds must be removed at application time and brought back only after 4 h.

4.1.2 *Space treatment*

Space treatment is the most effective method for rapidly reducing fly density inside and outside houses. Insecticides applied as aerosols at relatively low doses will kill adult flies that come into contact with spray droplets. There is, however, no residual effect of the insecticide, and larvae and pupae at breeding sites are unaffected; thus, treated areas often undergo rapid repopulation with new adults.

(a) *Target area*

Indoor treatment should be directed towards dwellings, kitchens, restaurants, shops, poultry farms and animal stables. Outdoors, the areas to be treated are night-time fly resting sites, refuse dumps, recreation sites, markets, food industry sites, rubbish containers and rubbish trucks.

(b) *Insecticides*

Suitable insecticides for space treatment against flies are listed in **Table 6**. For indoor treatment, water-based or deodorized kerosene formulations of the less hazardous insecticides are recommended. Mixtures of pyrethroids synergized with piperonyl butoxide (**Table 7**) and used in cold or thermal fog formulations have been found to be effective for fly control outdoors.

Table 6. Insecticides used for space treatment for fly control

Insecticide	Chemical type	Dosage of ai[b] (g/ha)	WHO hazard classification of ai[a]
Chlorpyrifos-methyl	Organophosphate	100–150	U
Diazinon	Organophosphate	336	II
Dimethoate	Organophosphate	224	II
Malathion	Organophosphate	672	III
Naled	Organophosphate	224	II
Pirimiphos-methyl	Organophosphate	250	III
Bioresmethrin	Pyrethroid	5–10	U
Cypermethrin	Pyrethroid	2–5	II
Cyphenothrin	Pyrethroid	5–10	II
d,d-trans-Cyphenothrin	Pyrethroid	2.5–5	NA
Deltamethrin	Pyrethroid	0.5–1.0	II
Esfenvalerate	Pyrethroid	2–4	II
Etofenprox	Pyrethroid	10–20	U
λ-Cyhalothrin	Pyrethroid	0.5–1.0	II
Permethrin	Pyrethroid	5–10	II
D-Phenothrin	Pyrethroid	5–20	U
Resmethrin	Pyrethroid	2–4	III

ai, active ingredient.

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use; NA, not available

(c) *Application procedures*

For indoor treatment, portable cold or thermal fog generators are used. For outdoor treatment, vehicle-mounted cold or thermal foggers are most appropriate, although portable equipment can be used in areas where vehicle access is limited. The rate of dispersion of the insecticide is determined by the target dose, the speed of the vehicle or person, the meteorological conditions, and the width of the band treated as the sprayer moves forwards, which can vary from 20–30 m in urban areas to 100 m in open spaces. For fly control, the rates of dispersion have been found to be in the order of 0.5–2.0 l/ha in cold

fog applications and 10–50 l/ha in thermal fogs. In community control, equipment can be mounted on vehicles that move through streets at 8–16 km/h and disperse the formulation at 24–48 l/km. Sprays are usually applied in the morning before temperatures get too high.

Table 7. Pyrethroid mixtures used in cold and thermal fog formulations for fly control

Pyrethroid mixture	Concentration (g ai/ha)	
	Cold fog	Thermal fog
Permethrin +	5.0–7.5	5.0–15.0
S-bioallethrin +	0.075–0.75	0.2–2.0
piperonyl butoxide	5.25–5.75	9.0–17.0
Bioresmethrin +	–	5.5
S-bioallethrin +	–	11.0–17.0
piperonyl butoxide	–	0–56
Phenothrin +	5.0–12.5	4.0–7.0
tetramethrin +	2.0–2.5	1.5–16.0
piperonyl butoxide	5.0–10.0	2.0–48.0
Etofenprox +	5–10	5–10
pyrethrins +	0.18–0.37	0.18–0.37
piperonyl butoxide	10–20	10–20
λ-Cyhalothrin +	0.5	0.5
tetramethrin +	1.0	1.0
piperonyl butoxide	1.5	1.5
Cypermethrin +	2.8	2.8
S-bioallethrin +	2	2
piperonyl butoxide	10	10
Tetramethrin +	12–14	12–14
D-phenothrin	6–7	6–7
D-Tetramethin +	1.2–2.5	1.2–2.5
cyphenothrin	3.7–7.5	3.7–7.5
D-Tetramethrin +	1.2–2.5	1.2–2.5
D,D-trans-cyphenothrin	2–8	2–8
Deltamethrin +	0.3–0.7	0.3–0.7
S-bioallethrin +	0.5–1.3	0.16–1.3
piperonyl butoxide	1.5	1.5

ai, active ingredient

(d) *Treatment cycle*

Indoor space treatment of dairies, food-processing plants and other places where hygienic conditions are important might be required daily to ensure effective fly control. In outdoor

space spraying in towns, villages or refugee camps, treatment should be applied every day for 1–2 weeks to kill adults as they emerge from breeding sites in the area. Once the breeding cycle has been broken, the spraying interval can be extended to once or twice a week, depending on the rate of immigration of flies from outside the area. To determine the precise timing of space treatments, adult fly density can be monitored by hanging sticky fly papers in kitchens or near night-time resting sites. If spraying is too frequent, it may accelerate the induction of resistance.

(e) *Precautions*

Food and water should be protected during indoor space treatment, and people and animals should be kept out of the way of outdoor space sprayers. The product label and local regulations should be read and followed.

4.1.3 *Larviciding*

Larviciding has both drawbacks and advantages as a fly control measure. As fly breeding media tend to accumulate and change continuously, frequent treatments with larvicides are required. The penetration and distribution of the larvicide in a medium is often problematic; the natural predators of fly larvae can be killed if non-selective treatments are used; and insufficient concentrations of insecticide in the breeding media can favour the development of resistance. In areas where fly breeding is confined to specific sites, however, carefully targeted larviciding can achieve useful results. When resources are available to maintain larviciding programmes, several applications during the fly season are likely to be necessary. Even when the resources to maintain such programmes are not routinely available, they might nonetheless be appropriate at the height of the fly season and during epidemics of fly-borne diseases such as dysentery.

(a) *Target area*

The main breeding sites of the housefly and related species are:

- *M. domestica* (housefly): refuse, animal or human excrement
- *M. sorbens* (face-fly): human excrement
- *M. vestutissima* (bush fly): cattle droppings
- *Calliphora* spp., *Lucilia* spp.: meat, fish, rubbish
- *Muscina* spp. (false stable fly): rubbish
- *Chrysomya* spp. (blowfly): latrines, meat, fish
- *Sarcophaga* spp. (flesh-fly): meat, animal excrement
- *Fannia* spp. (lesser housefly): animal excrement
- *Stomoxys calcitrans* (stable fly): straw stacks, piles of weeds, grass and animal excrement.

When fly densities are high, it is important to identify the predominant species and identify the principal breeding sources. Time and money can be saved and contamination of the environment reduced by targeting only the most important breeding sites.

(b) *Insecticides*

Insect growth regulators are preferred for use as larvicides as they are chemically unrelated to adulticides. Commonly used insect growth regulators are listed in **Table 8**. Although many compounds belonging to the traditional insecticide classes are also active against fly larvae, they should in general be reserved for control of adult flies, to minimize the selection pressure for resistance. The use of pyrethroids in particular should be reserved for space treatment.

Table 8. Insect growth regulators used as housefly larvicides

Insecticide	Dosage (g ai/m2)	WHO hazard classification of ai[a]
Diflubenzuron	0.5–1.0	U
Cyromazine	0.5–1.0	U
Pyriproxifen	0.05–0.1	U
Triflumuron	0.25–0.5	U

ai, active ingredient

[a] Class U, unlikely to pose an acute hazard in normal use.

(c) *Application procedures*

Either hand-operated compression or power-operated sprayers are used to apply larvicides at a rate sufficient to wet the upper 10–15 cm of the breeding medium thoroughly, i.e. 0.5–5 l/m^2, depending on the medium. The maggots might be deep in the medium and be unaffected by application of a small dose. Dust and granule formulations can also be used, particularly for chicken manure. When insecticides are applied to refuse dumps for fly control, controlled tipping should be practised. This involves covering the top and sides of the refuse dump each day after tipping has ceased with a 30-cm layer of soil or sand and then compacting it. The heat and toxic gases generated by decomposition kill larvae, and those that are not killed are unable to emerge through the cover. In this situation, the insecticide should be applied to the covering layer to kill the few females that emerge. The working face should not be treated as a precaution against the development of resistance.

(d) *Treatment cycle*

Generally, breeding sites should be treated at regular intervals, although over-frequent treatment can select for resistance (the label should be consulted for directions).

(e) *Precautions*

Spraying the food and drinking-water of livestock should be avoided. The product label and local regulations should be read and followed.

4.1.4 *Baits*

(a) *Target area*

Baits are placed or applied on sites where adult flies congregate to feed, such as in and around livestock farms, dairies and food-handling establishments.

(b) *Insecticides*

Table 9 lists the insecticides used in toxic fly baits. Dry baits typically contain 5–20 g ai/kg (0.5–2%) in a carrier such as sugar or sugar plus sand, ground corncobs or crushed oyster shells. Liquid baits typically contain insecticide at 1–12.5 g ai/l (0.1–1.25% in ready-to-use spray solutions) and sugar at 100–112.5 g/l (10–11.25%) in water. Baits can contain special attractants such as fish-meal, fermenting yeast, cheese flavour or the house fly pheromone z-9-tricosene.

Table 9. Insecticides used in toxic baits for fly control

Insecticide	Chemical type	WHO hazard classification of a[ia]
Spinosad	Biopesticide	U
Propoxur	Carbamate	II
Imidacloprid	Neonicotinoid	II
Thiamethoxam	Neonicotinoid	NA
Azamethiphos	Organophosphate	III
Diazinon	Organophosphate	II
Dimethoate	Organophosphate	II
Naled	Organophosphate	II
Phoxim	Organophosphate	II
Trichlorfon	Organophosphate	II

ai, active ingedient

[a] Class II, moderately hazardous; class III, slightly hazardous; NA, not available

(c) *Application procedures*

Dry baits are scattered in a thin layer by hand from a bag, shaker-top can or similar container, typically at a rate of 60–250 g/100 m^2. Liquid applications can be made with a hand compression sprayer or a sprinkling can, at a rate of 2–4 l/100 m^2. Viscous paint-on baits, typically composed of insecticide at 7–125 g ai/l (0.7–12.5%) with a binder and sugar to form a 'paint', can be applied by spotting with a paintbrush. This method is the most versatile and convenient, as the bait can be placed wherever flies congregate, including vertical surfaces such as posts, supports and walls, and it has a long residual effect.

To avoid the need for frequent renewal of baits, special reservoir containers can be designed. Gelatine or agar baits can be applied to a wire mesh square attached to a wooden paddle. The paddles can be distributed over the area by inserting them into the ground or by attaching them to existing supports.

(d) *Treatment cycle*

Scatter baits might need to be applied one to six times per week, depending on the rate of consumption by flies. Liquid bait dispensers or dry bait stations (trays) can work for 1–2 weeks. Paint-on baits can remain effective for 1–2 months or longer.

(e) *Precautions*

As baits contain a sweetening agent and food material, care should be taken that they are not placed where children or domestic animals are likely to find them. The product label and local regulations should be read and followed.

4.1.5 *Cords and strips*

During the night, houseflies prefer to rest on the edges of objects or on strings and wires, which suggests use of insecticide-impregnated tapes, strips or cords for fly control. This method is a useful, inexpensive way to control flies; it has a long-term residual effect, and there is less chance of resistance than with residual sprays. Nevertheless, the reduction in fly density can be rather slow. Insecticide-treated cords or strips can be hung from the rafters or ceilings of dwellings, restaurants, poultry farms or animal stables.

The insecticide, such as azamethiphos, diazinon, dimethoate, malathion, propoxur or suitable pyrethroids, is incorporated into a cotton cord, spongy plastic band or gauze band. Solutions or emulsions of organophophate and carbamate compounds at concentrations of 100–250 g/l (10–25%) or pyrethroids at 0.5–10 g/l (0.05–1%) are typically used. The strips or cords are suspended under the ceiling, firmly attached to the support by stapling or tying. Dark or red materials are often better than light colours, and 1 m of cord should be used for each square metre of floor space. Where permitted, the insecticide can be added to sugar or an attractant plus glue or oil to make a durable film. The strips and cords are effective for 2–6 months, depending on the insecticide, dosage and hanging site. Gloves should be worn when positioning cords or strips, which should not be suspended over food containers, watering troughs or within reach of animals.

4.2 *Glossina* spp.—tsetse flies

Species of *Glossina* are the vectors of trypanosomiasis in Africa south of the Sahara. The disease caused by *Trypanosoma* in humans is commonly referred to as 'sleeping sickness'. Only a few tsetse species are vectors, and even these do not transmit the disease throughout their ranges. The importance of *Glossina* populations as potential vectors of trypanosomiasis depends on the domestic habitat they occupy, the mammalian hosts on which they feed and other factors. The occurrence of African animal trypanosomiasis and sleeping sickness depends in some situations on reservoirs of trypanosomes in wild animals; elsewhere, however, transmission of the human disease is mainly human–fly–human.

Major epidemics of sleeping sickness occurred in the first half of the twentieth century, but these were largely under control by the 1960s. Since then, as rural health systems have deteriorated and control programmes abandoned or weakened, there has been a dramatic resurgence of the disease. Because sleeping sickness is often a disease of remote rural areas, it is difficult to obtain precise figures; however, in 1999, WHO estimated that some 60 million people in 36 countries were at risk and that about 300 000 were affected. Animal trypanosomiasis also has adverse impacts on human health, especially in terms of reduced supplies of meat and milk and the numbers of healthy animals available for pulling carts and agricultural implements. In some locations, cattle are reservoir hosts of human-infective trypanosomes.

Female tsetse flies produce only one fully-fed larva about every 9 days; thus, the potential for rapid population expansion is much lower than that of virtually all other insects, which produce large number of eggs which hatch into free-feeding larvae. The specialized reproductive biology of tsetse flies has two important consequences for their control: firstly, for practical purposes, control methods must be directed against adult flies, as

the larvae are intrauterine and the puparium is buried in the soil; second, a relatively limited proportion of the population need be killed in order to achieve an acceptable level of control. Thus, the difficulties of tsetse control are mainly associated with logistics and sustaining any success achieved, rather than a lack of effective control techniques.

There are three groups of species of *Glossina*. The five species of the *G. palpalis* group include the major vectors of sleeping sickness, *G. palpalis*, *G. tachinoides* and *G. fuscipes*. In wetter areas, these species are relatively widely distributed in forests or secondary forests, whereas in drier areas they are restricted to vegetation on the banks of rivers and lakes. The five species of the *G. morsitans* group include the major vectors of animal trypanosomiasis, *G. morsitans* and *G. pallidipes*; some species, especially *G. morsitans*, are also vectors of sleeping sickness in East Africa, where they occur in the extensive African savannah woodlands. The 13 species of the *G. fusca* group occur predominantly in rain forest; they do not feed on humans and have limited importance as vectors of animal trypanosomiasis.

Control of both human and animal trypanosomiasis relies primarily on the use of drugs, but vector control is a viable support in some situations. Before the advent of insecticides in the late 1940s, vector control was conducted primarily by clearing the vegetation that forms the habitats of the flies. Between the 1950s and the early 1980s, organochlorine insecticides were widely used, especially in anglophone Africa. Today, synthetic pyrethroid insecticides are used almost exclusively, both for space spraying and as a component of bait methods of control, in which flies are attracted, by vision or by natural or synthetic odours, to inanimate objects (traps and targets) impregnated with insecticide or to domestic animals, usually cattle, to which insecticide has been applied. In general, tsetse flies are highly susceptible to the available pyrethroids, although the susceptibility of individual flies to insecticides varies according to age, sex and physiological state; no resistance has been reported from the field.

4.2.1 *Application of non-residual insecticide from the air*

In the sequential aerosol technique, droplets of insecticide are emitted from low-flying, fixed-wing aircraft. As the droplets are too small (a volume mean diameter of 30 µm is optimal) to produce a persistent deposit on vegetation, an effective degree of control can be achieved only by repeating the application, usually five or six times at 12–18-day intervals, in order to take into account the duration of the puparial period and the length of female life before production of the first larvae. A block of savannah woodland is sprayed by one or more aircraft flying parallel swaths, about 300 m apart; this involves precise navigation, most effectively with a global positioning system fitted in the cockpit. Spraying should be undertaken only during temperature inversion conditions. Deltamethrin at an application rate of 20–25 mg ai/ha is typically used.

4.2.2 *Application of insecticide to traps and targets*

Cloth or netting traps and targets can be impregnated with insecticide. Today, synthetic pyrethroids are used exclusively, the commonest being deltamethrin suspension concentrate. Impregnation is achieved either by soaking the material in insecticide or by treating the trap or target in the field with a knapsack sprayer. The frequency of treatment varies according to the weather and other factors, but it is usual to apply a high dose of insecticide to maximize the duration of lethal deposition and to minimize maintenance costs. Many concentrations of deltamethrin have been used; a general recommendation

would be 0.1% ai for the initial application and 0.05% ai for subsequent applications to a device (15 mg ai/m^2 of cloth). λ-Cypermethrin has been used in some control programmes; it is considered to be as cost-effective as deltamethrin, despite the need for slightly higher concentrations. Other synthetic pyrethroids have been evaluated in field trials.

4.2.3 *Application of insecticide to domestic livestock*

Insecticides can be applied to domestic livestock, primarily cattle, by dipping or by pouring. For this to be an effective control measure, however, domestic animals must be present in sufficient numbers, a high proportion must be treated regularly and a high proportion of tsetse blood meals must be derived from them. Synthetic pyrethroids are used exclusively, most cost-effectively when an existing cattle-dipping infrastructure (for tick control) can be exploited. Deltamethrin suspension concentrate has been the most widely used insecticide applied by dipping; the 5% suspension concentrate should be diluted with water to an optimal concentration of 0.00375%. á-Cypermethrin and λ-cyhalothrin have also been used in the field. The alternative is to apply ready-to-use but more expensive pour-on, spot-on or spray-on formulations. Pour-on formulations are usually suspension concentrates; they are usually applied straight from the pack to an animal's back and require the addition of an oily 'spreader'. Deltamethrin has been the most widely used insecticide, at application rates based on 10 ml/100 kg body weight of a 1% ready-to-use suspension concentrate formulation. Trials of a number of other synthetic pyrethroids have been undertaken, most extensively with flumethrin and cypermethrin.

4.3 *Simulium* spp.—blackflies

Bloodsucking female blackflies are vectors of onchocerciasis in Africa (the *Simulium damnosum* and *S. neavei* complexes), Mexico and Central and South America (mainly *S. ochraceum*, *S. metallicum,S. callidum* and *S. exiguum*). The most important onchocerciasis foci were in West Africa, where vector control was carried out within the WHO Onchocerciasis Control Programme between 1975 and 2001. Larviciding is the only feasible method of vector control. This was relatively straightforward to perform in West Africa, where *S. damnosum sensu* lato tends to breed in the rapids of relatively large rivers, but is more difficult in Latin America, where several *Simulium* vector species breed in small streams that are difficult to access and treat. While the active flight range of blackflies is limited, they have been shown to be transported by the wind over hundreds of kilometres, re-infesting areas that have been cleared in vector control programmes.

4.3.1 *Larviciding*

(a) *Target area*

The insecticide is introduced into rivers and streams in several places. The number of application points should be determined from a preliminary survey and will vary by area and river according to the insecticide formulation used, the breeding habits of the local vector and the characteristics of the watercourse, such as flow rate.

(b) *Insecticides*

The insecticides suitable for *Simulium* control are listed in **Table 10**. In the area covered by the Onchocerciasis Control Programme, temephos was initially the preferred larvicide because of its effectiveness, the distance down river from the application point at which

it remains effective and its relative safety for non-target fauna. The appearance of resistance in West Africa in 1980, however, required adoption of a strategy in which insecticides with other modes of action were used alternately, to stop further development and spread of resistance and to forestall the appearance of new cases of resistance. This strategy of rotation of insecticides proved effective during the 15 years in which it was implemented.

Table 10: Insecticides used in rotation by the Onchocerciasis Control Programme for Simulium larval control

Insecticide	Formulation	Chemical type	Concentration (g ai/l)	River discharge (l/m^3 per s)	WHO hazard classification of ai[a]
Bacillus *thuringiensis*	Water-dispersible granules	Biopesticide	–	0.54–0.72	–
Carbosulfan	Emulsifiable concentrate	Carbamate	250	0.12	II
Phoxim	Emulsifiable concentrate	Organophosphate	500	0.16	II
Pyraclofos	Emulsifiable concentrate	Organophosphate	500	0.12	II
Temephos	Emulsifiable concentrate	Organophosphate	200	0.15–0.3	U
Permethrin	Emulsifiable concentrate	Pyrethroid	200	0.045	II
Etofenprox	Emulsifiable concentrate	Pyrethroid	300	0.06	U

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

B. thuringiensis H-14 is used at relatively high doses and has a short distance of effectiveness. Nevertheless, it was the main larvicide used during the last 10–15 years of the Onchocerciasis Control Programme. It can be used at discharge rates of up to 75 m^3/s; it is remarkable safe in the environment and is unlikely to induce resistance. The discharge limits at which the various larvicides can be applied (Table 10) are based on efficacy (dosage and length of effectiveness), toxicity to non-target fauna and cost.

Generally, *B, thuringiensis* H-14 is the preferred larvicide. In areas where there is no resistance, this product can be supplemented by temephos, especially when river discharges are relatively high and cannot be measured precisely for the proper dosage of the insecticide.

(c) *Application procedures*

Application from aircraft (fixed-wing aircraft for large rivers, helicopters for small and medium-sized rivers) is used for rapid coverage of extensive areas. For smaller areas, simple methods of ground application have been successful, e.g. in the eradication of *S. neavei* from Kenya, where applications were made mainly by suspending a 20-l container with a hole in the bottom over a stream. Other simple methods of application include insecticide-treated briquettes, as used in Guatemala for control of *S. ochraceum*, a small stream breeder. When rivers are treated with *B. thuringiensis* H-14, the product must be carefully sprayed from bank to bank, as it does not disperse spontaneously in water, unlike emulsifiable concentrates of chemical larvicides.

(d) *Treatment cycle*

Because of the life span of blackfly larvae, streams in tropical climates should be re-treated at 7-day intervals. In areas where water temperatures are lower (highlands), intervals of 10–14 days or even longer may suffice.

(e) *Precautions*

Because of potential risks to the aquatic environment, careful consideration must be given to the selection of larvicides and monitoring protocols. Monitoring involves continuous surveying of the populations of fish and of the benthic invertebrates on which most fish feed. Any insecticide used must be degradable and have minimal toxicity.

4.4 *Phlebotomus* spp. and *Lutzomyia* spp.—sandflies

Female sandflies (*Phlebotomus* and *Lutzomyia* spp.) bite humans and many kinds of vertebrate, typically at dusk or at night. Through this bloodsucking behaviour, sandflies can transmit the *Leishmania* pathogens responsible for visceral leishmaniasis (kala-azar), dermal or cutaneous leishmaniasis and the viruses that cause sandfly fever (pappataci fever), Oroya fever and verruga peruana.

Adult sandflies rest in soil cracks, rock crevices, limestone caves, tree holes, animal burrows, sheds or houses. The larvae live in soil but are difficult to locate. Hence, except in occasional laboratory experiments, sandfly control is directed exclusively against the adult stages. Since the first attempts to control sandflies with synthetic insecticides were carried out in Peru in 1944 with DDT, chemical control has been the main means used to reduce the transmission of sandfly-borne diseases. Assays of the susceptibility of sandflies, in laboratory and field tests, have shown that the lethal doses of organochlorines, organophosphates or pyrethroids are generally similar to those for mosquitoes. The only insecticide resistance recognized in wild sandfly populations to date is to DDT in India. As for mosquito control, sandfly control programmes worldwide now tend to be based on use of pyrethroids, such as cypermethrin, deltamethrin and λ-cyhalothrin.

At least 70 of the 700 or so sandfly species have been incriminated as disease vectors, and these differ greatly in their ecology and behaviour. Such differences are crucial in determining whether chemical control is likely to be effective and, if so, how it should best be applied. Key questions to be considered in determining the suitability of particular chemical control strategy are:

- Has the vector been identified?
- Is the transmission cycle partially or totally human–fly–human (i.e. anthroponotic)?
- If there is a reservoir of the *Leishmania* in wild or domestic animals (i.e. the disease is zoonotic), are these animal species known?
- Does transmission occur in or around houses or in some situations away from houses, such as inside forests?
- Is transmission seasonal or year-round?
- Is an infrastructure available that would allow organized, sustainable measures to be used?
- Are the human communities that are at risk willing to participate in the control measures proposed?

- What methods are available and are there practical, legal, environmental or cultural constraints on their use?

Strategies for the application of insecticides to control adult sandflies can be broadly divided into four categories: indoor residual spraying, insecticide-treated materials, insecticide-treated animals and space spraying.

4.4.1 *Indoor residual spraying*

Spraying of houses with insecticide is the most widely-used method for controlling endophilic sandflies, i.e. sandflies that rest inside houses. Its impact on disease incidence has, however, been evaluated reliably only recently[26]. Notably, house spraying with the pyrethroid λ-cyhalothrin (10% wettable powder at a rate of about 30 mg/m^2) reduced the incidence of cutaneous leishmaniasis in Kabul by 60% and reduced the risk in the Peruvian Andes by 54%. In both trials, protection of sprayed households was compared with that of nearby unsprayed ones. It remains unclear, however, whether 'blanket spraying' of all houses in a village would have a community-wide effect on sandfly populations.

The effectiveness of current residual insecticide spraying campaigns against visceral leishmaniasis on the Indian subcontinent and in Brazil is limited by the inherent difficulties in achieving widespread, regular coverage. No such campaigns are being conducted in areas of East Africa endemic for visceral leishmaniasis (where the sandfly vectors are largely exophilic). Depending on the length of the transmission season and on the characteristics of the surfaces sprayed and the insecticide used, re-treatment will be required after 3–6 months.

Where sandflies rest inside houses and in nearby structures, such as chicken houses or cattle sheds, both must be sprayed. A number of trials have been carried out to test the effect of spraying the resting sites of exophilic sandflies[27], including spraying tree trunks (to control a range of Latin American sandfly species) and spraying termite mounds (to control *P. martini* in East Africa). Generally, this strategy is designed to create a barrier zone around settlements, the width of which should be determined by sandfly dispersal behaviour. These strategies have yet to be fully evaluated for their efficacy, and their sustainability is questionable.

4.4.2 *Insecticide-treated materials*

When sandflies are endophagic and most active when people are asleep, mosquito nets provide significant protection. For example, a case–control study in Nepal showed that people using untreated nets were 70% less likely to develop visceral leishmaniasis than those using no nets. Owing to the small size of sandflies (with wings less than 3 mm long), however, untreated bed nets are effective only if they have small mesh size, which might not be acceptable in warmer climates. The protection provided by wide-mesh nets (even up to 1 cm^2) is enhanced by treating them with pyrethroids: this has reduced sandfly biting rates by 64% to 100%. The methods for impregnating nets to protect against sandflies are the same as those for treating mosquito nets (see chapter 3), although the mode of protection might be different, as insecticide treatment of wide-mesh nets does not inhibit all sandflies from passing through the net but greatly reduces the chance of being bitten, as sandflies entering a treated net are rapidly knocked down. There is

[26] Davies CR, Kaye P, Croft SL, Sundar S. Leishmaniasis: new approaches to disease control. *British Medical Journal 2*003, 326:377–382.

[27] Alexander B, Maroli M. Control of phlebotomine sandflies. *Medical and Veterinary Entomology* 2003, 17:1–18.

evidence from Colombia that sandflies are not diverted to people sleeping outside insecticide-treated nets: 'unprotected' people in the same room as those under a deltamethrin-treated net received 42% fewer sand-fly bites than people in houses without nets. As is the case for house spraying, it is unclear whether widespread use of insecticide-treated nets will have a mass effect, which will presumably depend on the extent to which humans are the principal blood meal source for sandflies.

To determine the likelihood that an insecticide-treated net programme could significantly reduce leishmaniasis transmission in a given locality, it is essential to have sufficient evidence about the principal site and the time of human transmission, for example by studying sandfly behaviour. Recent trials in Afghanistan and the Syrian Arab Republic demonstrated significant protection against cutaneous leishmaniasis (*L. tropica*) transmitted by *Phlebotomus sergenti*, and it can be assumed that this strategy would be effective throughout the range of *P. sergenti* (depending on local compliance). In these trials, polyester nets (100-denier, 156 mesh) were treated with 25 mg ai/m^2 deltamethrin suspension concentrate 1% and 500 mg ai/m^2 permethrin 25 emulsifiable concentrate, respectively.

Because *L. tropica* is anthroponotic, some leishmaniasis control programmes in places where this parasite is endemic provide insecticide-treated nets to cutaneous leishmaniasis patients as soon as the condition is diagnosed in order to reduce their potential infectiousness to sandflies and thus reduce the risk of transmission. Insecticide-treated nets are occasionally provided by health ministries to protect populations at risk of cutaneous leishmaniasis in some Latin American localities where transmission appears to occur in the domestic environment, but the effectiveness of such strategies has rarely been evaluated. The dicussion of net treatment methods against *Anopheles* in section 3.1.2 is also relevant to sandflies.

Where sandflies bite indoors but are significantly active from dusk onwards, insecticide treatment of curtains can provide effective protection for householders who are at risk of sand-fly bites, even before they have gone to bed. A field trial in Venezuela showed the protective effect of loosely hanging polyester curtains (0.05-mm mesh) treated with λ-cyhalothrin 2.5 capsule suspension at a rate of 12.5 mg ai/m^2 on the transmission of cutaneous leishmaniasis (*L. braziliensis*) transmitted by *Lutzomyia youngi*.

Where transmission to humans is largely an occupational hazard outdoors and away from the domestic environment, pyrethroid treatment of clothes can provide some protection. This method of chemical control is commonly used by military personnel who are transient visitors to endemic zones but is not considered practical for resident populations at constant risk. The results of trials of the effect of permethrin treatment of clothes on the risk for sand-fly bites or cutaneous leishmaniasis are inconsistent, possibly because of variation in concentrations used, from 125 mg ai/m^2 to 850 mg ai/m^2, and the extent of laundering during the trials. It is also possible that behavioural differences between sandflies explain the observed differences in effectiveness.

4.4.3 *Insecticide-treated animals*

Where leishmaniasis is zoonotic, transmission rates to humans can be reduced by targeting the animal reservoir hosts. In the past, this has involved the destruction of rodents by poisoning or by digging up their burrows, to control zoonotic cutaneous leishmaniasis caused by *L. major*, or culling infected domestic dogs, to control zoonotic visceral leishmaniasis caused by *L. infantum* or *L. chagasi*. Killing infected dogs has

become an increasingly unpopular strategy, and alternative tools have been developed. Dipping dogs in insecticide (deltamethrin, 50 ppm) or applying insecticide lotions along the middle of the back or the nape of the neck (e.g. 1–2 ml 65% permethrin, or 0.1 ml/kg body weight of 50% permethrin (w/v). Imidacloprid (10% w/v) can significantly reduce sand-fly bites on dogs and so protect them from infection, but this strategy requires regular re-treatment, as the insecticidal effect typically lasts only 2–3 months. A novel method for topical application of insecticide on dogs results in insecticide effectiveness for at least 8 months: experimental trials have consistently demonstrated that deltamethrin-treated collars reduce the proportion of sandflies that bloodfeed and survive by up to 90%. Widespread use of these collars on dogs in Italy reduced their risk of infection by *L. infantum*; and, in a randomized trial in the Islamic Republic of Iran, not only was the infection rate in dogs reduced by 54%, but children living in villages where the dogs were treated had 43% less risk of infection. The duration of the sand-fly transmission season, the dog population turnover rate, and the rate of collar loss all affect the logistics of this approach. Nevertheless, it can be assumed that community-wide use of treated collars could be an effective alternative to killing infected dogs.

Application of insecticides to animals that are not reservoir hosts of leishmaniasis can also reduce the transmission rate when the animals are the principal bloodmeal source of the sand-fly vectors. This result would be analogous to the demonstrable effect of insecticide sponging on livestock to control malaria in Pakistan, where the *Anopheles* vectors are highly zoophilic. Transmission is curtailed by reductions in both the population size and the survival rate of the mosquitoes. Such effects on sand-fly vectors of leishmaniasis have yet to be tested in trials in which livestock are the main source of blood, but this might be a promising control method in some localities.

4.4.4 *Space spraying*

Probably the most widely used control measure for sandflies after residual insecticide spraying is ground application of cold or thermal fogs. The effectiveness of this strategy has not, however, been well documented. The insecticides and basic application procedures are the same as those for the control of *Aedes* mosquitoes (see section 3.2.3), with the application time adapted to the peak flight activity of the target species.

4.5 *Culicoides*, *Leptoconops* and *Lasiohelea* spp.

Culicoides, *Leptoconops* and *Lasiohelea* spp. are the so-called biting midges, and species of all three genera can be vicious and persistent pests to humans and animals in many parts of the world. *Culicoides* spp. are also responsible for transmitting a range of helminth and viral pathogens of varying importance. They are vectors of the filarial worms *Mansonella perstens* and *M. streptocerca* in Africa and of *M. ozzardi* in the Caribbean islands. They also transmit Oropouche virus in parts Central and South America, which causes severe febrile infections. Interestingly, the pathogens transmitted to animals can be of much greater consequence than those transmitted to humans, and *Culicoides* spp. are therefore best known as vectors of bluetongue virus in ruminants and African horse sickness virus in horses, two of the most internationally feared pathogens of domestic livestock.

Biting midges breed in a wide range of habitats, depending on the species. Damp or wet soil with a high organic content is especially favoured, but they also breed in damp sand, tree holes, rotting banana stumps and other vegetation, and in the dung of large herbivores.

Most *Culicoides* spp. fly in the evening and at night, although the majority of the *Leptoconops* and *Lasiohelea* are diurnal. The flight range of biting midges varies with the species and with climate. Most fly only a few hundred metres to 2–3 km, but they can be transported passively on the wind as aerial plankton over distances in excess of 100 km. This can lead to rapid colonization of new habitats and to the introduction of disease into locations remote from the source if the dispersing midges are infected.

4.5.1 *Larval stages*

(a) *Habitat alteration to eliminate breeding sites*

This control method depends greatly on accurate identification of the target species and of their breeding sites. It can involve micro-intervention, e.g. repair of leaky irrigation pipes, cattle troughs and taps and disposal of farm dung heaps, or macro-intervention, including engineering methods such as land drainage and water level management.

(b) *Insecticide treatment*

This control method also depends on accurate identification of breeding sites, on the correct timing of applications in relation to seasonal abundance and, where there is intertidal breeding, on tidal flow. Important breeding sites of species that attack humans are often mangrove swamps and the intertidal zone, but they may also breed in other, inland locations, such as blanket bogs. Malathion (1120–1400 g ai/ha), diazinon (336 g ai/ha) or temephos (56–112 g ai/ha) can be applied, or other insecticides considered to have minimum impact on the environment and non-target organisms, by hand-compression or power-operated sprayers or applicators. Re-treatment might be required after 1–2 months, although use of slow-release formulations, e.g. temephos sand granules, can extend the time between treatments. If the breeding sites are extensive, as for *C. impunctatus* in Scotland, treatment of breeding sites might be impractical.

4.5.2 *Adults*

(a) *Repellents*

Some personal protection can be obtained by application of insect repellents to exposed skin or to clothing (see chapter 15). The level and duration of protection afforded by repellents varies with the species and genera of biting midge.

(b) *Insecticide treatment*

Few studies have dealt specifically with the control of adult biting midges by use of insecticides, but space spraying with any of the preparations indicated in Table 6 can provide temporary relief. Application should be restricted to the evening hours, when the insects are most active. Broad-scale application of such insecticides is, however, controversial, and products that have the minimum impact on the environment and non-target organisms should be selected. When it is important to protect livestock from disease-carrying midges, preparations based on one of the synthetic pyrethroids have been used, either on animal housing, e.g. λ-cyhalothrin applied at a rate of 0.05–0.1 g ai/1000 m^2, or as a spray on the animals themselves, e.g. 250 ml of 0.2% permethrin at 2-week intervals (equivalent to 5 g ai/bovine per application). If non-residual pyrethroids are used, it is recommended that application be restricted to the activity time of the midges, during the evening.

Use of ivermectin on livestock, as a pour-on or a systemic insecticide, is also effective and is reported to kill biting *Culicoides* for up to 10 days after treatment (200 µg ai/kg body weight). Systemic use of ivermectin has the additional advantage that the faeces of treated animals remain lethal to dung-breeding vector midges for up to 5 weeks after treatment. Should the faeces of treated animals be deposited on the breeding sites of soil-breeding vector midges during this period, their breeding is likely to be adversely affected to a variable extent.

In areas where the predations of certain midge species is particularly troublesome (e.g. *C. impunctatus*, the Highland biting midge in the west of Scotland), the complexities of their chemical signalling mechanisms, as used in mate location, host location and breeding site location, are being investigated in an attempt to develop semiochemical-based methods of control. Although such push–pull strategies show promise for the future, research is still at an early stage.

4.6 *Chrysops* spp. and other tabanids

These insects are commonly called horse flies or deer flies and can cause severe annoyance. Some species act as mechanical vectors of animal diseases such as anthrax, tularaemia and surra, and two species of *Chrysops* are vectors of *Loa loa* in Africa. *Chrysops* are difficult to control, both in adult and larval stages. The insecticides listed in Table 5 can be used for residual treatment, and those listed in Table 6 for outdoor space treatment for the control of adult *Chrysops* in littoral and bushy areas.

5. Fleas

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

More than 2000 species of fleas are distributed throughout the world, fewer than 30 of which are of public health importance. Adults of each sex suck blood; the females require it for maturation of their eggs. Many fleas are specific to a single host species, but a few can routinely parasitize a range of hosts. Some species, particularly nest breeders like the Oriental rat flea *Xenopsylla cheopis*, feed on blood frequently, often several times each day, and the mouth parts of some of the so-called sessile fleas are permanently attached to their host's tissues. Most species, however, can withstand long periods without feeding between emergence as adults and finding a host.

Eggs are generally laid on the host, but, because the eggs have smooth shells, they later drop to the ground or into the nest of the host, where the larvae hatch, grow, pupate and develop into adult fleas. The immature stages are usually found in areas frequented by the host animal, such as nests and burrows, and also regularly used roosts and resting-places.

Fleas are a major biting nuisance, causing stress and occasionally anaemia, particularly in penned domestic animals. The saliva of some species, such as the cat flea *Ctenocephalides felis*, can elicit a toxic reaction on some hosts, particularly young animals.

Several genera of flea have been implicated in the transmission of a range of pathogens, but it is as vectors of bubonic plague, tularaemia and murine typhus that they become an important problem. Species of *Xenopsylla*, particularly *X. cheopis*, are the most important vectors and commonly infest household rodents in many parts of the world. These fleas are effective disease vectors because they are not host-specific and, in the absence of rodents, often just as readily bite humans.

During an outbreak of bubonic plague, control of vector fleas should precede any measures against rodents. Otherwise, the number of plague cases can increase further as fleas leave dead rodent hosts or their nests to seek new sources of blood on humans. The most rapid and effective method for controlling fleas is to apply an appropriate insecticide formulated as a dust or low-volume spray that can be directed into small openings.

Tungiasis is caused by the flea *Tunga penetrans*. Growing urbanization, improved housing and use of appropriate footwear presumably have led to an overall reduction in the occurrence of this ectoparasitosis within past decades. It is nevertheless still highly prevalent among people living in extreme poverty in many Latin American and African countries.

5.1 *Xenopsylla* spp.

In addition to *X. cheopis*, *X. astia* in India and *X. brasiliensis* in Africa can be involved in transmitting plague. As rodents are the principal hosts of these fleas, the main sites of treatment are rodent burrows and runways. After coming into contact with insecticide dust, the rodents spread it on their fur while grooming. In houses and other buildings, the bottoms of all walls and the floor up to 15–30 cm from the wall should be treated with patches of dust. When food is stored above the floor and when the junction between the walls and the roof of a dwelling is open, dusts should be applied on top of the wall and along the rafters where runways are evident. Other areas in which rodents might live or visit, such as piles of wood, debris and rubbish in the vicinity of houses, should also be treated (see also chapter 14).

The insecticide dusts commonly used for flea control are listed in **Table 11**; these are effective against both adult and larval fleas. Hand-operated dusters are most commonly used. Sites frequented by rodents, including nests, holes and runways around and in burrow entrances, should be thoroughly covered with dust, applied in patches about 0.5 cm thick and 20–25 cm wide . For the control of fleas on wild rodents, about 30 g of dust should be blown into each burrow. Residual pyrethroid and carbamate insecticides remain effective for 2–4 months in dry conditions, but organophosphates of the same formulation are less persistent. Some insecticides are microencapsulated, which can extend their period of effectiveness. Re-treatments are generally carried out when the *X. cheopis* flea:rat index (i.e. the number of fleas per rat) exceeds 1.0. During an outbreak of disease, however, the occurrence of a new human case in a treated area is an indication for immediate re-treatment of the patient's dwelling and of other dwellings within 200 m. In

Table 11. Insecticide dusts used to control rodent fleas

Insecticide	Chemical type	Concentration (g/kg)	WHO hazard classification of ai[a]
Bendiocarb	Carbamate	10	II
Carbaryl	Carbamate	50	II
Propoxur	Carbamate	10	II
Chlorpyriphos	Organophosphate	20	II
Diazinon	Organophosphate	20	II
Fenitrothion	Organophosphate	20	II
Malathion	Organophosphate	50	III
Pirimiphos-methyl	Organophosphate	20	III
α-Cypermethrin	Synthetic pyrethroid	0.3–0.6	II
Cyphenothrin	Synthetic pyrethroid	0.05	II
Deltamethrin	Synthetic pyrethroid	0.5	II
Etofenprox	Synthetic pyrethroid	5	U
Permethrin	Synthetic pyrethroid	5	II
D-Phenothrin	Synthetic pyrethroid	4	U
Resmethrin	Synthetic pyrethroid	3	III
Tetramethrin	Synthetic pyrethroid	1–2	U

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

any area where plague is endemic, or in which it may threaten, the probable vector flea species should be tested periodically for susceptibility to insecticides to ensure that those used in an emergency control programme would be effective.

When port areas are infested with fleas and plague is present, ships might have to be fumigated with methyl bromide gas, in accordance with the *International Health Regulations*. This treatment should be conducted only by fully qualified persons in view of the extreme hazard to humans associated with these compounds. To prevent the spread of plague from endemic areas via rodents or fleas in cargoes in containers, dichlorvos resin strips can be enclosed in the container at the rate of one per 9 m^3. Exposure for 24 h should be sufficient to kill adult *X. cheopis* on rats.

In areas where plague is transmitted out of doors, the permanent reservoirs are rats living outdoors, e.g. *Arvicanthus niloticus* (Nile rat), *Bandicota bengalensis* and *B. indica* (Indian bandicoot rats), ground squirrels, voles and gerbils. Individual cases or outbreaks of plague are frequently traced to reservoirs in these animals. The control of outdoor rodents and their fleas is more exacting than that of household rodents. Bait boxes containing insecticide powder can be used. The rodent becomes coated with the insecticide as it feeds, and it then carries the insecticide back to its nest. Use of large bamboo tubes as bait boxes, with an insecticide dust at each open end, has proven successful in certain areas.

5.2 *Pulex* spp.

The commonest *Pulex* species is *P. irritans*, which, although it is called 'the human flea', is also found on household rats, pigs and domestic and outdoor-living carnivores. This flea requires a relatively cool, humid environment with plenty of organic detritus in which to breed. In Europe, most infestations in dwellings are brought in from farm animals. In houses, the flea rests by day in cracks and crevices as well as in mats and bedding. If dwellings are regularly and thoroughly swept or cleaned with a vacuum cleaner, flea infestations cannot become established. Therefore, adequate household hygiene, particularly in bedrooms, is the first requirement for *Pulex* control.

As *Pulex* fleas do not usually remain on the human body after feeding, the insecticides listed in **Table 12** should be applied directly to the sleeping area and beds. The mattress and the bed and cracks and crevices in the floor should be treated. If inhabitants object to the odour of insecticide on bedding, the sheets and blankets should be washed on the day the house is treated to ensure complete control. One treatment combined with adequate household hygiene should be sufficient. As a safety precaution, infants' bedding should be washed instead of being treated with insecticide.

In many countries, *Pulex* infestation occurs because the straw litter around intensively reared farm animals is not managed adequately. Under these conditions, the numbers of fleas can become extremely high, animals become unhealthy, and farmers easily carry the fleas back to their dwellings. Good management and hygiene can usually prevent or eliminate such problems. If they should arise, bedding material should be treated with insecticide before disposal, and walls and floors should be sprayed with a large enough volume of liquid that it runs off.

Table 12. Insecticides used for control of Pulex fleas

Insecticide	Chemical type	Concentration (g/l)	WHO hazard classification of ai[a]
Pyrethrum	Botanical pesticide	2	II
Bendiocarb	Carbamate	2.4	II
Fenoxycarb	Insect growth regulator	0.6	U
Methoprene	Insect growth regulator	1–5	U
Pyriproxyfen	Insect growth regulator	0.1–0.5	U
Triflumuron	Insect growth regulator	0.4–0.5	U
Chlorpyriphos	Organophosphate	2–5	II
Chlorpyriphos-methyl	Organophosphate	5	U
Malathion	Organophosphate	20	III
Pirimiphos-methyl	Organophosphate	10	III
α-Cypermethrin	Synthetic pyrethroid	0.3–0.6	II
Bifenthrin	Synthetic pyrethroid	0.48–0.96	II
Cypermethrin	Synthetic pyrethroid	0.5–2.0	II
Cyphenothrin	Synthetic pyrethroid	0.5–2.0	II
D,D-trans-Cyphenothrin	Synthetic pyrethroid	0.25–1.0	NA
Deltamethrin	Synthetic pyrethroid	0.3	II
λ-Cyhalothrin	Synthetic pyrethroid	0.3	II
Permethrin	Synthetic pyrethroid	2.5	II
D-Phenothrin	Synthetic pyrethroid	2–4	U

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use; NA, not available

5.3 *Ctenocephalides* spp.

5.3.1 *Treatment of animals*

The commonest species is generally *C. felis* (the cat flea), but *C. canis* (the dog flea) is commoner in some places. Control of these fleas depends on treatment of domestic pets and their living quarters. Dogs and cats can be treated with insecticides in dust, spray, spot-on concentrate, foam or shampoo preparations. There is little evidence that insecticide-impregnated collars have any effect. Suitable insecticides for treating dogs and cats are indicated in **Table 13**. These products are applied either all over the body or, in the case of concentrates, to the hair on the back or neck. In some areas, certain insecticides are no longer effective as fleas have become resistant.

Dusts and shampoos are still commonly used, even though they are less effective than other methods. They can be applied from a variety of dispensers and should be rubbed thoroughly into the fur. Sprays are available as hand-pump sprayers or pressurized aerosols; the animal's coat should be wetted thoroughly. These products are veterinary

medicines; thus, the animal's eyes and mouth should be protected, and certain treatments should not be used on young animals. The product label and local regulations should be read and followed.

Table 13. Insecticides used for flea control on pets

Insecticide	Chemical type	Formulation	Concentration (g/kg or g/l)	WHO hazard classification of ai[a]
Pyrethrum + synergist	Biopesticide	Dust, spray or shampoo	2 + 20	II
Rotenone	Biopesticide	Dust	10	II
Propoxur	Carbamate	Spray Dust Collar	10 10 94	II
Methoprene	Insect growth regulator	Shampoo Spray	0.2 1–5	U
Pyriproxyfen	Insect growth regulator	Spray , collar or spot-on	0.3–3.0	U
Imidacloprid	Neonicotinoid	Spot-on or spray	0.02–1.0	II
Chlorpyriphos	Organophosphate	Dust or shampoo	8	II
Malathion	Organophosphate	Dip	2.5	III
		Dust	50	
		Spray	5	
Fipronil	Phenyl pyrazole	Spray or spot-on	2.5	II
Deltamethrin	Pyrethroid	Spray or shampoo	0.025	II
Etofenprox	Pyrethroid	Dust	5	U
		Spray or shampoo	1–10	
		Spot-on	100 – 800	
Permethrin	Pyrethroid	Dust, spray or shampoo	10	II
		Wash	1	
D-Phenothrin	Pyrethroid	Dust or shampoo	2–4	U
		Spot-on	50–90	

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

Insect growth regulators can be given to both dogs and cats by mouth or injection. They are absorbed into the blood and ingested by fleas when they feed. As a result, they produce eggs that fail to hatch, or the emerging larvae are unable to develop. Some insect growth regulators have a depot effect in the animal's tissues and can be effective for several months. These products can be used in conjunction with other insecticides for quick kill of adult fleas in the early stages of treating an infestation. Label recommendations should be followed.

5.3.2 *Treatment of premises*

The interiors and exteriors of premises are often treated with sprays. Spot and foundation treatments can be used instead of comprehensive treatment of an entire property. Simultaneous use of adulticides and insect growth regulators can help to avoid further development of resistance to conventional insecticides. Neither insecticides nor insect growth regulators have any effect on the pupae, however, which are protected inside a silken cocoon that is usually coated with environmental debris, such as carpet fibres and sand grains.

Monitoring may be required after treatment, to ensure that infestation does not continue from pupae unaffected by treatment. Pupae usually take 2–4 weeks to mature, but adults can remain inactive inside the pupal skin until an appropriate stimulus to emerge arises. Under suitable cool and humid conditions, fleas can remain alive in this state for up to 2 years.

Treatment should be applied to the sleeping quarters and bedding of animals, in cracks and crevices in floors and particularly to the edges of carpets at the angle between walls and floors. Before rooms are sprayed, animal bedding and upholstered furniture should be brushed or vacuum-cleaned.

Exterior treatment should include all areas that animals use regularly as resting-places or for sun-basking, if the climate permits flea development in these places. Oil-based or water-based sprays containing the insecticides listed in Table 12 are most suitable for interior and exterior treatment. A hand sprayer or compressed air sprayer can be used indoors or outdoors at a rate of 4–8 l/100 m^2. A fine mist or an ultra-low-volume spray should be used for interior treatment to avoid staining fabrics. Generally, a single treatment is adequate to control an infestation.

6. Bedbugs

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

Two species of bedbug, *Cimex lectularius* (the common or temperate bedbug) and *C. hemipterus* (the tropical bedbug), are closely associated with humans. They differ little in their biology, except that the latter species does not thrive outside the tropics.

Eggs are laid singly in crevices in the bugs' harbourages and hatch within 10 days to 3 weeks, depending on temperature. Like all true bugs (order Hemiptera), bedbugs are hemimetabolous, i.e. the juveniles (nymphs) are like small versions of the adult rather than an entirely different larva. All five nymphal stages and both sexes of adult feed on blood at intervals of 3–14 days, depending on the ambient temperature. Adults and older nymphs can withstand long periods (up to 1 year) without food if the temperature and humidity are favourable. Nymphs usually moult in their harbourage, and the moulted skins often persist for long periods.

Bedbugs are mainly nocturnal and usually hide in cracks, crevices and dark places during the day or when artificial light levels are high. They are active when ambient light levels are low, especially at night. Although bedbugs are annoying pests that cause considerable skin irritation resulting from their biting and can disturb sleep, they have never been shown to be important in the transmission of disease. They have, however, been shown experimentally to be invertebrate hosts for South American trypanosomes, and there is some speculation that they are involved in the transmission of certain viruses.

Bedbug populations were reduced considerably by residual spraying with DDT and other insecticides between 1950 and 1970, and they were all but eradicated in many communities in the temperate zone. During the 1990s, however, their numbers increased significantly in most developed countries, apparently due to greater international travel and the appearance of insecticide resistance.

Control of *Cimex lectularius* and *C. hemipterus* consists of applying interior residual sprays or dusts to harbourages and to the surfaces over which the bedbugs crawl to reach the host. Bed frames and slats, both wooden and metal, the welted seams and buttons of mattresses, cracks and crevices in walls and floors, door and window frames and joints in furniture should be treated. Care should be taken to ensure penetration of the insecticide into the crevices where bedbugs hide. Blankets and other bedclothes are less likely to be infested, but, if they are, they should be washed in hot water and dried in the sun or hot ironed (dry-cleaning will also kill bugs). Items that cannot be heat-treated can be sealed in plastic bags and placed in a freezer (–18 °C) for 24 h to kill the bedbugs.

Suitable insecticides for bedbug control are listed in **Table 14**. Pyrethroids have been used extensively because, initially, they were not only highly active but also had an irritant excitation (flushing) effect on the bugs. In some areas, natural pyrethrins at 1–2 g/l (0.1–0.2%) have been added to organophosphate and carbamate insecticide formulations to increase flushing from harbourages, forcing the bugs into contact with fresh insecticide deposits.

Insect growth regulators are now an important element of bedbug control, especially for those that have become resistant to conventional insecticides. Mixtures of pyrethroids with insect growth regulators have proved effective in controlling infestations that are tolerant to pyrethroids alone.

Hand sprayers, compressed air sprayers and dusters are used to apply the insecticides. For walls, baseboards and floors, sprays can be applied to the point of run-off at about 1 l per 25–50 m^2. For other surfaces, the insecticide should be applied directly to cracks and crevices. The fabric under soft furnishings, e.g. sofa bases and stuffed armchairs, should be cut open and insecticide applied to the interior frames and surfaces. A single, thorough treatment with residual insecticide might be sufficient to eliminate an infestation; however, checks should be made after 4–6 weeks to ensure that nymphs emerging from hidden eggs have not evaded the insecticide residues. If the infestation persists, re-treatment should be carried out at not less than 2-week intervals. If possible, the bedding of infants, including cribs, should be treated by physical means rather than with residual insecticide. Treated mattresses should be allowed to dry completely before use. Residual spraying should be undertaken early in the day to allow residual deposits to dry thoroughly before rooms are occupied at night.

Mosquito nets treated with pyrethroid insecticides for malaria control (see chapters 3 and 15) are highly effective in eliminating bedbug bites. In some areas, this is a major incentive for people to use their nets regularly. In areas where bugs have become resistant to currently used net treatments, use of other insecticides or mixtures of insecticides with insect growth regulators is being investigated.

Table 14. Insecticides suitable for bedbug control

Insecticide	Chemical type	Concentration (g/l or g/kg)	WHO hazard classification of ai[a]
Bendiocarb	Carbamate	2.4	II
Flufenoxuron	Insect growth regulator	0.3	U
Methoprene	Insect growth regulator	0.9	U
Chlorpyifos	Organophosphate	2–5	II
Malathion	Organophosphate	20	III
Pirimiphos-methyl	Organophosphate	10	III
α-Cypermethrin	Pyrethroid	0.3–0.6	II
β-Cyfluthrin	Pyrethroid	0.25–0.5	II
Bifenthrin	Pyrethroid	0.48–0.96	II
Cyfluthrin	Pyrethroid	0.4	II
Cypermethrin	Pyrethroid	0.5–2.0	II
Cyphenothrin	Pyrethroid	0.5–1.0	II
Deltamethrin	Pyrethroid	0.3 (0.5b)	II
λ-Cyhalothrin	Pyrethroid	0.03	II
Permethrin	Pyrethroid	1.25	II
D-Phenothrin	Pyrethroid	1.0–2.0	U
Resmethrin	Pyrethroid	3	III
Tetramethrin	Pyrethroid	1–2	U

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

[b] Dust formulation

7. Triatomine bugs

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

Species of Triatominae (Hemiptera, Reduviidae), especially of the genera *Triatoma*, *Rhodnius* and *Panstrongylus*, are the vectors of *Trypanosoma cruzi*, which causes Chagas disease (American trypanosomiasis). In 1990, WHO estimated that about 18 million people in Latin America were infected with *T. cruzi*, and a further 100 million were at risk of infection; these figures have since fallen as a result of extensive vector control programmes, and it is estimated that around 12 million people are currently infected. The trypanosomes are transmitted to humans mainly via the faeces of infected triatomine bugs. The parasites can readily penetrate mucus membranes and may also penetrate wounds or abrasions as a means of entry into the circulation. Chagas disease is a zoonosis, and over 100 species of small mammals have been found to be naturally infected with *T. cruzi* (although birds are refractory to the infection). The disease is a particular problem in rural areas where low-quality housing makes suitable habitats for domestic triatomine bugs, but it can also occur in urban regions.

Over 130 species of Triatominae are currently recognized, and over half of these have been found to be naturally infected with *T. cruzi*. In view of their similar behaviour and physiology, all species should be considered potential vectors; nevertheless, the most important are those that colonize domestic and peri-domestic habitats. The most highly domestic species is *Triatoma infestans*, which is the principal vector in Argentina, Bolivia, Brazil, Chile, Paraguay, southern Peru and Uruguay. *Rhodnius prolixus* is an important vector in parts of Central America, Colombia and Venezuela. Other important vectors include *T. brasiliensis* and *Panstrongylus megistus*, which are found in parts of central and north-eastern Brazil, and *T. dimidiata* which is found principally in Central America, Colombia and Ecuador. Several species occupy peri-domestic habitats such as chicken coops, guinea-pig runs and goat pens, and a wide range of sylvatic species can enter houses, causing adventitious transmission but without necessarily colonizing the house.

Domestic triatomine bugs spend most of their time in cracks, fissures and other sites in the walls and ceilings of human dwellings and animal habitations. Both sexes feed on a variety of host animals. Their bite may be barely perceptible but in some cases can cause severe dermal reactions, including intense itching, nausea, flushed face and rapid pulse. Owing to the large quantity of blood taken, heavy infestations are also believed to contribute to chronic iron-deficiency anaemia.

Chagas disease is difficult and, on a public health scale, impractical to treat. Thus, control programmes rely primarily on elimination of domestic triatomine vectors. Of the wide range of methods that have been tested, only house improvement and the use of insecticides have been effective in controlling triatomine bugs. These interventions can be used together, although their operational impacts differ. House improvements tend to reduce the number of houses infested, irrespective of their infestation rates, whereas insecticides reduce the overall infestation density. House improvements are designed to eliminate the bugs' resting-places and include laying compacted earth or concrete floors, plastering walls and replacing thatch roofs with tiles or corrugated metal. Residual spraying

of insecticides on the inside walls of houses and outbuildings is still the principal method used in national vector control programmes. Domestic triatomine bugs are particularly susceptible to chemical control because they have a lower rate of reproduction than most other insect pests and also have little genetic variability, making development of insecticide resistance less likely. Generally, fifth-instar nymphs are better able to tolerate insecticides than earlier instars or adults.

7.1 *Triatoma*, *Panstrongylus* and *Rhodnius* spp.

7.1.1 *Target area*

The interior wall surfaces and ceilings of all rooms and outhouses should be treated, with special attention to surface cracks. Indoor furniture should also be sprayed, especially the underside of beds; bed-linen and clothes should be hung outside during spraying, preferably in the sun for long enough to kill any bugs hiding in the material. Although peri-domestic habitats such as latrines, chicken coops and goat pens should be treated at the same time as domestic premises, insecticides might be less effective in the former partly because of the physical complexity of some such habitats, so that the insecticide might not reach all the bugs' hiding places, but also because insecticide deposits might be more rapidly degraded by climatic extremes (especially direct sunlight) and frequently become covered with dust and debris.

7.1.2 *Insecticides*

Suitable insecticides for residual treatment for triatomine bug control are listed in **Table 15**. Fenitrothion and pyrethroids are the insecticides most commonly used for indoor residual

Table 15. Suitable insecticides for interior residual treatment for control of domestic Triatominae

Insecticide	Chemical type	Dosage of ai (g/m2)	WHO hazard classification of ai[a]
Bendiocarb	Carbamate	0.400–1	II
Propoxur	Carbamate	1	II
Fenitrothion	Organophosphate	1	II
Malathion	Organophosphate	2	III
α-Cypermethrin	Pyrethroid	0.050	II
β-Cyfluthrin	Pyrethroid	0.025	II
Bifenthrin	Pyrethroid	0.050	II
Cyfluthrin	Pyrethroid	0.050	II
Cypermethrin	Pyrethroid	0.125	II
Deltamethrin	Pyrethroid	0.025	II
Etofenprox	Pyrethroid	0.125	U
λ-Cyhalothrin	Pyrethroid	0.030	II

ai, active ingredient

[a] Class II, moderately hazardous; class III. slightly hazardous; class U, unlikely to pose an acute hazard in normal use

spraying against Chagas disease vectors. To avoid subsequent reinfestation, all houses in affected communities should be treated, followed by community vigilance and selective re-treatment when necessary.

7.1.3 *Application procedures*

Residual treatments are usually applied with hand-operated compression sprayers.

7.1.4 *Treatment cycle*

The length of residual effectiveness varies with the insecticide, substrate and vector species. In campaigns in which lindane was used, houses generally had to be re-sprayed every 3–6 months to ensure elimination of surviving vector populations. The operational procedure was modified with the advent of the pyrethroids, which allow a single mass treatment of all houses followed by a check on infestation rates after 1 year. If more than 5% of all the houses in a community show evidence of reinfestation after 1 year, every house is sprayed again. In communities with less than 5% reinfestation, re-spraying is carried out in the reinfested houses and in houses and animal shelters within 200 m of the target house. The 5% cut-off point is derived from studies in Brazil, which showed that new cases of Chagas disease are rare when less than 5% of houses are infested.

7.1.5 *Precautions*

Care should be taken during spraying to avoid contaminating water sources, food, cooking utensils and infant bedding with insecticide.

8. Lice

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

There are three species of human louse: the body louse (*Pediculus humanus*), the head louse (*P. capitis*) and the crab, or pubic, louse (*Phthirus pubis*). All nymphal stages and both sexes of adult human lice suck blood.

The body louse is generally found attached to clothing in contact with the body and to coarse body hair. The head louse is generally confined to the hair of the head but may rarely be found on hairs on other parts of the body. The crab louse generally lives in the pubic area but may also be found on the eyelashes, particularly of children. All species and forms spend their entire life cycle on the host, without which they cannot thrive for more than a short time.

Only the body louse has been implicated as a vector of disease, i.e. of epidemic typhus, endemic relapsing fever and trench (quintana) fever. Epidemic typhus is not transmitted by the bite of lice but by scratching infected lice or their faeces into the site of the bite or into scratched skin. Transmission can also take place by inhalation of infected louse faecal dust. Relapsing fever is transmitted only when the infected lice are crushed directly onto skin, as neither the faeces nor the bites are infectious. Epidemics of these diseases are often associated with wars or natural disasters, when standards of hygiene are low and people are living in crowded conditions. Louse-borne disease in temperate regions is transmitted predominantly in winter.

8.1 *Pediculus humanus*

Cleanliness is important in preventing body louse infestations. The easiest means of destroying an infestation is to expose infested clothing to a minimum temperature of 70 °C for at least 1 h. In emergency situations, people may find it impractical or impossible to wash properly, and fuel for heating water may be in short supply. In general, chemical control is required, especially where louse-borne disease threatens. Two application procedures have been tried. The oldest method, used extensively in Europe during and after the Second World War, is application of insecticidal dusts to the clothing of the infested population. The second approach is impregnation of clothing with a suitable insecticide. Treatment campaigns should target people most exposed to the threat of disease or areas of high population density where lice can easily spread.

8.1.1 T*he dusting technique*

The dusting technique used in the 1940s required the creation of two distinct enclosed areas—infested and treated. The target population passed from the infested to the treated area through a series of check-points where they were dusted manually with DDT powder. This method was found to be effective because an existing infrastructure was present, labour was plentiful, the logistics and finance were assured and compliance with the

regime was not in question. In current emergency situations, some of the prerequisites for effective control with the dusting technique might not be present, and alternative approaches should be considered.

For mass treatment, dusts should be applied through neck openings, up sleeves and from all sides of the loosened waist of trousers. Socks, head coverings, the inner surfaces of extra garments and bedding should also be treated. Awareness of cultural and religious customs is essential in delousing programmes, particularly with regard to the treatment of women.

In view of the spread of resistance of body louse populations to insecticide, the choice of chemical for a campaign should be preceded by a survey of insecticide susceptibility. Suitable insecticidal dusts for body louse control are listed in **Table 16**. The instructions for application that accompany the insecticide should be followed carefully.

Delousing dusts can be applied with any type of dusting apparatus, from compressed air dusters to application by hand. Some problems have been encountered with compressed air dusters for mass treatment, however, and hand application is somewhat wasteful. One thorough treatment of infested clothing with insecticide should be sufficient, although re-treatment might be required at 3–4-week intervals if infestations persist or reinfestation is expected. Dusting is not recommended for people with dermatological problems or exposed wounds. The precautions on the insecticide label should be followed carefully.

8.1.2 *Treating clothing*

Treatment of clothing with insecticide is simple and cheap and affords protection for at least 6 weeks, even with repeated washing. Thus, repeated treatments are unnecessary

Table 16. Insecticide suitable for the control of human lice

Insecticide	Chemical type	Formulation	Concentration (g/l or g/kg)	WHO hazard classification of ai[a]
Carbaryl	Carbamate	Dust	50	II
Propoxur	Carbamate	Dust	10	II
Lindane	Organochlorine	Dust	10	II
		Lotion	10	
Malathion	Organophosphate	Dust	10	III
		Lotion	5	
Temephos	Organophosphate	Dust	20	U
Bioallethrin	Synthetic pyrethroid	Lotion	3–4	II
		Shampoo	3–4	
		Aerosol	6	
Permethrin	Synthetic pyrethroid	Dust	5	II
		Lotion	10	
		Shampoo	10	
D-Phenothrin	Synthetic pyrethroid	Dust	2–4	U
		Shampoo	2–4	
		Lotion	2–4	

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

in areas that are difficult to reach regularly. The pyrethroid insecticide permethrin is recommended for impregnation; it should be diluted with water to give an optimal target dose of 0.65–1 g/m^2 on clothing. As the insecticide is close to the skin, only public health-grade insecticide should be used. Clothing is dipped in the insecticide solution, removed and allowed to dry. Dipping can be done in large tubs or baths, in which the amount of insecticide and water added is proportional to the amount of clothes to be treated. Clothes should be sorted into synthetic, cotton and wool, as each material absorbs different amounts of liquid. As, in general, cotton absorbs twice as much as synthetic material, cotton clothes should be dipped in a solution half as concentrated as that for synthetic clothes. When relief organizations provide clothing or blankets to louse-infested populations, pretreatment with insecticide is recommended.

8.2 *Pediculus capitis*

Commercial insecticides for use against lice are readily available in most regions and are the treatment of choice where resources permit. Most products contain either pyrethroid (phenothrin, permethrin, synergized pyrethrum) or organophosphate (malathion) compounds, although carbamates, particularly carbaryl, are occasionally available. As their efficacy against eggs is not guaranteed, re-application after about 7 days is recommended. Resistance has been widely reported to both organophosphates and pyrethroids; *kdr*-type mutations appear to be responsible for resistance to pyrethroids. Lotions are the application of choice, and aqueous, rather than alcohol-based, formulations are preferred if the recipient is asthmatic. As transmission occurs through direct head-to-head contact, other family members and close friends, particularly those in schools, should be checked and treated if lice are found. Commercial products should be used as directed by the manufacturer, with particular attention to recommended application rates and time before washing out the treatment.

8.3 *Phthirus pubis*

Although crab lice are found most often in pubic hair and in the perianal and axillary areas, they occasionally infest the hair of the trunk, thigh and beard, as well as eyebrows and eyelashes. Insecticides used for control of body lice or head lice are also effective against crab lice. Powders or emulsions are usually applied by rubbing a small amount into the hair of the affected parts, which should not be washed for at least 24 h after application. One application is usually sufficient, but, if necessary, re-treatment may be done at 4–7-day intervals. Shaving pubic hair is unnecessary. To eliminate crab lice from the eyelashes, a vaseline ointment containing pyrethrins is recommended.

8.4 *Precautions*

For individual treatment, care should be taken to avoid getting insecticide in the eyes. Some powders used in the treatment of pubic lice can cause contact dermatitis. If this occurs, the insecticide should be washed from the affected area. For mass treatment of body lice with dusts, protective clothing, including face masks or aspirators, should be worn by operators.

9. Cockroaches

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

Of the approximately 4000 species of cockroach, most are exophilic, feeding off vegetable debris on forest floors. Some species come into contact with humans only accidentally, by flying into buildings through lighted windows, and less than 30 species are significant pests.

The commonest species in houses are *Blattella germanica* (the German cockroach), *Blatta orientalis* (the Oriental cockroach), *Periplaneta americana* (the American cockroach), *P. australasie* (the Australian cockroach) and *Supella longipalpa* (the brown-banded cockroach).

The adults of most species have two pairs of wings, which may be functional or vestigial. In the tropics, species such as *P. americana* do fly, but they usually run about; others, such as *Blatella* spp., glide. In temperate regions, pest species rarely, if ever, fly. Eggs are deposited in a capsule-like structure called an ootheca, which is either deposited within a few days in some appropriate location or, as in the case of the German cockroach, carried by the female until it is ready to hatch. Most household cockroaches are active at night. They have successfully adapted to the human environment, as these species will eat almost anything. During the day, they hide in crevices and other humid places, such as beneath refrigerators, under kitchen fittings or behind household decorations, e.g. picture frames. They are involved in physical spoilage of food materials by eating them, defaecating onto them and regurgitating some of the contents of the foregut during feeding. As many domestic cockroaches either live in, or obtain water from, drains and sewers, they probably play a role in the mechanical transmission of pathogenic microorganisms, including those that cause diarrhoeal diseases. They are pests with an unpleasant smell, spread filth and ruin food, fabrics and bookbindings.

Good food hygiene practices in kitchens, including preventing access to food by sealing it in containers with close-fitting lids, and preventing cockroaches from reaching water, by repairing dripping taps and covering plug holes in sinks and drains, are effective in restricting cockroach populations. When infestation becomes established, however, there are no realistic alternative to the use of insecticides.

Chemical control involves use of insecticide baits and gels or application of residual insecticides to the surfaces over which cockroaches crawl and the cracks and crevices in which they hide. Insecticide resistance (see section 1.6) is an important problem in cockroach control: resistance to organochlorine, organophosphate, carbamate and pyrethroid insecticides has been reported in the German cockroach, which is the most important pest species. In general, these chemicals are gradually being replaced by more modern insecticides.

9.1 *Blattella* spp. and other genera

Different domestic cockroach species prefer different habitats: *Blatta orientalis* generally prefers cooler, moist conditions; *Blattella germanica* is tolerant of a wider range of conditions and may even be found in dry places, provided it has access to water; while *Periplaneta* spp. prefer warm, humid conditions.

9.1.1 *Target area*

Before treatment is begun, the extent of infestation should be monitored and attempts made to identify harbourages, using traps to highlight areas of maximum cockroach activity. The household areas that should be treated are primarily in the kitchen, along cockroach runs and in harbourages. These may be behind and along baseboards or skirtings, in and around sinks, in and under cupboards and around refrigerators. Special attention should be given to warm areas with high humidity. In commercial establishments such as restaurants, all food storage and preparation areas should be treated, but care should be taken not to contaminate surfaces on which food is prepared. Other sites, such as ducts and pipes, also require treatment. The treated area should be minimized by structural modifications where possible to reduce the number of hiding places. All sources of food should be removed or carefully sealed before application of insecticide.

9.1.2 *Insecticides*

Before selecting an insecticide for treatment, the susceptibility of the local cockroach population should be assessed. The insecticides commonly used are listed in **Table 17**. Use of gels and baits is easily controlled and monitored, particularly when bait stations are used, as the amounts taken by cockroaches can be measured and they are less likely to be accidentally affected by cleaning. When feasible, alternation between insecticide classes is recommended to delay the build up of resistance. Insect growth regulators can be used to control cockroaches, but, because they are relatively slow acting, they are generally used in combination with a fast-acting insecticide. This combination reduces adult cockroach activity while inhibiting juvenile development, resulting in highly effective treatment.

9.1.3 *Application procedures*

Residual spraying is usually done with a hand-operated compression sprayer containing a fan nozzle fitted for spraying surfaces and a pin-stream nozzle for spraying the insecticides into cracks and areas that are difficult to reach. Generally, the insecticide is applied at a rate of 4 l/100 m (linear measure) in a 0.3–0.5-m band of spray. In practice, this means spraying until the surface is almost completely saturated and the insecticide starts to run off. In catering environments, where most surfaces are non-porous by design, an emulsion or flowable concentrate is preferable, although wettable powders can be effective, particularly when applied to cockroach hiding places. Water-based microencapsulated formulations are effective at low doses, have low mammalian toxicity and a long residual life. In order to destroy heavy infestations rapidly or to drive cockroaches from protected areas, a pyrethrin aerosol can be used before residual spraying.

Table 17. Insecticides suitable for cockroach control

Insecticide	Chemical type	Formulation	Concentration (g/l or g/kg)	WHO hazard classification of ai[a]
Bendiocarb	Carbamate	Spray Dust Aerosol	2.4–4.8 10 2.5–10	II
Hydramethylnon	Hydrazone	Bait	21.5	III
Boric acid	Inorganic	Bait	1–100%	–
Fenoxycarb	Insect growth regulator	Spray	1.2	U
Flufenoxuron	Insect growth regulator	Spray	0.3	U
Pyriproxyfen	Insect growth regulator	Spray	0.4–1.0	U
Hydroprene	Insect growth regulator	Spray	0.1–0.6	U
Dinotefuran	Neonicotinoid	Bait Spray	0.2 – 1.0 0.5	NA
Imidacloprid	Neonicotinoid	Bait	1.85–2.15	II
Chlorpyrifos	Organophosphate	Spray Aerosol Dust Bait Microcapsule	5 5–10 10–20 5 2–4	II
Chlorpyrifos-methyl	Organophosphate	Spray	7–10	U
Diazinon	Organophosphate	Spray Dust Microcapsule	5 20 3–6	II
Fenitrothion	Organophosphate	Spray Aerosol Bait Microcapsule	10–20 5 50 2.5–5	II
Malathion	Organophosphate	Spray Dust	30 50	III
Pirimiphos-methyl	Organophosphate	Spray Dust	25 20	III
á-Cypermethrin	Pyrethroid	Spray	0.3–0.6	II
β-Cyfluthrin	Pyrethroid	Spray	0.25	II
Bifenthrin	Pyrethroid	Spray	0.48–0.96	II
Cyfluthrin	Pyrethroid	Spray Dust Aerosol	0.40 0.5 0.2–0.4	II
Cyphenothrin	Pyrethroid	Spray Aerosol Microcapsule	1–3 1–3 1–3	II
D,D-trans-Cyphenothrin	Pyrethroid	Spray Aerosol Microcapsule	0.5–1.5 0.5–1.5 0.5–1.5	NA
Cypermethrin	Pyrethroid	Spray	0.5–2.0	II

Deltamethrin	Pyrethroid	Spray Dust Aerosol	0.30 0.5 0.1–0.25	II
Esfenvalerate	Pyrethroid	Spray	0.5–1	II
Etofenprox	Pyrethroid	Spray Dust Aerosol	5–10 5 0.5	U
λ-Cyhalothrin	Pyrethroid	Spray	0.15–0.3	II
Permethrin	Pyrethroid	Spray Dust Aerosol	1.25–2.5 5.0 2.5–5.0	II
Fipronil	Arylpyrazole	Bait	0.1–0.5	II
Sulfluramid	Sulfonamide	Bait	10	III

ai, active ingredient

[a] Class II, moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use; NA, not available

Dust formulations are used to treat the inside of hollow walls and cracks and other inaccessible voids. They should not be applied to wet surfaces or in humid areas, as this will reduce their effectiveness. In appropriate sites, a light, uniform film of dust can be applied with a puff duster. In addition to the dusts listed in Table 17, boric acid and silica gel are occasionally used; they have little toxicity to mammals but act slowly and are less effective.

Several types of bait are commercially available, in the form of child-proof bait stations or gel pastes. Modern insecticides have largely superseded the older insecticides. Baits should be placed at sites frequented by the cockroaches. Lacquers and varnishes containing residual insecticides, such as 1% cypermethrin and 0.5% λ-cypermethrin, can be painted onto walls and other surfaces and may be effective for several months.

9.1.4 *Treatment cycle*

Treatment success should be monitored by use of discreetly and strategically placed sticky traps. These should be inspected regularly, and further treatment, perhaps with an alternative insecticide, should be initiated if healthy cockroaches continue to appear after 1 week. If residual sprays are being used, at least one more treatment will be needed after about 1 month (depending on the average temperature) in order to kill newly hatched nymphs from the original infestation. If insect growth regulators are used, some nymphs might continue to be trapped after this time.

9.1.5 *Precautions*

Care must be taken to avoid contamination of food or food preparation surfaces. In special situations, such as zoos or pet shops, the use of residual sprays or dusts might be precluded, and baits and gels are more suitable. For practical and safety reasons, dusts should not be applied in kitchens. Some spray formulations can stain fabrics, wallpaper, floor tiles or other household materials.

10. Ticks and mites

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

Ticks are vectors of numerous pathogens that cause disease in humans. As they are nearly all zoonotic, control methods require knowledge of the wild reservoir hosts. The only exception is probably tick-borne relapsing fever, transmitted by *Ornithodoros moubata* ticks in Africa, which are highly adapted to feeding on humans. Humans are rarely the hosts for full feeding of adult ticks and are often poor hosts for immature ticks, either because ticks are not adapted to attach to humans or because humans carefully remove any ticks that they see on themselves.

Ticks and mites have an economic impact on humans, as they cause disease in domestic animals. Most of the literature on control of ticks therefore refers to treatment of animals with acaricides, and a different approach is needed for control of human diseases associated with these pests. The aim of control of ticks and mites of public health importance is to reduce the risk of transmission of pathogens by preventing attachment mainly of larval and nymphal ticks. Control of ticks on domestic animals such as dogs contributes greatly to reducing human exposure to the ticks.

Ticks of the family Ixodidae are known as 'hard ticks' because of the presence of a sclerotized plate, the scutum, on their dorsal surface. Hard ticks and trombiculid mites attach for days to weeks, depending on their life-cycle stage. Ticks of the family Argasidae are known as 'soft ticks' because they do not have a sclerotized scutum; however, they are tough and can survive for many years without feeding. Soft ticks feed rapidly, without prolonged attachment. The ticks within the *Ornithodoros moubata* group which feed on humans are highly domesticated, being confined for the entire life cycle to the nest or housing of their hosts. *Otobius megnini* soft ticks are usuaally parasites of horses and cattle but can infest humans, causing intense irritation by feeding as immature stages in the external ear canal.

All types of ticks show strong habitat specificity. Their distribution is determined mainly by climatic factors at a microclimate scale defined by vegetation or shelter in the nests of their hosts. This provides much scope for tick control by habitat modification. Ticks have limited mobility away from the host environment, so that treating them by applying acaricides to the environment is more difficult than for more mobile insects.

Mites of direct human importance fall into two categories: trombiculid mites, which feed like larval ticks, cause intense irritation and can transmit the pathogen that causes scrub typhus; and sarcoptic and demodectic mites, which feed directly on human skin and cause dermatitis.

As ticks and mites must crawl onto their hosts from the vegetation or ground, an effective barrier to infestation is appropriate clothing, consisting mainly of long trousers worn tucked into long socks or over the outside of long boots. For persons such as foresters and farm workers, long-sleeved shirts or jackets with elasticated closures at the wrist are useful.

Chemical repellents can usefully supplement the primary clothing barrier and are potentially effective at reducing the risk of exposure to attaching ticks and mites as long as they are applied with sufficient frequency (see section 15.1).

10.1 Tick- and mite-borne pathogens of greatest importance to human health

Tick-borne encephalitis virus is a flavivirus transmitted by *Ixodes ricinus* and *I. persulcatus* hard ticks in Europe. The disease it causes has had various names, including 'Russian spring–summer encephalitis' and 'Central European encephalitis', but these are now subsumed under the name 'tick-borne encephalitis'. Kyasanur forest disease virus is a flavivirus that causes encephalitis and is transmitted by *Haemaphyalis spinigera* hard ticks in India. Omsk haemorrhagic fever virus is a flavivirus transmitted by *Dermacentor reticulatus* hard ticks in the Russian Federation. Powassan virus is a flavivirus that causes encephalitis in North America and the Russian Federation and is transmitted by various hard ticks of the genera *Dermacentor*, *Haemaphysalis* and *Ixodes*. Colorado tick fever virus is an orbivirus that causes fever and generalized symptoms and is transmitted by *D. andersoni* in North America. Crimean–Congo haemorrhagic fever virus is a Nairovirus that causes generalized symptoms, especially haemorrhage, and is transmitted by a variety of hard ticks, such as *Hyalomma marginatum marginatum*, *Hyalomma truncatum* and *D. marginatus* in Africa, Asia and Europe.

Rickettsia rickettsii is a rickettsial bacterium that causes Rocky Mountain spotted fever and is transmitted by *D. variabilis* and *D. andersoni* in North America. *R. conorii* causes boutonneuse fever, also known as Mediterranean spotted fever, tick-bite fever or tick typhus, and is transmitted in many countries of the Old World mainly by the hard tick *Rhipicephalus sanguineus* and ticks within the genera *Dermacentor*, *Ixodes* and *Haemphysalis*. *R. tsutsugamushi* (or *R. orientalis*) is transmitted by trombiculid mites, mainly of the *genus Leptotrombidium*, especially *L. akamushi* and *L. deliniense*. It causes scrub typhus, mainly in south-east Asia.

Borrelia burgdorferi and closely related species of spirochaete bacteria cause Lyme borreliosis and are transmitted by hard ticks of the genus Ixodes in Asia, Europe and North America. *B. duttoni* is transmitted by soft ticks within the *Ornithodoros moubata* complex in Africa, causing tick-borne relapsing fever. Numerous other species of *Borrelia* cause forms of human tick-borne relapsing fever, transmitted by a variety of *Ornithodoros* ticks in many countries. *Francisella tularensis* is a coccobacillus that can be water-borne, fly-borne or tick-borne to various wild animals but can easily infect humans by contaminative routes, especially during the handling of animal carcasses. The human disease it causes is tularaemia. which is widely distributed throughout the world.

Babesia species of haemoprotozoa can cause babesiosis in humans with reduced immune competence due to splenectomy. The syndrome is similar to fulminating malaria and has a poor prognosis. This is caused mainly by *B. divergens* and *B. major*, which are transmitted by *Ixodes ricinus* in Europe; but *B. microti* transmitted by *I. dammini* has been incriminated as a cause of babesiosis in humans with normal spleens in North America.

10.2 Parasitic diseases caused directly by ticks and mites

The feeding activity of some ticks can cause paralysis as the result of secretion of an incidental (apparently non-functional) toxin in the saliva of some strains and stages of ticks. The hard ticks *Ixodes holocyclus* in Australia and *Dermacentor andersoni* and *D. variabilis* in North America are the most important for humans. The paralysis can be fatal to children.

Sarcoptes scabiei mites burrow into the epidermis of their hosts to feed. Antigenic material in the mites' faeces initiates hypersensitivity reactions, leading to a severe pruritus known as scabies. *Demodex* mites invade the hair follicles of their hosts, and, although they are not pruritic, they can in rare cases cause inflammation at the follicles.

Pruritus resulting from attachment of trombiculid mites to the skin is severe and can lead to dermal vesiculation. The species that typically infest humans are *Leptotrombidium akamushi*, *L. deliniense*, *Eutrombicula alfreddugesi* and *Trombicula autumnalis*. Larval and nymphal ticks of many genera and species can attach to humans in large numbers, at least temporarily, causing pruritic inflammatory and hypersensitivity lesions in the skin.

Argas species of soft ticks and dermanyssid mites such as *Dermanyssus* species can cause biting stress among workers in poultry houses by spillover infestations from the poultry.

10.3 Interior residual application of acaricides

Human housing is a primary habitat of those species of the *Ornithodoros moubata* complex that feed on humans. All stages of the life cycle can be found in cracks and crevices in floors and lower walls, especially when these are made of mud brick or daub. The ticks crawl out of their hiding places at night to feed on sleeping humans. The same ticks feed on domestic pigs. Improved domestic hygiene and improved standards of house construction are the most effective means of reducing the risk of infection. Raising beds off the ground on metal legs or standing wooden legs in pots of oil can be effective. Use of a heavy wetting acaricidal spray, to place the acaricide on surfaces in sufficient concentration, can supplement these measures. Pyrethroid treatment of mosquito nets is being investigated in the United Republic of Tanzania for controlling tick-borne relapsing fever, in addition to spraying of the mud floors from which the ticks emerge.

The housing of domestic dogs can be sprayed with acaricide to control *Rhipicephalus sanguineus*. All stages of the life cycle occur in such housing, in cracks and crevices, often high above floor level. A heavy wetting spray should be directed at floors and walls.

Hand-operated compression sprayers are generally used for surface treatment. Suitable acaricides for indoor residual application are listed in **Table 18**.

Table 18. Suitable acaricides for indoor residual treatment.

Acaraicide	Chemical type	Concentration (g/l or g/kg)	WHO hazard classification of ai[a]
Carbaryl	Carbamate	50	II
Propoxur	Carbamate	10	II
Chlorpyriphos-methyl	Organophosphate	5	U
Diazinon	Organophosphate	5	II
Malathion	Organophosphate	20	III
Pirimiphos-methyl	Organophosphate	10	III
α-Cypermethrin	Pyrethroid	0.3–0.6	II
Bifenthrin	Pyrethroid	0.48–0.96	II
Cypermethrin	Pyrethroid	0.5-2.0	II
Deltamethrin	Pyrethroid	0.25	II
λ-Cyhalothrin	Pyrethroid	0.25	II
Permethrin	Pyrethroid	2.5	II

ai, active ingredient

[a]Class II. moderately hazardous; class III, slightly hazardous; class U, unlikely to pose an acute hazard in normal use

10.4 Exterior residual application of acaricides

Residual acaricides can be applied in cases of heavy infestation with ticks or trombiculid mites when the infestation is associated with a high risk for pathogen transmission. This method is, however, expensive and is less effective than when used in insect control, because ticks are often more inaccessible when immobile in micro-habitats in leaf litter at ground level or in cracks in the ground during egg laying or moulting. Such treatments are best used as a supplement to vegetation clearance and improved domestic hygiene.

Only the larvae of trombiculid mites, often known as chiggers, are blood feeders; nymphs and adults are free-living predators on other arthropods. Larval mites naturally feed on small mammals and have high habitat specificity, associated with the ecological requirements of their hosts. Typically, this is scrubby vegetation and secondary growth in farmed areas. Vegetation clearance has some effect in the control of trombiculids, but the foci of infestation can be difficult to localize precisely. Reducing rodent populations can be effective. Wearing appropriate clothing and use of chemical repellents are the most effective means of reducing the risk of attaching trombiculids.

Some of the acaricides listed in Table 18 can also be used for exterior residual treatment, e.g. carbaryl, propoxur, deltamethrin and λ-cyhalothrin. Liquid formulations are best applied with hand-operated compression sprayers or backpack or vehicle-mounted power sprayers. Pellet formulations should be used where ground cover is extensive, because they penetrate the vegetation and can reach the microhabitats of ticks and mites. Care must be taken to avoid contamination of watercourses and adjacent areas and to prevent hazard to non-target organisms.

10.5 Control of ticks on domestic animal hosts

Dogs can be treated to control *Rhipicephalus sanguineus* with a wide range of veterinary preparations, such as acaricide-impregnated collars, shampoos or oily pour-on or spot-on formulations, which permeate the entire hair coat after a small initial application. The acaricides commonly used for this purpose are amitraz, carbaryl, fipronil and permethrin.

The risk for *Otobius megnini* infestation of humans can be reduced by treating cattle with any of the wide range of pour-on, dip-tank or spray formulations of veterinary acaricides. On horses, the insecticides sold for control of lice have a substantial effect in controlling ticks. In both species of host, formulations such as greases or pour-ons for application to the ears are likely to be the most economical. The acaricides commonly used for this purpose are amitraz, permethrin and propoxur. Infestation of the human ear requires medical intervention to remove the ticks from the external ear canal.

Systems are available to reduce the risk for infection with *Borrelia burgdorferi*, which is transmitted by feeding *Ixodes dammini* ticks in North America. In these systems, permethrin-treated cotton wool is supplied as nesting material in mouse bait boxes placed in the habitat of the natural rodent host of immature ticks and *Borrelia*. The mice pick up the permethrin on their fur. This system has substantially reduced tick populations, but their commercial availability is limited.

10.6 Control of mites by direct treatment of humans

Mite infestation of humans at levels that cause disease are usually associated with poor living conditions or immune suppression. Mites of the family Sarcoptidae are known as 'mange mites'. The species *Sarcoptes scabiei* var. *hominis* is specific to humans and causes scabies, but varieties of the same species infest pigs, cattle, camels and many wild animal species. These animal infestations can cause temporary infestations of humans but do not give rise to established infestations. The mites burrow into the living layers of the epidermis, feeding on skin cells as they go. Antigenic proteins in their faeces initiate dermal hypersensitivity reactions, resulting in acanthosis and intense pruritus. As *Sarcoptes* infestations are highly contagious for people in close domestic contact, domestic and personal hygiene can reduce the initial risk of infestation.

Clothing can be treated by thorough washing in very hot water or with acaricide sprays such as permethrin at 1.0%. Acaricidal treatments for infested persons include lotions of benzyl benzoate at 25% and the organochlorine acaricide γ-hexachlorocyclohexane (lindane) at 0.1%. In many countries, the distribution and use of lindane are now restricted. The avermectin antiparasitic material ivermectin, as an oral formulation, has been shown in clinical studies to be effective against *Sarcoptes* infestation (scabies) of humans, but avermectins are currently registered for veterinary use only.

Demodex mites of the species *D. folliculorum* are a common commensal infestation of humans but are usually not noticed and cause no disease. They are not pruritic, even in heavy infestations. They live external to the epidermis but deep within hair follicles. In rare circumstances, however, they cause concentrated infestations in the hair follicles of the eyelids, causing blepharitis and sometimes spreading to the forehead. Antiparasitic treatments can be supplemented with topical application of permethrin in an ointment at 5%.

11. House-dust mites

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

Acari: Pyroglyphidae mites can establish viable populations in house dust. *Dermatophagoides* spp. constitute 70% of mites found in house dust worldwide, the two major species being *D. pteronyssinus* and *D. farinae*. *Euroglyphus maynei* is the third most important species globally. The distribution and abundance of house-dust mites vary according to location and season, mainly in response to ambient relative humidity. The critical relative humidity, at which water uptake through the supracoxal glands is equal to or greater than water loss, is 55–73% at 15–30°C. A relative humidity of 70–75% and a temperature of 20–25 °C are optimal for house-dust mites (with some variation between species), and under such conditions they have high population growth rate and reproductive potential. Therefore, any measure to reduce their density must be effective and be used frequently if it is to have a sustained effect on the mite population density. The time needed for development lengthens as the temperature or the relative humidity decreases. This might explain why mites are more abundant in mattresses and sofas than in carpets and floors, as mattresses and bedding remain at a temperature and humidity ideal for mites throughout the year and contain an abundant supply of their main food source: shed human skin fragments.

House-dust mites digest their diet of shed human skin with proteases. The allergenic glycoproteins of the two main house-dust mite species, *Der* p 1 and *Der* f 1, are principally found in faecal pellets. They become airborne when house dust is disturbed, at a mean diameter of about 20 μm. Each faecal particle contains around 0.2 ng allergen, which sensitizes and triggers human allergies such as asthma, atopic dermatitis and perennial rhinitis. The prevalence of atopic conditions is increasing worldwide in both developed and developing countries. A study published in 1998 showed that the prevalence of symptoms of asthma was 20–30% in Australia and New Zealand, 15–25% in Brazil, 5–20% in India, 15% in South Africa and 15–35% in the United Kingdom. The rise in prevalence is partly due to increased exposure to house-dust mite allergens.

To achieve significant control, exposure must be reduced to < 2 μg of *Der* p 1 (the sensitization threshold for mite-sensitive atopics) and preferably to < 1 μg/g or 100 mites/g of dust. Eradication is not feasible.

11.1 Control of house-dust mites

In interventions to reduce the levels of house-dust mites and allergens in homes to below the sensitization threshold, exposure must first be measured. This involves taking samples of dust, usually in a vacuum cleaner, from 1 m^2 of carpet or mattress for 2 min. The dust is sieved and weighed, and mites are extracted by flotation or filtering and counted. Exposure should be expressed as number of mites per unit area, rather than per unit weight, as repeated measurements artificially deplete the amount of dust available and might confound the estimates. Specific immunoassays, such as the enzyme-linked

immunosorbent assay, with purified allergens are used to quantify the amount of allergen in a dust sample. These are less time-consuming and laborious than mite extraction.

Control should be targeted to sites where exposure to house-dust mites and allergens is greatest. As people spend 6–8 h in close contact with their mattress, pillow and bedding, treatment of bedrooms is critical.

Once it was accepted that house-dust mites and allergens are risk factors for allergic conditions, many attempts were made, both in the laboratory and in homes, to reduce them. This can be achieved either by changes to their domestic habitats, by completely removing them, by making them less conducive to mite population growth, or with chemicals. Not all clinical trials of anti-mite measures have been successful, especially when only one method was used. A measure must be applied consistently for more than 6 months for proven efficacy. Furthermore, an integrated approach, with measures to kill mites and remove allergens, is required.

Ideally, control measures should:

- be effective in the long-term, as clinical studies have shown that 6 months of intervention are required before asthma symptoms are reduced;
- be suitable for persons with asthma, i.e. not aggravate their condition;
- be suitable for home use;
- be simple and cheap; and
- reduce exposure to allergens to < 2 μg of *Der* p 1, or 100 mites/g of dust.

11.2 Chemical control of house-dust mites

Chemicals have been used to denature house-dust mite allergens (e.g. tannic acid and benzyl tannate), to kill fungi (e.g. antifungal antibiotics) in order to reduce the food supply of the mites or to kill the mites directly (acaricides).

Tannic acid applied as a spray at 20 ml/m^2 can reduce allergen levels for 1–2 months but should be used with caution by atopic individuals as it can aggravate, rather than alleviate, symptoms. Antifungal antibiotics such as natamycin (marketed as Tymasil, sprayed at 600 mg/m^2 three times a year) do not reduce house-dust mite or allergen levels under realistic conditions. Application of fungicides can either increase or decrease house-dust mite levels.

Many acaricides that are commercially available have been found to be effective in killing house-dust mites in the laboratory, but their application in the home has had mixed success, and clinical improvement is often limited or absent. Their efficacy might be influenced by the method of application, the allergen load before the intervention and the type of treated substrate (e.g. carpets with natural or synthetic fibres or long or short pile).

The most widely used acaricide is benzyl benzoate. It is usually more effective on carpets than on mattresses, probably because mattresses contain such a large reservoir of

allergens, and reinfestation with mites from untreated bedding and carpets in a bedroom might quickly follow treatment. The organophosphate pirimiphos-methyl, applied in a carpet shampoo at a rate of 2 g/m^2 or as an aerosol to soft furnishings, can reduce mite and allergen levels for up to 2 months. As acaricides have only short-term effects, several applications are required to achieve long-term control. This raises concerns about their safety for domestic use, especially as treatment is targeted to sites of prolonged close contact, such as mattresses and bedding.

Synthetic pyrethroids, such as permethrin and D-phenothrin, have fewer side-effects in humans than benzyl benzoate and organophosphates. Permethrin was effective in laboratory tests against *D. pteronyssinus* and *D. farinae*. Pyrethroid-based aerosols, which can also contain fungicide, are available for domestic use in industrialized countries. Spraying aerosols containing acaricides directly can be effective in killing house-dust mites, but repeated applications are required, which can cause irritation in some persons with asthma who accidentally inhale the spray. Bedding impregnated with permethrin at 450 mg/m^2 is a more suitable method for domestic use. The slow release of permethrin significantly reduces house-dust mite levels in mattresses, for at least 27 months, and no side-effects were reported in non-atopic individuals. The efficacy of permethrin-impregnated bedding in reducing symptoms of asthma remains to be tested.

The chemical ecology of house-dust mites is currently receiving attention because of the potential use of semio-chemical attractants to lure house-dust mites to acaricide-treated traps. This would reduce the amount of acaricide required to achieve effective control, thereby decreasing the potential risk of side-effects.

Nevetherless, house-dust mite allergens are remarkably stable, remaining active for up to 18 months. Even the most effective acaricide kills only living mites and does not destroy the allergens that the mites produced earlier. Thus, acaricides are not clinically effective in isolation, and further measures are required to remove the existing allergen reservoir, such as intensive vacuum cleaning.

11.3 Non-chemical anti-mite measures

11.3.1 *Habitat removal*

Clinical improvement has been observed after bedroom carpets were replaced by sealed wooden floors or vinyl floor coverings. Replacing beds and bedding has only a short-term benefit, however, because new beds are quickly infested by mites migrating from other soft furnishings and carpets.

11.3.2 *Dust removal*

Live house-dust mites can resist the suction of vacuum cleaners because they can cling to fibres by suckers on their legs. Dust removal by vacuum cleaning alone is effective in reducing allergen levels but will not achieve long-term control because the remaining live mites will soon replenish the allergen reservoir. Several models of vacuum cleaner are now available that contain high-efficiency particulate air filters, which, when properly fitted, prevent the escape of particles > 1 μm. Persons with asthma should not use vacuum cleaners without such filters because they blow allergens into the air of the room during use.

11.3.3 *Freezing and heating*

Bedding should be washed at > 55 °C. Small articles of soft furnishing, e.g. children's toys, can be placed in polythene bags and kept overnight in a deep-freeze to kill house-dust mites. Application of liquid nitrogen to carpets and soft furnishings by trained personnel is effective in reducing house-dust mite densities, but repeated applications are required for long-term efficacy, and this can be expensive. Likewise, steam-cleaning of carpets has a short-term effect of killing mites and reducing allergen levels.

11.3.4 *Reducing humidity*

In temperate climates, reducing the indoor air humidity to < 7.0 g/kg or 45% relative humidity at normal indoor temperature during winter months should significantly reduce house-dust mite levels. 'Climate therapy', with central mechanical ventilation heat recovery units, relieved symptoms in asthma patients allergic to mites in Denmark but did not do so in the United Kingdom, where the climate is mild and humid and houses are less energy efficient than in Denmark. Similarly, de-humidifiers did not significantly reduce mite allergen levels in the United Kingdom.

11.3.5 *Semi-permeable casings*

Semi-permeable casings are barriers to allergens and house-dust mites which still allow air circulation and are therefore more comfortable to sleep on than plastic covers. These casings are suitable for use on beds, and long-term clinical improvement of asthma symptoms has been reported. Their continued efficacy requires washing all bedding at > 55 °C and wiping their surface regularly, as allergens will continue to accumulate on top of the casing, from the carpet, and inside the casing, from the mattress.

12. Venomous arthropods

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

There are six groups of medically important venomous arthropods: Scorpiones (scorpions), Araneae (spiders), Myriapoda (millipedes and centipedes), Coleoptera (beetles), Hymenoptera (bees, wasps, hornets, ants) and Lepidoptera (moths and their larvae). None of these transmits infectious disease. Control measures involve educating people to avoid contact, excluding arthropods from dwellings and killing or repelling them with chemicals. So far, none of these taxa, except perhaps spiders, is known to have developed resistance to insecticides.

12.1 Scorpions

Scorpions are easily recognized by their two pedipalps (pincers), which are relatively fine in the species that are dangerous to humans and large and lobster-like in some less dangerous species; they also have long tails terminating in a bulbous telson bearing the sting. Their chitinous exoskeletons fluoresce in ultra-violet light, which assists in their detection after dark. Stings are common in many tropical countries, occurring most often on the fingers or toes when the scorpion is inadvertently touched or trodden upon. The sting almost always results in intense local pain, but life-threatening systemic envenoming (poisoning) is almost entirely confined to young children in areas inhabited by dangerous genera such as North Africa and the Middle East (e.g. *Leiurus, Androctonus*), South Africa (*Parabuthus*), south India (*Mesobuthus*) and Central and South America (*Centruroides*, *Tityus*). The victim of a scorpion sting needs immediate medical attention, primarily analgesia. A local anaesthetic (e.g. 1% lignocaine) can be infiltrated into the site of the sting, or a strong pain-killing tablet can be taken by mouth. For minor stings, a piece of ice over the wound site can reduce pain. Patients with severe envenoming require antivenom and intensive care. Scorpions are active at night, hiding during the day beneath loose stones, bark, fallen trees and other debris, as well as under houses, in cracks in walls and in attics. Scorpions can effectively be excluded from houses by incorporating a row of ceramic tiles, at least 20 cm high, at the base of outside walls and steps. Inside the house, cracks should be filled in with plaster or putty. Well-fitted, insecticide-impregnated mosquito nets can protect sleepers (but see 'pyrethroid insecticides' below). Outside, clearing compounds of rubbish and keeping chickens can discourage infestation, but, if this is impracticable, chemicals can be used for residual treatment.

12.1.1 *Target area*

Inside dwellings, pesticides should be applied to the sites where scorpions are apt to enter or hide, such as baseboards (skirtings), closets, inlets for plumbing and under furniture, as well as in attics and basements. For outdoor treatment, pesticides should be applied to any portion of the structure (e.g. foundations, porches) in contact with the

soil, to a height of 0.6 m above ground level. Accumulations of stone, lumber and firewood should also be treated, but not shrubs

12.1.2 *Insecticides*

Solutions, suspensions or emulsions of azamethiphos at 10 g/l (1%), bendiocarb at 2.4–4.8 g/l (0.24–0.48%), chlorpyrifos at 2–5 g/l (0.2–0.5%), deodorized malathion at 50 g/l (5%) or propoxur at 20 g/l (2%) can be applied as indoor residual sprays. Dusts of bendiocarb at 10 g/kg (1%), carbaryl at 20–50 g/kg (2–5%), pirimiphos methyl at 20 g/kg (2%) or propoxur at 20 g/kg (2%) can also be used. The same insecticides at the same dosages are used for outdoor residual spraying, while, for dusting, carbaryl can be applied at 100 g/kg (10%). Granules of diazinon at 100 g/kg (10%) are also effective for area treatment. Pyrethroid insecticides are not usually recommended, as they can irritate scorpions, increasing the danger to residents. Hand-operated or power-operated sprayers are used for spraying, and the surfaces of infested areas should be thoroughly wetted. Hand-operated dusters are used for dusting.

12.2 Spiders

All but one family of spiders are venomous, but members of only a few genera are dangerous to humans, including the neurotoxic *Latrodectus* and *Steatoda* (the cosmopolitan black and brown widow spiders); *Phoneutria* (South American wandering, armed or banana spiders); *Atrax* and *Hadronyche* (Australian funnel web spiders) and the necrotoxic *Loxosceles* (American recluse spiders). Many peri-domestic species have been wrongly incriminated in cases of chronic necrotic ulcerating and granulomatous skin reactions. Neurotoxic envenoming, especially by Australian funnel web spiders, is often painful and can be rapidly life threatening. After a recluse spider bite, the pain can increase gradually for many hours before the characteristic 'red, white and blue' skin lesion appears and eventually evolves into a black necrotic eschar or scab. *Loxosceles* bites are often inflicted indoors, while people are dressing or if they brush against walls or curtains. Dusting spiders, their egg masses and webs with pesticides mechanically is a useful method of control. Pesticides can also be applied to spiders' resting-places, such as walls, corners, cracks, under furniture, toilets, rubbish heaps and stacks of old lumber. Suspensions or emulsions of the insecticides listed in **Table 19** can be used; dust formulations of bendiocarb or malathion at 10 g/kg (1%) are also appropriate. Hand-operated sprayers are used for spot treatment in dwellings, and treatment can remain effective for 2–3 weeks. Care should be taken in spraying overhead surfaces, as *Latrodectus* spp. irritated by the spray might drop down and bite.

12.3 Centipedes and millipedes

Centipede stings, inflicted by a pair of jaw-like modified legs, are very painful and can cause systemic symptoms. Fatalities have been alleged but have not been reliably documented. Millipedes exude noxious secretions from the bases of their legs, which can cause severe irritation, blistering and ulceration to the skin and mucous membranes. Some are large and attractively coloured and may be picked up by children, who might even try to eat them. Emulsions or solutions of 2% chlordane, 1% lindane or 2–4%

malathion are effective for spot applications, while 2–5% chlordane or malathion dust can be used as a residual agent.

Table 19. Insecticides used for control of spiders

Insecticide	Chemical type	Concentration (g/l or g/kg)	WHO hazard classification of ai[a]
Bendiocarb	Carbamate	2.5–4.8	II
Azamethiphos	Organophosphate	10	III
Chlorpyrifos	Organophosphate	2–5	II
Diazinon	Organophosphate	5	II
Malathion	Organophosphate	30	III
α-Cypermethrin	Pyrethroid	0.3–0.6	II
Bifenthrin	Pyrethroid	0.48–0.96	II
Cypermethrin	Pyrethroid	0.5–2.0	II
Deltamethrin	Pyrethroid	0.3	II
λ-Cyhalothrin	Pyrethroid	0.7	II
Permethrin	Pyrethroid	1-2	II

ai, active ingredient

[a]Class II, moderately hazardous; Class III, slightly hazardous.

12.4 Beetles

Vesicating beetles such as 'Spanish fly' (*Lytta vesicatoria*, Meloidae) and *Paederus* spp. (Staphiliidae), the cause of 'Nairobi eye', cause redness, itching and blistering of the skin and mucous membranes and, in severe cases, systemic symptoms. The efficacy of chemical repellents and insecticides has not been investigated.

12.5 Hymenoptera (bees, wasps, yellow jackets, hornets and ants)

Bees can sting only once and leave their barbed sting in the wound. Bee and wasp nests are found in the branches of trees and shrubs, in the attics of buildings, beneath eaves or underground. Ant nests are usually on or under the ground. Hymenoptera attack in large numbers in defence of their nests and also sting when trapped inside clothing. Multiple stings, as in the continuing epidemic of attacks by African 'killer bees' (*Apis mellifera scutellatus*) in the Americas, can kill by direct envenoming. Large tropical hornets, such as *Vespa mandarina*, are so aggressive in defence of their nests and territory that they can prevent agricultural activity. Commonly, people become hypersensitive to the venom of Hymenoptera from previous stings and then develop life-threatening anaphylactic shock after a single sting.

Wasps' nests are usually treated directly with insecticide, and this method can also be used against bees when necessary. Suspensions or emulsions of the insecticides listed in Table 19 can be used, as well as carbaryl at 20 g/l (2%), chlorpyrifos at 5 g/l (0.5%), deltamethrin at 0.15 g/l (0.015%) and dichlorvos at 10 g/l (1%). Dusts of bendiocarb at 10 g/kg (1%), carbaryl at 50 g/kg (5%) and pirimiphos-methyl at 20 g/kg (2%) are also suitable. Hand-operated or power-operated equipment is used for spraying and dusting nests. Wasps' nests are most safely destroyed at night, when all the wasps are inside. The spray mixture should be directed at the entrance of the nest in a continuous jet. A single treatment should be sufficient to destroy it. If nests are treated during the day, sting-proof suits, hard gloves and thick rubber boots should be worn for protection.

12.6 Lepidoptera (moths and their caterpillars)

Urticating hairs from the imago (adult) stage of some moths (e.g. South American *Hylesia* spp.) and venom from the projecting spines of some caterpillars (e.g. South American *Lonoma* spp. and European *Thaumetopoea processionea*) can cause severe and even fatal reactions in humans. The role of chemicals in controlling epidemic hatchings of these Lepidoptera has not been investigated.

13. Snails

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

Schistosomiasis (bilharziasis) is a waterborne helminth disease of both humans and animals. The schistosome worm requires an aquatic intermediate host snail to complete its complex lifecycle.

Embryonated parasite eggs are deposited in either urine or faeces of infected mammalian hosts, often in large amounts. Upon contact with freshwater, miracidia are released from these eggs. The miracidial stage actively seeks out specific snails to further its obligatory aquatic parasitic lifecycle. Asexual multiplication takes place in infected intermediate snail hosts, which—after a few weeks—liberate cercariae, another specific larval stage. This larva is able to penetrate unbroken mammalian skin. Infection usually takes place after direct contact with infested freshwater. Owing in part to poor sanitation or hygiene and the wide dispersion of suitable freshwater snail hosts, human schistosomiasis still poses a serious public health problem in many parts of the developing world. From a veterinary perspective, the associated loss of national agricultural revenue attributable to schistosomiasis in domestic livestock, especially in farmed bovids, is also substantial.

Control of schistosomiasis is of international concern, and the aim of control programmes, on their own or jointly with other measures, is to reduce morbidity within the definitive host with anthelminthic chemotherapy or to reduce general parasite transmission in the snail and associated aquatic stages by use of molluscicides and environmental modification. Today, several million United States dollars are annually set aside to increase international de-worming initiatives to improve the health of school-age children. Despite these control efforts, however, 200 million people in 74 countries are still thought to suffer from the disease.

Schistosomiasis is caused by infection with one or more species of *Schistosoma* blood fluke. The genus itself comprises some 20 species, but five main ones are associated with human infections. From a medical perspective, the three most important species are *S. japonicum* transmitted by the amphibious prosobranch snail genus *Oncomelania* in eastern Asia; *S. mansoni* transmitted by the pulmonate snail genus *Biomphalaria* in the Middle East, Africa and the Americas; and *S. haematobium* transmitted by the pulmonate snail genus *Bulinus* in the Middle East and Africa. The two former species are responsible for intestinal schistosomiasis, while the latter is alone responsible for urinary schistosomiasis. Less important, because of its limited distribution, is *S. mekongi,* which causes intestinal schistosomiasis along the Mekong River in South-East Asia and is transmitted by the prosobranch snail genus *Neotricula*; another infectious species is *S. intercalatum*, which causes rectal schistosomiasis in Central and West Africa and is transmitted by *Bulinus*. In most areas, transmission is seasonal, occurring during times when human contact with water, snail populations and larval schistosome development rates are all high. The frequency and intensity of such seasons can contribute to the severity of disease in certain communities. Moreover, the highly localized nature of transmission sites between schistosome and snail can complicate control of the

intermediate host snails. Snail control is just one intervention in integrated control, which is now dominated by control of human morbidity by chemotherapy with the orally administered anthelminthic drug praziquantel. This drug is cheap, safe and highly efficacious against all adult schistosome species.

The truly aquatic snails *Bulinus* and *Biomphalaria* are those most amenable to control with chemical molluscicides of synthetic or natural origin. Control of the more amphibious *Oncomelania* should be coupled with environmental modification, as not all snails are within reach of an aquatically administered molluscicide. Owing to the large water volume and high flow rates of rivers, chemical molluscicide is not considered feasible against the riverine *Neotricula*. These minute snails are usually found in large numbers, adhering to the underside of small rocks and stones. The much larger *Biomphalaria* and *Bulinus* inhabit stable water bodies such as lakes and ponds as well as slow-flowing streams or rivers. They can also invade less stable, isolated sites seasonally under favourable conditions by passive transfer (e.g. after flooding or by human or avian movements). Such sites should be kept under regular epidemiological surveillance. The rationale of use of molluscicides is to reduce seasonal *Schistosoma* transmission peaks by eliminating at least 95% of the local snail population, by application at the time when the highest proportion of infected snails is observed.

Chemical molluscicide is sometimes used in biological control, and the two strategies are not mutually exclusive. The many different methods of biological control are outside the scope of this chapter; the most important, however, is to introduce competing snail species that are refractory (resistant) to infection into habitats containing intermediate host snails. The introduced species either displace or curtail the intermediate snail populations, thereby removing the 'homes' of the parasite. In addition, if miracidia show no preferential penetration, the refractory species draws miracidia away from the transmission cycle, acting as a so-called 'miracidial sponge'. Chemical molluscicides can therefore be used to 'kick start' control or 'knock down' the initial numbers of susceptible snail species before introduction of the refractory species. The choice of a method of snail control must be considered carefully, as it is becoming increasingly important to promote and maintain a healthy environment. The suitability of introducing alien species and the use of molluscicides require careful planning and supervision after application.

13.1 Suitable molluscicides for snail control

The older molluscicidal compounds are no longer recommended by WHO for use in aquatic habitats in view of their toxicity to humans and other adverse environmental effects, and they have long been abandoned. The synthetic molluscicide niclosamide ($C_{13}H_8C_{l2}N_20_4$) is the only effective, commercially available product. There have been no confirmed reports of resistance in field snail populations since it was introduced in the early 1960s. Niclosamide has minimal toxicity against mammals, with a median lethal dose (LD_{50}) in rats treated orally of 5000 mg/kg body weight. The compound is also used as an anthelmintic against human tapeworms, at much lower doses.

Niclosamide is available as a wettable powder and as an emulsifiable concentrate. The wettable powder is diluted in water for field application with knapsack sprayers or

dispensers at not less than 1:20 (w/v), and the emulsifiable concentrate at 1:15 (v/v). In practical use, concentrations of 1 mg/l ai in water for 8 h or 0.33 mg/l ai for 24 h both result in the recommended dose of 8 mg/l for aquatic snail control. Lower concentrations can be applied to stagnant water, where the active ingredient decays slowly over several days. It is essential that the specified concentrations be maintained in treated water for the full time in order to achieve the required dose. Home-made granules of wettable powder, sand and gum, and gelatin capsules of wettable powder have been used successfully in certain situations to act as a controlled-release, continuous delivery system. In addition, there have been attempts to impregnate niclosamide into snail baits to further target molluscicide delivery. When used focally or seasonally, in judicious combination with other control measures, niclosamide can be cost-effective, with no serious adverse effects on the environment.

13.2 Where to apply molluscicides

The distribution of snails in their aquatic habitat is often highly aggregated, reflecting the presence of food (e.g. water plants, algae, decaying vegetation) and physical features of the microhabitat (e.g. water flow, substrate, shade, temperature), which attract or repel them. For cost-effective molluscicide, surveys should be undertaken to identify potential transmission sites favoured by snails both geographically and seasonally. Infected snails can be identified easily, as schistosome cercariae can be seen with a hand lens or dissecting microscope when snails caught in the field are exposed to light for 2–3 h.

Selective molluscicide applications are usually restricted to sites where there is intensive human–water contact (e.g. activities such as rice farming, fishing, swimming, bathing and laundering) and adjoining snail habitats. The water contact sites are usually well known to local people and are easily verified by evidence of frequent access and use. Basic maps should be prepared, perhaps with use of global positioning system devices, showing the location of transmission sites and, if possible, the local human population. These maps should be updated regularly to form a database of 'hot spots' of likely transmission. Molluscicides usually need not be applied at sites where there is little human–water contact, at sites in poorly populated areas or at drinking-water sources, which are often separate and play little part in transmission. Likewise, large rivers and lakes are not in themselves important to transmission but may contain transmission sites along their banks (e.g. fish landing sites). Snails are often associated with specific vegetation such as water lilies and floating algae, especially if it is not too dense, and special attention should be given to such microhabitats. The situation may alter after the construction of dams across rivers, with ecological changes that favour transmission.

In irrigation schemes, transmission is usually most intense at sites near human dwellings, where water contact and contamination with urine and faeces are frequent. Transmission sites and seasons are likely to vary from one scheme to another, but they can usually be identified by experienced personnel in carefully conducted surveys. Snail populations should be surveyed to detect any significant expansion of the distribution of intermediate host species. For example, in Niger, *Biomphalaria* appears to be spreading slowly upstream along the Niger River, colonizing new areas and creating conditions under which disease transmission could begin.

13.3 When to apply molluscicides

The timing of molluscicide should be linked to and combined with the delivery of population-based chemotherapy, if possible, especially during periods of intense transmission, to lengthen the effects of chemotherapy by reducing the potential for subsequent re-infection at that site. The aim of molluscicide should be to reduce the intensity of transmission to an insignificant level. Three molluscicide applications or more might be necessary during each transmission season, for instance, towards the end of the rainy season when flooding has ceased, about 6 weeks later during the early dry season, and again if water persists into the dry season. Molluscicide is most efficient in small, still water bodies such as ponds, borrow pits and small dams when they are relatively full; it may be inappropriate when they have nearly dried out. More frequent applications might be needed where transmission is continuous and, especially in flowing sites, if rapid re-invasion from upstream snail colonies is anticipated.

13.4 How to apply molluscicides

A simple calculation of the volume and, where appropriate, the flow is needed to calculate the correct dosage for treatment. Precision is not essential except to avoid waste of the expensive chemical when treating large habitats. Watering cans, hand-operated compression sprayers and motorized sprayers can be used to apply molluscicide to moist soil or still water. Focal applications must extend to a radius of at least 15 m around a transmission site and any adjoining snail reservoirs. Preliminary removal of aquatic vegetation can improve penetration of the molluscicide.

Flowing water is treated by drip-feeding molluscicide for a predetermined time, 8 or 24 h, from automated dispensers made from plastic or metal containers that empty their contents at a fixed time, such as every 30 or 60 min. The dispensers should have some means of agitation to prevent settling of wettable powder formulations and, if possible, a constant head device. They should be placed upstream above a stretch of turbulence to ensure even delivery of the molluscicide to the transmission sites. Clearing of vegetation will improve penetration of the molluscicide, but supplementary hand-spraying of stagnant backwaters might be needed.

13.5 Evaluation of molluscicide operations

Although the manufacturers provide a chemical analysis kit to test the concentration in treated sites in the field, it is difficult to use in turbid water. The simplest way of assessing the effectiveness of molluscicide is to compare counts of standardized field snail collections immediately before and 1 week after molluscicide. A more precise evaluation can be made by using sentinel snails: 10–20 locally caught snails are placed in small nylon mesh cages at several places around the site before treatment; 24 h after the completion of molluscicide application, the cages are recovered and the numbers of dead snails in each cage are counted. All the snails in test cages within the zone of application should be dead, whereas high survival rates should be found in control cages placed in nearby untreated ponds or, in flowing sites, upstream of the dispensers.

13.6 Precautions

Use of protective clothing (masks for wettable powder, gloves for emulsifiable concentrate) is recommended during the preparation and mixing of solutions for field use. Niclosamide at molluscicidal concentrations (1 mg/l) is not toxic to humans, domestic animals or crops. Such concentrations do, however, kill crustaceans, amphibians and fish by suffocation. As niclosamide is biodegradable, however, these mobile species repopulate treated sites within a few weeks of focal application. The crustaceans and fish killed during mollusciciding can be safely eaten, if collected immediately. Care must be taken to inform the community of planned molluscicidal activities so that their daily activities, such as those of fisherman, are minimally disturbed.

14. Rodents

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

The 35 families of rodents comprise 389 genera with about 1700 species. They make up about 40% of the known mammal species in the world. Some rodent species are carriers of a variety of infectious organisms, which can be transmitted to humans and domestic animals. The causative agents of these rodent-borne zoonotic diseases include viruses, rickettsiae, bacteria, protozoa and helminths.

14.1 Rodent-borne diseases

14.1.1 *Viral diseases*

Only the more important viral diseases carried by rodents are discussed here. Tick-borne encephalitis is endemic, from France to the east of the former USSR, the field mouse *Apodemus flavicollis* and the bank vole *Clethrionomys glareolus* being the most important reservoirs. Venezuelan equine encephalitis involves mosquito vectors and rodent reservoirs such as the cotton rat Sigmodon hispidus, the cotton mouse *Peromyscus gossypinus*, the rice rat *Oryzomys palustris* and the ship or roof rat *Rattus rattus*.

The causative viruses of the rodent-borne haemorrhagic fevers (Argentine, Bolivian, Venezuelan, Lassa and haemorrhagic fever with renal syndrome) are transmitted to humans by direct contact with the faeces, urine and nasal or oral secretions of a wide range of infected rodents, depending on the virus and locality.

Hantaviruses are carried by numerous rodent species throughout the world. In 1993, a previously unknown group of hantaviruses emerged in the United States as the cause of an acute respiratory disease now known as hantavirus pulmonary syndrome. This is a deadly disease transmitted by infected rodents through urine, droppings or saliva. Humans can contract the disease when they breathe in aerosolized virus.

14.1.2 *Rickettsial diseases*

The most important of the rickettsial disease is murine typhus, which is flea-borne, with worldwide distribution. *R. norvegicus* and *R. rattus* are the main rodent reservoirs. Rocky Mountain spotted fever is transmitted by ticks, the rodent reservoirs belonging to the genera *Microtus*, *Peromyscus*, *Sigmodon* and *Spermophilus*. Scrub typhus (tsutsugamushi disease) is transmitted by mites of the genus *Leptotrombidium* (see chapter 10). It is widespread in the western Pacific and in South-East Asia, and its principal rodent hosts are species of the genus *Rattus*.

14.1.3 *Bacterial diseases*

Lyme disease is caused by the spirochaete bacterium *Borrelia burgdorferi* and occurs in Australia, Europe and North America. It is transmitted by ticks of the genus *Ixodes* (see chapter 10). The most important rodent reservoir in the United States is the white-footed mouse *Peromyscus leucopus*, although a wide range of other mammals and birds can act as reservoirs in other localities.

The causative agents of leptospirosis, spirochaete bacteria of the genus *Leptospira*, are transmitted to humans either in water contaminated with the urine of infected animals or by direct exposure to infected urine. Rats, particularly *R. norvegicus*, are the commonest reservoirs. Plague is caused by *Yersinia pestis*, and the most frequent source of the disease in humans has been the bite of infected fleas (especially the Oriental rat flea, *Xenopsylla cheopis*, see chapter 5). The disease occurs in Africa, Asia and the Americas, and the reservoir hosts include many species of rodents. *R. norvegicus* and *R. rattus* are the commonest urban rodent hosts. The causative agents of tick-borne relapsing fevers are transmitted to humans by Argasid ticks from a variety of rodent hosts. Rats are also an important reservoir of *Salmonella typhimurium*.

14.1.4 *Protozoal diseases*

Chagas disease is caused by *Trypanosoma cruzi* and transmitted to humans by triatomine bugs (see chapter 7) from many vertebrate hosts. The rodent reservoirs include *R. rattus* and the guinea-pig *Cavia porcellus*. Leishmaniasis is transmitted by phlebotomine sandflies (see chapter 4) from hosts such as the gerbil *Psammomys obesus*, *Arvicanthis niloticus*, and species of *Meriones*, *Oryzomys*, *Proechimys*, *Akodon* and *Rattus*, as well as dogs. Toxoplasmosis is caused by the intracellular protozoan *Toxoplasma gondii*. Transmission occurs through consumption of food or water contaminated with the faeces of infected animals. The domestic cat is the definitive host, but rodents such as *R. rattus*, *R. norvegicus*, *Mus musculus* and *Peromyscus maniculatus* constitute sources of infection for cats.

14.1.5 *Helminthic diseases*

Rats, such as *R. rattus* and *R. exulans*, serve as reservoir hosts for schistosomiasis caused by *Schistosoma japonicum*. Rodents are also reservoir hosts for nematodes such as *Angiostrongylus cantonensis*, *Trichinella spiralis* and *Capillaria hepatica* and the tapeworms *Hymenolepis diminuta*, *H. nana* and *Echinococcus granulosus*.

14.2 Rodent control

Rodents can be controlled by chemical and non-chemical methods. Non-chemical methods, such as environmental sanitation, rodent exclusion, rodent proofing, electrical barriers, trapping and use of biocontrol agents, are becoming more widespread and are recommended when applicable. Nevertheless, chemical methods (rodenticides) are the mainstay of most rodent control programmes.

14.2.1 *Repellents, chemosterilants and fumigants*

Although some repellents are effective in keeping rodents away from specific areas, they are toxic. They include thiramcycloheximide, tributyltin salts and R-55. Chemosterilants and chemical inhibitors of reproduction are used to target male and female rodents. α-Chlorohydrin is the only male antifertility compound currently marketed; however, for polygynous species, a high proportion of males must be treated to have any effect on population density. Early work with the synthetic estrogen BDH 10131 appeared promising, as a single dose made female rats infertile for 1 year, but its unpalatability halted its development.

Fumigants can be effective in eliminating rodent infestations in small, restricted areas. Application is, however, hazardous; personnel must be properly trained, and applications should not be made near human habitations or buildings where animals are kept. The most commonly used fumigants are calcium cyanide (to produce hydrogen cyanide), methyl bromide, chloropicrin and aluminium phosphide (to produce phosphine). Carbon dioxide, carbon monoxide and carbon disulfide are also sometimes used.

14.2.2 *Rodenticides*

Rodenticides are usually administered as poisoned food baits, liquids or dusts. Acute rodenticides are fast-acting, often a single dose sufficing, while anticoagulant rodenticides are slow-acting and cause death due to chronic internal bleeding. Generally, anticoagulant rodenticides are preferred because they are more effective and safe. A list of rodenticides is given in **Table 20**.

Acute rodenticides

These compounds are administered at high concentrations in baits but are relatively cheap to produce. They are also highly toxic to non-target animals, including humans, and few have a specific antidote. In addition, they cause poison or bait shyness, which disinclines rats from returning to consume more bait after an initial exposure. The advantage of acute rodenticides is their rapid effect with a minimal amount of bait. This is an asset when rodent infestation is intense.

Anticoagulant rodenticides

Anticoagulants act by interrupting the vitamin K cycle in liver microsomes, causing fatal internal haemorrhage. In terms of human safety, their slow action allows time for administration of a specific antidote, vitamin K_1, in cases of accidental poisoning. These compounds are classified into first- and second-generation anticoagulants. All are either hydroxycoumarins or indane-dione compounds. First-generation anticoagulants are generally effective against many rodent species, but two important commensal rodents, *Mus musculus* and *R. rattus*, have a degree of natural tolerance to these substances. The second-generation anticoagulants were thus developed to combat species that are physiologically resistant to first-generation compounds. Warfarin was once the most widely used rodenticide, but resistance to this and many other first-generation anticoagulants was established in *R. norvegicus*, *M. musculus* and, to a lesser extent, *R. rattus* in parts of Europe, North America and South-East Asia. Some rodents in North Africa and the Middle East also show natural tolerance to warfarin. Calciferol, an acute rodenticide, is suitable for use against anticoagulant-resistant rodents, although it is toxic to non-target mammals, including humans.

Table 20. Some fast-acting and anticoagulant rodenticides commonly used for control of rodents. Not all the compounds are registered for use in all countries.

Rodenticide	Formulation	Effect	Concentration (%)	WHO hazard classification of ai[a]
Brodifacoum	Bait, wax block	Anticoagulant[b]	0.005	Ia
Bromadiolone	Bait, oil-based, wax block, powder concentrate Tracking powder	Anticoagulant[b]	0.005 0.1–2.0	Ia
Bromethalin	Bait	Acute	0.005–0.01	Ia
Calciferol	Bait	Sub-acute	0.075–0.10	NA
Chlorophacinone	Bait Oil-based concentrate Tracking powder	Anticoagulant	0.005–0.05 0.25 0.20	Ia
Coumatetralyl	Wax block, bait Tracking powder	Anticoagulant	0.0375 0.75	Ib
Difenacoum	Wax block, bait	Anticoagulant[b]	0.005	Ia
Difethialone	Wax block, bait	Anticoagulant[b]	0.0025	Ia
Diphacinone	Powder concentrate Water-soluble concentrate Bait	Anticoagulant	0.1–0.5 0.1–2.0 0.005–0.05	Ia
Flocoumafen	Wax briquette	Anticoagulant[b]	0.005	Ia
Warfarin	Concentrate Tracking powder, bait	Anticoagulant	0.5–1.0 0.025–0.05	Ib
Zinc phosphide	Bait	Acute	1–5	Ib

ai, active ingredient

[a] Ia, extremely hazardous; Ib, highly hazardous; NA, not available.

[b] Second-generation anticoagulant.

14.2.3 *Application of rodenticides*

Most rodenticides are applied as food baits, although some are applied as liquid baits or as contact poisons (dusts). A good-quality cereal is normally used as the base material in food baits, with a coloured dye to alert against accidental human consumption or feeding to livestock or non-target animals. Human taste deterrents (e.g. denatonium benzoate) are also used to reduce accidental human consumption. Various attractants, additives and preservatives can be added to facilitate preparation or to improve the efficacy of baits. If perishable baits are used, they should be applied in the early evening to ensure their freshness overnight. Baits should be laid in suitable containers, such as tamper-resistant bait stations, which allow access to rodents but reduce scattering and prevent the access of non-target animals that are larger than rodents. Efforts should be made to remove all alternative foods for rodents during baiting programmes in order to facilitate good bait acceptance. For application in damp environments, such as in sewers, baits mixed with wax that remain effective for longer and will not mildew are recommended.

For effective control with acute rodenticides, unpoisoned bait is laid down for several days, until the rodents are used to the new source of food and are feeding freely. The poison is then added. One or two nights of exposure to the poison bait is adequate to kill

many of them. The main advantage of acute rodenticides, i.e. rapid control, is lost, however, if several days of preliminary baiting are required. Therefore, when immediate control is essential, preliminary baiting with unpoisoned bait can be omitted, and, although incomplete control may result, anticoagulants can be used to eliminate the remaining rodents, provided a different bait base is used.

Baits containing anticoagulants or any other rodenticide should be placed under cover and protected from the weather and non-target animals. Surplus bait should be provided throughout the poisoning cycle, and excess bait removed subsequently. All dead rodents should be recovered and disposed of appropriately.

In arid areas and in habitats where water is scarce, water baits are efficient for control. Water-soluble salts of anticoagulants are most commonly used for this purpose. Poisoned water baits should be placed at ground level only and should be inspected regularly. Extra care should be taken to hinder the access of non-target species and spillage.

When acceptance of bait or other problems arise, use of poison dusts might be successful. Such application is usually wasteful, as rodents consume only a small amount of the poison on their fur and feet while grooming. Great care must be taken in using dusts, as they can be carried or blown into areas where they pose a danger to non-target species. This is particularly important, as poison dusts carry a much higher concentration of active ingredient (usually 20 times) than baits with the same substance.

14.2.4 *Rodent control strategy*

The control strategy can be broadly based on an initial survey, followed by application of control methods and maintenance of control and hygiene practices. The survey defines the severity and scope of the infestation. The commonest reason for control failure is an underestimate of the extent of infestation. The surveyor can identify the species present and estimate population density from signs and traces, such as droppings, runs and holes. The survey should include examinations of roof spaces, walls, floors, basements, drains, sewers and outdoor shelters.

If chemical control is indicated, a choice must be made between an acute rodenticide and an anticoagulant. Anticoagulants are generally more effective, except when rapid control of a large population requires the use of fast-acting compounds. Sub-lethal doses of anticoagulants will not result in bait shyness, which can occur with sub-lethal doses of acute compounds. Baits should be placed in the areas of rodent activity identified in the survey. Open bait trays may be more attractive to rodents, but, for safety reasons, access to bait should be restricted to prevent accidental poisoning of non-target mammals. Bait consumption rates might increase if unpoisoned water is placed next to the bait.

Control efforts must be maintained until the desired level of control is attained. If local eradication is the aim, the treated areas should be visited weekly to monitor rodent activity and replace bait. As a general rule, if no bait has been taken for 2 weeks and there are no fresh signs of rodent infestation, the infestation has been cleared. After control, environmental hygiene should be practised to reduce sources of food and shelter and hence the likelihood of reinfestation.

14.2.5 *Precautions*

The recommendations on the labels of rodenticides and the guidelines provided in sections 2.2.4, 2.3.1 and 2.3.2 should be followed carefully, gloves should be worn and hands should be thoroughly washed afterwards. Bait trays or baiting stations should be used to protect baits from the weather, to limit the access of non-target animals and to allow baits to be removed and disposed of safely at the end of treatment. Persons responsible for laying rodenticides should be trained and should provide information to the local population on the identity of the compound used and where information can be obtained on treatment in the case of accidents. The carcasses of poisoned rodents should be collected frequently and safely disposed of by burning or burying to limit secondary poisoning of predators scavenging on dead rodents. As rodenticides are often applied in the domestic environment, accidental poisoning of humans and non-target animals may occur. Rodent control programmes should ensure the ready availability to physicians and veterinarians of specific antidotes to the compounds being used. One advantage of using anticoagulants is that the symptoms of accidental poisoning can be recognized in time and the antidote (vitamin K_1) administered.

Fumigants should be handled only by professionals.

15. Personal and household protection

This chapter should be considered in conjunction with chapter 1, in which general information on selection of appropriate vector control strategies and use of pesticides and application equipment is provided; and with chapter 2, on safe use of pesticides.

15.1 Repellents

Repellents are products that are applied to the skin or clothing to prevent or deter arthropods from attacking humans and other animals. They are used in particular against outdoor biting insects and in situations where individual protection is a priority but treated mosquito nets, vaporizing mats and other chemical control methods are not appropriate. There is some evidence that use of a repellent reduces the risk for malaria infection.

15.1.1 Compounds used as repellents

Synthetic repellents are a common means of personal protection against biting arthropods. *N,N*-Diethyl-3-methylbenzamide (deet; formerly *N,N*-diethyl-*meta*-toluamide) is the most commonly used commercially available repellent, and, because of its efficacy and low toxicity (proven over many decades of widespread consumer use), is usually the standard ingredient against which the performance of other compounds is evaluated. IR3535 [3-(*N*-acetyl-*N*-butyl) aminopropionic acid ethyl ester] and icaridin [1-piperidinecarboxylic acid 2-(2-hydroxyethyl)-1-methylpropylester] are the other two active ingredients of widely available commercial products and have been tested and evaluated within the WHOPES for personal protection[28].

Impregnation of garments with deet or a comparable repellent can prolong their action but must be repeated more frequently than with pyrethroids such as permethrin to achieve comparable levels of protection. Permethrin has low dermal absorption, low mammalian toxicity, no odour and does not irritate the skin.

15.1.2 Application methods

Repellents are available as liquids, lotions, solid waxes (stick-type formulations), creams, foams, soaps and impregnated wipe-on towelettes and can be dispensed from tubes, squeeze bottles, pressurized cans, roll-ons and hand pump containers. The repellent can be applied directly to exposed skin from the container or first applied to the hands and then rubbed over the skin. Care must be taken to avoid contact with mucous membranes; insect repellents should not be sprayed on the face or applied to the eyelids or lips. The palms of the hands should be washed after applying the repellent. Repellents should not

[28] Report of the 4th WHOPES Working Group Meeting—IR3535, KBR3023, (RS)-methoprene 20%EC, pyriproxyfen 0.5%GR and lambda-cyhalothrin 2.5%CS. 4–5 December 2000, Geneva, World Health Organization, 2001 (unpublished document WHO/CDS/WHOPES/2001.2; available on request from Department of Control of Neglected Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland, and at: http://whqlibdoc.who.int/hq/2001/WHO_CDS_WHOPES_2001.2.pdf).

be applied to sensitive, sunburned or damaged skin or deep skin folds. Repeated applications may be required every 3–4 h, especially in hot, humid climates. Repellents should be used in strict accordance with the manufacturers' instructions, and the dosage must not be exceeded, especially for young children.

Clothing can be impregnated with a repellent by spray-on application or by dipping clothes in a solution at a concentration of 0.65–1 g ai/m^2 for permethrin and 20 g/m^2 or a total of 70 g ai for other repellents, for a jacket or shirt, trousers and socks.

15.1.3 Treatment sites

When applying repellent, the attacking habits of the various arthropod groups should be considered. For *Culex* and *Anopheles* mosquitoes, repellent should be concentrated around the feet and ankles, and socks should be treated, as mosquitoes often bite through these. For general protection against mosquitoes, blackflies and other Diptera, all exposed parts of the body, such as the legs, arms, face (except near the eyes), ears and neck, should be treated. Although blackflies do not bite through clothing, they tend to find their way inside collars, sleeves and trouser legs, rendering treatment of those areas necessary.

To repel chigger (Trombiculid) mites, all openings of clothing should be treated by hand or with a spray. Particular attention should be given to the cuffs, front opening, inside the neck band and along the belt line of shirts, the flies and cuffs of trousers, and socks above shoes. Usually, a 1.5-cm band of repellent will suffice. As a further preventive measure, it is wise to tuck trouser cuffs into the tops of socks, when possible. When vegetation is not infested with chiggers above knee level, adequate protection can be obtained by treating socks and trouser cuffs. In conditions of frequent exposure to chiggers, impregnated clothing provides the best protection. To repel fleas, the shoes, socks and lower trouser legs should be sprayed with repellent or the clothing properly impregnated. Benzyl benzoate and permethrin are highly effective against flea bites when used to impregnate clothes.

Tick repellents are usually applied to clothing, using strongly repellent pyrethroid, permethrin, or other insect repellents. Trousers should be tucked into socks.

15.2 Mosquito nets and curtains

Mosquito nets provide a degree of personal protection against night-biting mosquitoes and other night-biting insects, provided that the nets are intact and the mesh is fine enough. Even if nets are torn, they provide protection if treated with a pyrethroid insecticide. If used by a large proportion of a community, treated nets suppress the vector population and hence disease transmission. For further details of insecticide-treated nets, see section 3.1.2. Nets are portable and are recommended for use by travellers in areas endemic for disease borne by night-biting insects. Many travellers might prefer using pretreated nets to avoid having to treat them.

Pyrethroid-treated curtains help to exclude mosquitoes from houses. Studies in Burkina Faso showed that treated eave and door curtains significantly reduced child mortality due to malaria. Treated curtains can also reduce dengue transmitted by day-biting *Aedes* mosquitoes.

15.3 Household insecticide products

Household insecticide products are a common and popular mode of personal protection against insect pests in all parts of the world. These products include aerosols, mosquito coils, vaporizing mats, liquid vaporizers and baits.

15.3.1 Types of household insecticide product

A wide range of products are available to combat household insect pests. In temperate climates, the most important household pests are cockroaches, ants, fleas and, in the summer months, flies, mosquitoes and wasps. In tropical climates, mosquitoes are the most important household insect pests, in addition to houseflies, cockroaches, ants, sandflies, bedbugs and (in parts of Latin America) triatomine bugs. The active ingredients used in household insecticide products should be cost-effective and have low mammalian toxicity. The commonest insecticidal products available are discussed below, and the active ingredients are listed in **Table 21**.

Table 21. Active ingredients and concentrations commonly used in household insecticide products

Product	Active ingredient	Concentration (%)	WHO hazard classification of ai[a]
Aerosol			
	D-Allethrin	0.1–0.5	NA
	D-trans-allethrin	0.1–0.5	NA
	S-Bioallethrin	0.04–0.7	NA
	Bendiocarb	0.1–0.5	II
	Bioresmethrin	0.04–0.2	U
	Chlorpyrifos	0.1–1.0	II
	Cyfluthrin	0.01–0.1	II
	Cypermethrin	0.1–0.35	II
	Cyphenothrin	0.1–0.5	II
	D,D-trans-Cyphenothrin	0.05–0.25	NA
	Deltamethrin	0.005–0.025	II
	Dimefluthrin	0.002–0.05	NA
	Dinotefuran	0.5–2	NA
	Etofenprox	0.5–1.0	U
	Fenvalerate	0.05–0.3	II
	Imiprothrin	0.04–0.3	NA
	Metofluthrin	0.002–0.05	NA
	Metoxadiazone	1–5	NA
	Permethrin	0.05–1	II
	D-Phenothrin	0.05–1.0	U
	Pirimiphos methyl	0.5–2	III
	Prallethrin	0.05–0.4	II
	Propoxur	0.5–2	II

	Pyrethrins	0.1–1.0	II
	Tetramethrin	0.03–0.6	U
	D-Tetramethrin	0.05–0.3	NA
Mosquito coil			
	D-Allethrin	0.1–0.3	NA
	D-trans-Allethrin	0.05–0.3	NA
	Dimefluthrin	0.004–0.03	NA
	Metofluthrin	0.004–0.03	NA
	Prallethrin	0.03–0.08	II
	trans-Fluthrin	0.02–0.05	U
Vaporizing mat			
	D-Allethrin	25–60 mg/mat	NA
	D-trans-Allethrin	15–30 mg/mat	NA
	S-Bioallethrin	15–25 mg/mat	NA
	Dimefluthrin	1–300 mg/mat	NA
	Metofluthrin	1–300 mg/mat	NA
	Prallethrin	6–15 mg/mat	II
	trans-Fluthrin	6–15 mg/mat	U
Liquid vaporizer			
	D-Allethrin	3–6	NA
	D-trans-Allethrin	1.5–6	NA
	S-Bioallethrin	1.2–2.4	NA
	Dimefluthrin	0.01–1.5	NA
	Metofluthrin	0.01–1.5	NA
	Prallethrin	0.6–1.5	II
	trans-Fluthrin	0.8–1.5	U
Dust			
	Bendiocarb	0.5	II
	Deltamethrin	0.05	II
	Permethrin	0.5	II
	D-Phenothrin	0.4–1.0	U
	Propoxur	0.5–1.0	II
Bait			
	Abamectin	0.05–0.1	-
	Boric acid	1.0–52	-
	Chlorpyrifos	0.1–2	II
	Dinotefuran	0.2–1	NA
	Fenitrothion	1–5	II
	Fipronil	0.01–0.05	II
	Hydramethylnon	1– 2.15	III
	Imidaclorpid	1.85–2.15	II
	Pirimiphos methyl	0.5–2	III
	Propoxur	0.25–2	II
	Sulfluramid	0.5–2	III

ai, active ingredient

[a] Ia, extremely hazardous; Ib, highly hazardous; NA, not available.

[b] Second-generation anticoagulant.

Aerosols

Aerosol sprays are the most widely used household insecticide product. They can be categorized as flying-insect killers, for use against mosquitoes, flies and wasps, and crawling-insect killers, for use against cockroaches, ants, fleas, bedbugs and triatomine bugs. Flying-insect killers can be either oil-based or water-based, the latter generally being more popular with consumers because their odour is less noticeable. The main differences between flying- and crawling-insect killers are the nature and concentration of the active ingredients and the characteristics (e.g. droplet size) of the spray; flying-insect killers are designed to be sprayed into the air, while crawling-insect killers are designed to be sprayed onto surfaces. The active ingredients of flying-insect killers are predominantly pyrethroid knock-down agents, while those in crawling-insect killers are usually residual pyrethroids. Sometimes flying- and crawling-insect killers contain the same active ingredients, but the concentrations tend to be higher in the latter in order to leave a residual deposit on surfaces.

Trigger sprayers, which are similar to crawling-insect killer aerosols but without the need for propellants, are also widely used.

Mosquito coils

Mosquito coils are most commonly used in Africa, Asia and the Western Pacific region. They are made from a mixture of active and inert ingredients, such as sawdust or coconut husks and pigment. The active ingredients are usually pyrethroids with quick knock-down action, which are carried in the smoke produced when the coil is burned. Coils deter mosquitoes and other flying insects from entering houses, and the mosquito biting rate can be reduced by up to 80% in the presence of a burning coil, depending on the size of the room in which it is used and the active ingredient in the coil. As coils are less effective in a draught, their use outdoors (e.g. by night-watchmen) is unlikely to give much protection.

Electric vaporizing mats

These products, which comprise a mat heater and vaporizing mat, have become increasingly popular since the early 1980s. The mat is made from fibreboard impregnated with insecticide, stabilizers, release-control agents, perfumes and colouring agents. The mat is plugged into an ordinary household electric socket and heats to an optimum temperature of 110–160 °C, depending on the type of heater and its mats. When the mat is heated, insecticide vapour is released to provide a low aerial concentration. This induces behavioural changes in flying insects (particularly mosquitoes) through a sequence of sub-lethal effects, including deterring them from entering a room, inhibiting biting and knock-down. Continued exposure kills the insects. The size of the mat is compatible with the brand of heater for easy insertion and removal. The advantage of mats over coils is that the former release no unpleasant smoke. The disadvantages are that electricity is required and replacement mats are generally more expensive than coils.

Electric liquid vaporizers

The principle of this product is similar to that of the electric vaporizing mat. It consists of an electric heater and a bottle of liquid insecticide. The liquid, typically a hydrocarbon solvent mixture with a dissolved pyrethroid insecticide, is drawn up through a wick made of a variety of materials (e.g. carbon, ceramic or fibre). The end of the wick is positioned within the heating element so that the insecticide vaporizes from the wick when the heater is activated. Vaporizing mats must be replaced each day, whereas the liquid in a liquid vaporizer needs to be replaced only every 1 or 2 months.

Passive vaporizers

Passive vaporizers consist of a reservoir of a volatile insecticide, which evaporates at ambient temperature. The advantage is that no power source or heat is required.

Dusts (insecticide powders)

Insecticidal dusts are typically mixtures of a low concentration of active ingredient and an inert carrier such as talc. Dusts are usually intended for control of crawling insects such as cockroaches and ants. These products are usually supplied in a puffer or shaker pack with a perforated cap, so that the dust can be applied directly to areas in which pests have been seen. Application of the dusts tends to leave an unsightly deposit on surfaces; however, the nature of the formulation and the delivery system make these products relatively inexpensive.

Baits

Baits can be formulated to control ants, cockroaches and houseflies. They can be in the form of loose granules, a purpose-built station or a gel. The baits consist of a food attractant (e.g. glucose) and an insecticide. For cockroach and ant baits, the active ingredients include abamectin, boric acid, chlorpyrifos, fenitrothion, fipronil, hydramethylnon, imidacloprid, propoxur and sulfluramid (see section 4.1.4 for fly baits).

15.3.2 Household insecticide products and public health

Household insecticide products are a popular and cost-effective mode of personal protection against insect pests. Use of household insecticide products also constitutes a form of active community participation in domestic insect pest control. As the main targets for household insecticides are often mosquitoes and other disease vectors, emphasis should be placed on promoting use of these products as an integral part of vector-borne disease control programmes. Given the unsupervised way in which these products are used, however, it is important that they be subject to approval and that the products carry appropriate information on safe use and disposal.

Annex: Pesticide application rates and conversion factors

The information given in this section is meant to enable operators to prepare formulations properly and to convert the percentage concentrations of spray or quantities to be applied for a given area into metric, imperial (United Kingdom) or United States equivalents. For practical purposes, the conversion rates are rounded off.

A.1 Preparation of spray suspension from wettable powders

Amount of wettable powder required for preparation of approximately 380 l (83 imperial gal; 100 US gal) of various concentrations (%) of spray suspension

Concentration of active ingredient (%)	Amount of wettable powder required (kg (lb))				
	5%	2.5%	1%	0.5%	0.25%
90	21.0 (46.3)	10.5 (23.1)	4.2 (9.3)	2.1 (4.6)	1.0 (2.3)
75	25.2 (55.6)	12.6 (27.8)	5.0 (11.1)	2.5 (5.6)	1.3 (2.8)
50	37.8 (83.3)	18.9 (41.7)	7.6 (16.7)	3.8 (8.3)	1.9 (4.2)
25	75.6 (166.7)	37.8 (88.3)	15.1 (33.3)	7.6 (16.7)	3.8 (8.3)

The general formula is:

$$X = \frac{A \times B \times D}{C}$$

where X = amount of water-dispersible powder required
A = percentage concentration desired
B = quantity of spray desired
C = percentage concentration of water-dispersible powder
D = 1 when X and B are expressed in kilograms and litres, respectively
8.33 when X and B are expressed in pounds and US gallons, respectively
10 when X and B are expressed in pounds and imperial gallons, respectively.

Example: 380 l (100 US gal) of 1% spray suspension are to be prepared from 50% powder:

$$X = \frac{1 \times 380 \times 1}{50} = 7.6 \text{ kg} \quad \text{or} \quad X = \frac{1 \times 100 \times 8.3}{50} = 16.7 \text{ lb}$$

7.6 kg (16.7 lb) of water-dispersible powder are required.

A.2 Formulation of emulsifiable concentrates and sprays

Preparation of emulsifiable concentrates from technical-grade material

Concentration desired (%)	Weight of technical material required to make given volumes of concentrate[a]		
	100 l	100 imperial gal	100 US gal
35	35 kg	350 lb	292 lb
25	25 kg	250 lb	208 lb
15	15 kg	150 lb	125 lb
12.5	12.5 kg	125 lb	104 lb
6.25	6.25 kg	62.5 lb	52 lb

[a] To every 100 parts of concentrate, 2 parts of emulsifier should be added.

The general formula is:

$$X = \frac{A \times B \times C}{100}$$

where: X = amount of technical material-grade required
A = percentage concentration desired
B = quantity of emulsion concentrate desired
C = 1 when X and B are expressed in kilograms and litres, respectively
8.33 when X and B are expressed in pounds and US gallons, respectively
10 when X and B are expressed in pounds and imperial gallons, respectively.

Example: 190 l (41.5 imperial gal; 50 US gal) of 25% concentrate are to be prepared from technical-grade material:

$$X = \frac{25 \times 190 \times 1}{100} = 47.5 \text{ kg} \quad \text{or} \quad X = \frac{25 \times 50 \times 8.33}{100} = 104 \text{ lb}$$

47.5 kg (104 lb) of technical-grade material are required.

Emulsifiable concentrates should be formulated by professional formulators.

Preparation of emulsions from emulsifiable concentrates (ECs) of different strengths

Percentage of active ingredient	Parts water to be added to 1 part EC for given final concentration				
	5%	2.5%	1%	0.5%	0.25%
80	15	31	79	159	319
60	11	23	50	119	239
50	9	19	49	99	199
25	4	9	24	49	99
10	1	3	9	19	39

The general formula is:

$$X = (A/B) - 1$$

where: X = parts of water to be added to 1 part of emulsifiable concentrate
A = concentration of the emulsifiable concentrate (%)
B = required concentration of the final formulation (%)

Example: A 0.5% formulation is to be prepared from a 25% concentrate:

$$X = (25/0.5) - 1 = 49$$

49 parts of water to 1 part of concentrate are required.

A.3 Amount of formulation required to give a specific weight of active ingredient per unit area

Requirements for spray formulations

Dosage (weight/unit area)	Litres[a] of spray required per 100 m² (1000 ft²) with given concentrations of technical-grade insecticide				
	0.25%	0.5%	1.0%	2.5%	5.0%
2 g/m² (200 mg/ft²)	–	–	20	8	4
1 g/m² (100 mg/ft²)	–	20	10	4	2
0.5 g/m² (50 mg/ft²)	20	10	5	2	1
0.2 g/m² (20 mg/ft²)	8	4	2	0.8	0.4

[a] 1 litre is approximately equivalent to 0.2 imperial gal or 0.25 US gal. For more precise equivalents, see below.

Requirements for emulsifiable concentrates and dusts

Dosage		Amount of 25% concentrate[a] required		Amount of 5% dust[b] required	
kg/ha	lb/acre			kg	lb
4.54	10	18.2 l	4.0 imperial gal 4.8 US gal	90.8	200
2.27	5	9.1 l	2.0 imperial gal 2.4 US gal	45.4	100
1.36	3	5.5 l	1.2 imperial gal 1.4 US gal	27.2	60
1.0	2.2	4.2 l	0.9 imperial gal 1.1 US gal	20.0	44
0.45	1	1.8 l	1.6 imperial pt 1.9 US pt	9.1	20
0.23	0.5	900 ml	1.6 imperial pt 1.9 US pt	4.5	10
0.045	0.1	200 ml	6.4 imperial fl oz 6.1 US fl oz	–	–

[a] Containing 0.25 kg/l (2.5 lb/imperial gal; 2.1 lb/US gal)

[b] Containing 50 g of active ingredient per kg

The general formulae are:

$$\text{for concentrates:} \quad X = \frac{A \times 100}{B \times C}$$

$$\text{for dusts:} \quad X = \frac{A \times 100}{B}$$

where: X = amount of concentrate or dust required
A = dosage (kg/ha or lb/acre)
B = percentage concentration of product used
C = 1 when X and A are expressed in litres and kilograms per hectare, respectively
8.33 when X and A are expressed in US gallons and pounds per acre, respectively
10 when X is expressed in imperial gallons

Examples: For a dosage of 4.54 kg/ha (10 lb/acre):

(a) With a 25% concentrate:

$$X = \frac{4.54 \times 100}{25 \times 1} = 18.2 \text{ l} \quad \text{or} \quad X = \frac{10 \times 100}{25 \times 8.33} = 4.8 \text{ US gal}$$

18.2 l of concentrate per hectare or 4.8 US gal of concentrate per acre are required.

(b) With a 5% dust:

$$X = \frac{4.54 \times 100}{5} = 90.8 \text{ kg} \quad \text{or} \quad X = \frac{10 \times 100}{5} = 200 \text{ lb}$$

The amount of dust required is 90.8 kg/ha or 200 lb/acre.

A.4 Conversion tables for dosages in parts per million

Concentrations of active ingredient equivalent to one part per million

1 part per million (ppm)	= 1 mg (0.015 grain) per kilogram
	= 1 g (15.4 grain) per tonne
	= 0.007 grain (0.45 mg) per pound
	= 1 ml (0.035 imperial fl oz per 1000 litres
	= 0.16 imperial fl oz (4.5 ml) per 1000 imperial gallon
	= 0.13 US fl oz (3.8 ml) per 1000 US gallon

Dilution factors for a 25% concentrate

Required concentration (mg/l)	Volume of 25% concentratea needed for the given volumes of water		
	1 million l of water	1 million imperial gal of water	1 million US gal of water
1	4 litres	4 imperial gal	4 US gal
0.1	400 ml	3.2 imperial pt	3.2 US pt
0.01	40 ml	6.5 imperial fl oz	5.1 US fl oz
0.001	4 ml	0.6 imperial fl oz	0.5 US fl oz

Relations between concentration, treatment dosage and water depth

Treatment dosage		Concentration (ppm) at given depth[a]	
g/ha	lb/acre	2.5 cm (1 In)	30 cm (1 ft)
2240	2.0	8.8	0.74
1120	1.0	4.4	0.37
560	0.5	2.2	0.18
280	0.25	1.1	0.092
112	0.10	0.44	0.037
56	0.05	0.22	0.018
28	0.025	0.11	0.0092
11	0.01	0.044	0.0037

[a] The concentrations at other depths or other treatment dosages can be obtained by simple proportion; for example, the concentrations (mg/l) at depths of 10 and 20 cm are one-fourth and one-eighth, respectively, of those at 2.5 cm.

A.5 Area measurements for space applications

Numbers of hectares in areas of different linear dimensions

Length	Number of hectares in rectangle of given width			
(m)	25 m	50 m	100 m	500 m
1600	4.0	8.0	16.0	80.0
1000	2.5	5.0	10.0	50.0
600	1.5	3.0	6.0	30.0
400	1.0	2.0	4.0	20.0
250	0.63	1.25	2.5	12.5

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

$$\text{area (ha)} = \frac{\text{length (m)} \times \text{width (m)}}{10\,000} \quad \text{or} \quad \frac{\text{length (km)} \times \text{width (ft)}}{10}$$

$$\text{area (acres)} = \frac{\text{length (ft)} \times \text{width (ft)}}{43\,560} \quad \text{or} \quad 0.121 \times \text{length (miles)} \times \text{width (ft)}$$

Aerial spray coverage in relation to speed of aircraft and swath width

Speed of aircraft[a]		Aerial spray coverage per minute for given swath width[b]				
km/h	mile/h	15.2 m (50 ft)	22.9 m (75 ft)	30.5 m (100 ft)	61.0 m (200 ft)	152.5 m (500 ft)
128	80	3.2 ha 8 acres	4.9 ha 12 acres	6.5 ha 16 acres	12.9 ha 32 acres	32.4 ha 80 acres
144	90	3.6 ha 9 acres	5.5 ha 13.5 acres	7.3 ha 18 acres	14.2 ha 36 acres	36.4 ha 90 acres
160	100	4.0 ha 10 acres	6.1 ha 15 acres	8.1 ha 20 acres	16.2 ha 40 acres	40.5 ha 100 acres
192	120	4.9 ha 12 acres	7.3 ha 18 acres	9.7 ha 24 acres	19.4 ha 48 acres	48.6 ha 120 acres
240	150	6.1 ha 15 acres	9.1 ha 22.5 acres	12.1 ha 30 acres	24.3 ha 60 acres	60.7 ha 150 acres

[a] 1 knot = 1.85 km/h = 1.15 mile/h

[b] Other coverage values can be determined by simple proportion or by the following formulae:
hectares per min = (swath width in m) x (speed in km/h) x 0.00166
acres per min = (swath width in ft) x (speed in miles/h) x 0.002

Given the area an aircraft covers per minute, the spray system is calibrated to disperse the desired amount of pesticide per unit area. To find the rate of pesticide dispersal required per minute, multiply the area covered per minute by the amount of pesticide to be applied per unit area.

Example: A volume of 220 ml/h is to be applied from an aircraft which covers 4.0 ha/min.

$$220 \times 4.0 = 880$$

The spray system is calibrated to deliver 880 ml/min.

A.6 Dosages in relation to space applications

Required concentration (g/m^3)	Quantity (g) of active ingredient required for treatment of given volume[a]				
	0.5 m^3 (17.7 ft^3)	1.0 m^3 (35.3 ft^3)	5.0 m^3 (176.6 ft^3)	10.0 m^3 353.1 ft^3)	100.0 m^3 (3531.5 ft^3)
0.1	0.05	0.1	0.5	1.0	10
0.15	0.075	0.15	0.75	1.5	15
0.2	0.1	0.2	1.0	2.0	20
0.25	0.125	0.25	1.25	2.5	25
0.3	0.15	0.3	1.5	3.0	30
0.35	0.175	0.35	1.75	3.5	35

[a] Volume sizes can be determined as follows:

cube or oblong = height x width x length
cylinder = height x π x $(\text{radius})^2$
cone = (1/3) x height x π x $(\text{radius})^2$
pyramid = (1/3) x height x width x length
sphere = (4/3) x π x $(\text{radius})^3$

A.7 Approximate conversion factors: metric, imperial and United States units

Length

1600 m	= 1.6 km	= 1 mile	= 1760 yd	= 5280 ft
10^5 cm	= 1000 m	= 1 kilometre (km)	= 0.625 mile	= 1100 yd
91.4 cm	= 0.91 m	= 1 yard (yd)	= 3 ft	= 36 in
1000 mm	= 100 cm	= 1 metre (m)	= 1.093 yd	= 3.28 ft = 39.37 in
0.3048 m	= 30.48 cm	= 1 foot (ft)	= 12 in	
25.4 mm	= 2.54 cm	= 1 inch (in)	= 1/12 ft	
10 000 μm	= 10 mm	= 1 centimetre (cm)	= 0.394 in	= 0.033 ft
1000 μm		= 1 millimetre (mm)	= 0.0394 in	
0.001 mm	= 0.0001 cm	= 1 micrometre (μm)	= 0.000039	= about 1/25 000 in

Area

	259 ha	= 1 square mile (sq mile)	= 640 acres	
	100 ha	= 1 square kilometre (km^2)	= 0.39 sq mile	= 247 acres
10000 m^2	= 0.01 km^2	= 1 hectare (ha)	= 2.47 acres	
4047 m^2	= 0.405 ha	= 1 acre	= 4840 yd^2	= 43 560 ft^2
	10000 cm^2	= 1 square metre (m^2)	= 1.2 yd^2	= 10.76 ft^2 = 1550 in^2
	0.84 m^2	= 1 square yard (yd^2)	= 9 ft^2	= 1296 in^2
930 cm^2	= 0.093 m^2	= 1 square foot (ft^2)	= 144 in^2	
	6.45 cm^2	= 1 square inch (in^2)	= 0.007 ft^2	
	100 mm^2	= 1 square centimetre (cm^2)	= 0.155 in^2	
	93 m^2	= 1000 square feet (ft^2)		

Volume

1000 l	= 1 cubic metre (m^3)	= 1.307 yd^3	= 35.32 t^3
2.83 m^3	= 100 cubic feet (ft^3)	= 3.7 yd^3	
0.77 m^3	= 1 cubic yard (yd^3)	= 27 ft^3	
28.32 l	= 1 cubic food (ft^3)	= 0.037 yd^3	= 1728 in^3
16.39 cm^3	= 1 cubic inch (in^3)	= 0.000579 ft^3	

Liquid capacity

3.79 l	= 1 US gallon (gal)	= 0.83 imperial gal	= 231 in^3
4.55 l	= 1 imperial gallon (gal)	= 1.2 US gal	
10 000 ml	= 1 litre (l)	= 0.26 US gal	= 0.22 imperial gal
32 US fl oz	= 1 US quart (qt)	= 0.9463 l	
~ 40 imperial fl oz	= 1 imperial quart (qt)	= 1.136 l	
3 tea spoonsful	= 1 tablespoonful	= 0.5 US fl oz	

Weight

1000 mg	= 1 gram (g)	= 0.0352 oz	
28.35 g	= 1 ounce (oz)	= 1/16 lb	= 437.5 grains
64.8 ng	= 1 grain	= 1/7000 lb	
453.6 g	= 1 pound (lb)	= 16 oz	
1000 g	= 1 kilogram (kg)	= 2.2 lb	= 35.27 oz
1000 kg	= 1 tonne (t)	= 2204 lb	
907 kg	= 1 US short ton	= 2000 lb	= 0.893 UK ton
1018 kg	= 1 imperial ton (1 US long ton)	= 2240 lb	= 1.12 US short tons

Weight of water in various volumes at 16.7 °C (62 °F)

1 ft^3	= 62.3 lb		
1 l	= 1000 g	= 1 kg	= 2.2 lb
1 US gal	= 8.33 lb		
1 imperial gal	= 10 lb		