CHAPTER 5

Vector surveillance and control

The most important vector of dengue virus is the mosquito *Aedes aegypti*, which should be the main target of surveillance and control activities. Other species should be considered for vector control only where there is reliable evidence that they play an epidemiologically significant role in the transmission of dengue infections.

Vector surveillance

Entomological surveillance is used to determine changes in the geographical distribution and density of the vector, evaluate control programmes, obtain relative measurements of the vector population over time and facilitate appropriate and timely decisions regarding interventions. It may also serve to identify areas of high-density infestation or periods of population increase. A number of methods are available for detecting or monitoring immature and adult populations. Selection of appropriate sampling methods depends on the surveillance objectives, levels of infestation, available funding and skills of personnel. Guidance on the choice of surveillance methods for *Ae. aegypti* is presented in Table 5.1.

Several indices have been described and are currently used to monitor *Ae. aegypti* populations for dengue virus transmission. Those related to immature populations include the house index, i.e. the percentage of houses infested with larvae or pupae; the container index, i.e. the percentage of water-holding containers infested with larvae or pupae; and the Breteau index, i.e. the number of positive containers per 100 houses inspected. When using the house index or the Breteau index, the definition of a house should be one unit of accommodation and the surrounding premises, irrespective of the number of people residing therein.

The abundance of adult mosquitos is expressed as either the landing rate or the indoor resting density during a fixed period of collection time. Landing or biting collections on humans are a sensitive but labour-intensive means of detecting low-level infestations. Rates of capture are usually expressed in terms of landing–biting counts per person-hour. Resting collections consist of the systematic search for *Ae. aegypti*, which typically spends periods of inactivity in secluded places indoors such as in closets and under furniture. Resting collec-

Table 5.1
Aedes aegypti surveillance methods

Objective	Method					
	Larval survey	Collection on humans	Collection of resting mosquitos	Ovitrap	Tyre larvitraps	Insecticide susceptibility
Baseline infestation surveys	×			×		×
Control programme monitoring low infestation levels: <5% house index	×	×	×[a]	×	×	
Control programme monitoring ≥5% house index level	×	×	×[a]			
Surveillance against reinfestation	×			×	×	
Verification of eradication	×	×	×	×	×	
Evaluation of control methods[b]	×	×	×	×	×	×

[a] Use of backpack aspirator recommended.
[b] Choice depends on intervention used.

tion studies performed with backpack aspirators are an efficient and effective means of evaluating adult densities. Densities are recorded either as the number of adult mosquitos per house (females, males, or both) or the number of adult mosquitos collected per unit of time. Wherever larval surveys indicate low infestations (e.g. when the Breteau index is <5), ovitraps can be used as a complementary surveillance method. They have proved especially useful for the early detection of new infestations in areas from which the mosquito had been eliminated.

Ae. aegypti has a relatively short flight range, but even so, a very large number of catching stations are required to provide accurate monitoring of areas at risk. Since this is not usually feasible, the best alternative is to concentrate monitoring on high-risk areas as determined by experience or environmental conditions. Special attention should also be given to the evaluation of areas where control activities have been carried out, so that remedial measures can be implemented if required.

In areas of high human population density, many people may be exposed, even if the mosquito house index is low. Distances between houses may thus be of epidemiological significance, especially in areas with single-storey dwellings. In multistorey dwellings, the population per unit area is likely to be higher, and thus survey data for single-storey and multistorey dwellings should be kept separate.

Emergency control measures are based primarily on application of insecticides, and it is essential to monitor periodically the vector's susceptibility to the insecticides most widely used, e.g. temephos, malathion, fenthion and fenitrothion. In tropical countries where there are large areas free of the vector, surveillance against infestation is of paramount importance. Special attention should be given to the surveillance of seaports, airports, other points of entry, cemeteries, and used-tyre storage or retreading facilities. Ports that receive vessels from infested areas should have ongoing inspection programmes. Cemeteries where live or artificial flowers are placed in vases and other containers are important *Aedes* loci. Tyre-retreading facilities that receive used tyre shipments from infested areas may be important sites for the introduction of *Aedes* vectors to urban areas. A good surveillance programme designed to avoid infestation is much less costly than an eradication or control programme that must be established after infestation has occurred.

Vector control[1]

The most effective means of vector control is environmental management, which includes planning, organization, carrying out and monitoring activities for the modification or manipulation of environmental factors with a view to

[1] See also Rozendaal JA. *Vector control: methods for use by individuals and communities*. Geneva, World Health Organization, 1997.

preventing or reducing vector propagation and human–vector–pathogen contact. In Asia and the Americas, *Ae. aegypti* breeds primarily in man-made containers, while in Africa, it breeds both in natural containers, such as tree holes and leaf axils, and in artificial containers. Control of *Ae. aegypti* in Cuba and Panama in the early part of this century was based on forms of environmental management, and many programmes in the Americas are returning to this fundamental tactic. Environmental management is also part of the control measures taken against *Ae. albopictus*, a secondary vector for dengue in the Pacific and Asia, and a potential vector following recent infestations in Africa, southern Europe, and the Americas.

In 1980, the WHO Expert Committee on Vector Biology and Control defined three types of environmental management:[1]

- *Environmental modification*—long-lasting physical transformations of vector habitats.
- *Environmental manipulation*—temporary changes to vector habitat as a result of planned activity to produce conditions unfavourable to vector breeding.
- *Changes to human habitation or behaviour*—efforts to reduce human–vector–pathogen contact.

Methods for environmental management

Environmental management methods to control *Ae. aegypti* and *Ae. albopictus* and reduce human–vector contact include the improvement of water supply and storage, solid waste management and the modification of man-made larval habitats. Table 5.2 summarizes the primary methods of environmental manipulation used to control *Aedes* larval habitats.

Environmental management should focus on the destruction, alteration, disposal or recycling of containers and natural larval habitats that produce the greatest number of adult *Aedes* mosquitos in each community. These programmes should be conducted concurrently with health education programmes and communications that encourage community participation in the planning, execution and evaluation of container-management programmes (e.g. regular household sanitation or clean-up campaigns).

Improvement of water supply and storage

One method for controlling urban *Aedes* vectors, particularly *Ae. aegypti*, is to improve domestic water supplies. The mere delivery of potable water to neigh-

[1] *Environmental management for vector control. Fourth report of the WHO Expert Committee on Vector Biology and Control*. Geneva, World Health Organization, 1980 (WHO Technical Report Series, No. 649). See also: *Vector control for malaria and other mosquito-borne diseases. Report of a WHO Study Group*. Geneva, World Health Organization, 1995 (WHO Technical Report Series, No. 857).

Table 5.2
Environmental management actions for control of *Aedes aegypti* larval habitats[a]

Larval habitats	Clean	Cover	Store under roof	Modify design	Use EPS[b] beads	Fill (sand/soil)	Collect: recycle or dispose	Puncture or drain
Useful:								
Water storage tank/cistern	+	+		+	+			
Drum (150–200 litres)	+	+		+	+			
Flower vase with water	+					+		
Potted plants with saucers	+							
Ornamental pool/fountain	+							
Roof gutter	+							
Animal water container	+							
Non-essential:								
Used tyres		+	+			+	+	
Discarded large appliances							+	
Discarded buckets (<20 litres)			+				+	+
Tin cans							+	+
Natural:								
Tree-holes						+		
Rock holes						+		

[a] Adapted, by permission, from *Dengue and dengue hemorrhagic fever in the Americas: guidelines for prevention and control*, Washington, DC, Pan American Health Organization, 1994 (Scientific Publication No. 548).
[b] EPS = expanded polystyrene.

bourhoods or individual homes is not, however, sufficient to reduce the use of the water storage containers that play a dominant role in *Ae. aegypti* breeding in many urban areas. For example, after piped water had been supplied to households in one municipality in Thailand, approximately eight water storage jars were still kept by each household. Similar situations have been reported elsewhere in Asia and the Caribbean. Households typically continue to store water because water supplies are not reliable. With such water storage comes the concomitant problem of *Ae. aegypti* breeding and the increased risk of dengue infection. Therefore, potable water must be delivered in sufficient quantity, quality and consistency to reduce the use of water storage containers that serve as larval habitats, such as drums, overhead tanks, and jars. Water piped to households is preferable to wells, communal standpipes, rooftop catchments and other delivery systems. If storage tanks, drums and jars are required for water storage, they should be covered with tight lids or screens. Many people fail to cover water containers because lids and screens are not designed in such a way that they will seal containers while nevertheless enabling users to withdraw water easily. Water storage systems, however, can be designed to prevent *Ae. aegypti* oviposition or adult emergence. In Sarawak, Malaysia, for example, mosquito-proof rainwater collection and storage containers made of high-density polyethylene have fibreglass screens in the lids that allow rainwater to enter but prevent adult mosquitos from emerging. Covered containers should be routinely inspected because even the best-designed lids and screens can tear or deteriorate in harsh climates and with age.

Solid waste management

Vector control efforts should encourage effective and environmentally sound waste management by promoting the basic rule of "reduce, reuse, recycle". In some parts of Africa, plastic containers that may serve as potential larval habitats are effectively recycled. Used tyres are another form of solid waste that is of critical importance to urban *Aedes* control; they should be recycled or disposed of by proper incineration in waste transformation facilities (e.g. incinerators, energy-production plants, lime kilns). If cut into halves, shredded, or chipped, tyres can be mixed with other wastes and buried in landfills, as local sanitary regulations allow. Whole tyres should be buried in a separate area of a landfill, to avoid their rising upwards under compaction and disrupting soil cover.

Modification of man-made larval habitats

Common-sense approaches should be employed to reduce the potential for *Ae. aegypti* mosquitos to breed in and around human habitats. For example, fences and fence posts made from hollow stems, such as bamboo, should be cut to the node; tyres and containers stored outside should be covered or placed in a shed, and buckets and other small containers should be inverted if stored outdoors. Ant traps used to protect food storage cabinets can be filled with oil or salty water instead of fresh water; condensate-collection pans under refrigerators and air-conditioning units should be drained and cleaned regularly. Floor drains should be cleaned and kept covered. Roof gutters, outdoor sinks, laundry basins and similar items that can retain water and serve as larval habitats should be drained and kept free of debris. Ornamental pools and fountains can be either chlorinated or populated with larvivorous fish. Where possible, housing should be designed or modified to reduce opportunities for mosquitos to enter, i.e. without open eaves and with screened doors and windows. These measures and others will help reduce or prevent the breeding of vector mosquitos near humans, and thereby diminish the risk of dengue viral disease.

Chemical control

Chemicals have been used to control *Ae. aegypti* since the turn of the century. In the first campaigns against yellow fever in Cuba and Panama, in conjunction with widespread clean-up campaigns, *Aedes* larval habitats were treated with oil and houses were dusted with pyrethrins. When the insecticidal properties of DDT were discovered in the 1940s, this compound became the principal method for *Ae. aegypti* eradication programmes in the Americas. When resistance to DDT emerged in the early 1960s, organophosphate insecticides, including fenthion, malathion, fenitrothion and temephos, were used for *Ae. aegypti* control. Current methods for applying insecticides include larvicide application, perifocal treatment and space spraying.

Application methods

Larvicidal or "focal" control of *Ae. aegypti* is usually limited to containers maintained for domestic use that cannot be eliminated. Three larvicides can be used to treat containers that hold drinking-water: 1% temephos sand granules, the insect growth regulator methoprene in the form of briquettes, and BTI (*Bacillus thuringiensis* H-14), which is considered below in the section on biological control. All these larvicides have extremely low mammalian toxicity, and properly treated drinking-water is safe for human consumption.

Perifocal treatment involves the use of hand or power sprayers to apply wettable powder or emulsifiable-concentrate formulations of insecticide as a spray to larval habitats and peripheral areas. This will destroy existing and subsequent larval infestations in containers of non-potable water, as well as kill the adult mosquitos that frequent these sites. This method can be used to treat containers that are preferred by *Ae. aegypti*, whether or not they hold water. The internal and external walls of containers are sprayed until they are covered by a film of insecticide; spraying is also extended to cover any wall within 60 cm of the container. The surface of non-potable water in containers is also treated.

The insecticides currently used in perifocal treatment are malathion, fenitrothion, fenthion, and some pyrethroids.

Space spraying is the spreading of microscopic droplets of insecticide in the air to kill adult mosquitos and is used in emergency situations when an outbreak of dengue fever is already in progress. Two forms of space spray are generally used for *Ae. aegypti* control: thermal fog and ultra-low volume (ULV) aerosols (cold fogs) and mists. Thermal fog is produced by equipment in which the insecticide, usually mixed in an oil with a suitably high flashpoint, is vaporized by being injected into a high-velocity stream of hot gas. When discharged into the atmosphere, the oil carrying the pesticide condenses in the form of a fog. Malathion, fenitrothion, fenthion and some pyrethroids are used in thermal fogging operations. ULV aerosols and mists involve the application of a small quantity of concentrated liquid insecticide. An insecticide concentrate application of less than 4.6 litres per ha (0.5 US gal per acre) is usually considered to be a ULV application. Selected insecticides and the dosages suitable for use in cold sprays in the control of *Ae. aegypti* are listed in Table 5.3.

Aerosols and mists may be applied using portable machines, vehicle-mounted generators, helicopters or fixed-wing aircraft. Portable backpack equipment can be used to apply insecticide mists in small areas or where vehicle-mounted equipment cannot be used. An average of 80 houses per day can be

Table 5.3
Selected insecticides and dosages for cold-spray control of *Aedes aegypti*[a]

Insecticide	Dosage (grams of active ingredient per ha)
Organophosphates	
Malathion	112–693
Fenitrothion	250–300
Naled	56–280
Pirimiphos-methyl	230–330
Pyrethroids	
Deltamethrin	0.5–1.0
Resmethrin	2–4
Bioresmethrin	5
Permethrin	5
Cypermethrin	1–3
Lamda-cyhalothrin	1

[a] Source: DC Chavasse, HH Yap, eds. *Chemical methods for the control of vectors and pests of public health importance*, Geneva, World Health Organization, 1997 (unpublished document WHO/CTD/WHOPES/97.2, available on request from Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

thus treated, but two or three operators are required because the weight of the machine and engine vibrations make it necessary for operators to rest frequently.

Vehicle-mounted aerosol generators can be used in urban or suburban areas with good road systems. One machine can cover 1500–2000 houses per day. It is necessary to monitor environmental conditions and to calibrate the equipment, vehicle speed and swath width to determine the coverage obtained by a single pass. Maps of the areas to be sprayed showing all passable roads are helpful in planning maximum coverage. An educational effort may be required to persuade residents to open their doors and windows in order to improve the effect of the spraying programme. As *Ae. aegypti* routinely rests indoors, the effectiveness of vehicle-mounted aerosol control measures has been questioned, and surveillance of the natural mosquito population, as opposed to caged bioassay mosquitos, should accompany control efforts in order to determine the impact of the spray programme on each habitat.

Aerial spraying is often used when an extensive area must be treated in a short time. Although the equipment (aircraft equipped with a spray system) may have a high initial cost, this form of application may be the most cost-effective, since very large areas can be treated during a single flight. As with vehicle-mounted operations, it is important to ensure that insecticide is reaching the actual mosquito habitats. Insecticides that can be used in aerial ULV applications are malathion, fenitrothion, naled, pirimiphos-methyl, resmethrin, cypermethrin, lambda-cyhalothrin and deltamethrin. Parameters for the aerial application of insecticides vary according to the types of aircraft, local insecticide susceptibility and the equipment used. Early morning applications are preferable, temperature should be less than 27 °C (80 °F) and wind velocity should be less than 16 km (10 miles) per hour.

Guidelines for chemical control

The indiscriminate use of insecticides for prevention and control of dengue infection should be discouraged. During periods of little or no dengue virus activity, the routine source reduction measures described above in the section *Methods for environmental management* can be integrated with larvicide application in containers that cannot be eliminated, covered, filled or otherwise managed. For emergency control to suppress a dengue virus epidemic or to prevent an imminent outbreak, a programme of rapid and massive destruction of the *Ae. aegypti* population should be undertaken with insecticides, using the techniques described above.

Safety precautions for chemical control

All pesticides are toxic to some degree; safety precautions should be followed, including care in the handling of pesticides, safe work practices for those who apply them and their appropriate use in and around occupied housing. A safety plan for insecticide application can be organized along the following lines:

- Instructions on pesticide labels should be carefully followed.
- Spray operators should be provided with at least two uniforms to allow for frequent changes.
- Safety gloves and masks should be used for high-exposure activities like machine calibration.
- Changing and washing facilities with sufficient water and soap should be available.
- All work clothes should be removed at the end of each day's operations and a shower or bath taken.
- Work clothes should be washed regularly.
- Particular attention should be given to washing gloves, as wearing contaminated gloves can be dangerous.
- Spray operators should wash their hands before eating and should not smoke during work hours.
- Spray operators should not be exposed to toxic material for periods that are longer than recommended.
- Care must be taken in the disposal of used insecticide containers.
- Blood cholinesterase levels should be monitored if organophosphate insecticides are used.
- Supervision by a well trained individual is essential.

Specific guidelines on insecticides and safety procedures are included in *Safe use of pesticides. Fourteenth report of the WHO Expert Committee on Vector Biology and Control*, Geneva, World Health Organization, 1991 (WHO Technical Report Series, No. 813), and *Chemical methods for the control of vectors and pests of public health importance*, Geneva, World Health Organization, 1997 (unpublished document WHO/CTO/WHOPES/97.2, available on request from Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland).

Insecticide susceptibility monitoring

During the past 40 years, chemicals have been widely used to control mosquitos and other insects of public health importance. As a result, *Ae. aegypti* and other dengue vectors in several countries have developed resistance to commonly used insecticides, including temephos, malathion, fenthion, permethrin, propoxur and fenitrothion. It is therefore advisable to obtain baseline data on insecticide susceptibility before control operations are started and to continue monitoring susceptibility levels periodically. WHO kits are available for testing the susceptibility of adult and larval mosquitos and other arthropod vectors. These can be obtained from the Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland (fax: 41 22 791 4777).

Personal protection

Personal protection measures have been extensively used in efforts to protect indigenous and rural populations against malaria. Pyrethroid-impregnated bednets or curtains appear to be effective against mosquitos that feed at night. In the case of the day-feeding *Aedes* vectors of dengue, however, these measures have less relevance. Nevertheless, they may be useful to special groups, such as the bed-ridden, infants or those who must sleep during the day. Tourists and short-term visitors to dengue endemic areas should use commercially available insect repellents. For residents and those staying longer in endemic areas, clothing can be impregnated with permethrin.

Biological control

Interventions based on the introduction of organisms that prey upon, parasitize, compete with or otherwise reduce the numbers of *Ae. aegypti* or *Ae. albopictus* remain largely experimental, and information on their efficacy is based on the results of small-scale field operations. Larvivorous fish and the biocide *Bacillus thuringiensis* H-14 (BTI) are the two organisms most frequently employed. The advantages of biological control measures include no chemical contamination of the environment, specificity against target organisms (the effect of BTI, for example, is limited to mosquitos and related Diptera) and the self-dispersion of some agents into sites that could not be easily treated by other means.

The disadvantages of biological control measures include the expense of raising the organisms, difficulty in their application and production and their limited utility in aquatic sites where temperature, pH and organic pollution may exceed the narrow requirements of the agent, as well as the fact that they are only effective against the immature stages of vector mosquitos. Moreover, a reduction in larval numbers does not necessarily result in a corresponding reduction of disease transmission, since if food is limited, lower larval densities may result in larger, healthier adults that are better able to survive.

BTI is a proven, environmentally non-intrusive mosquito larvicide that appears to be entirely safe for humans. It is commercially available under a number of trade names. The large parasporal body that forms in this agent contains a toxin that degranulates solely in the alkaline environment of the mosquito midgut. The advantage of this material is that an application destroys larval mosquitos but spares any entomophagous predators that may be present. BTI formulations tend to settle at the bottom of water containers soon after application and require frequent reapplications. In addition, the toxin is photolabile and is destroyed by sunlight. Briquette formulations that appear to have greater residual activity are commercially available and can be used with confidence in drinking-water.

Integrated control

Integrated vector control is the combination of available control methods in the most effective, economical and safe manner to maintain vector populations at acceptable levels. The 1981 *Ae. aegypti* eradication campaign in Cuba combined the reduction of larval habitats (source reduction) and modification of drinking-water storage tanks with a variety of other interventions, including legislative measures to encourage householder compliance, health education, biological control and chemical control. This effort markedly reduced the densities of this vector. Control of *Ae. aegypti* can also be combined with the control of other disease vectors, as was done in urban areas of Suva, Fiji (1978–1979), and of the United Republic of Tanzania (1972), and in Singapore (1968–1980s). The Suva programme consisted of clean-up campaigns, house inspections, ULV malathion spray, legislative measures and health education. Monthly inspections of larval habitats were a major adjunct to reducing larval indices. The Tanzanian programme combined source reduction, public education and clean-up campaigns and reduced adult populations of both *Ae. aegypti* and *Culex pipiens quinquefasciatus*.

The joint *Ae. aegypti* and *Ae. albopictus* control programme in Singapore consisted of slum clearance, resettlement of displaced persons, source reduction by uniformed health officers, drain cleaning, mosquito-proofing of water tanks, health education, and strict enforcement of control measures, including fines. The *Aedes* house index in the slums fell from 27.2% of houses infested during 1966–1968 to 5.4% in 1969 after slum clearance and resettlement, and to 1.61% city-wide in 1981. The Singapore programme cost US$1–1.50 per person per year and resulted in a reduced incidence of dengue and lower densities of both *Aedes* and *C. pipiens quinquefasciatus* mosquitos.

Environmental management of dengue virus vectors can be successfully combined with health education and public health communication, where source reduction activities are promoted by local health care workers. For example, a campaign was undertaken in Indonesia in which local clinic workers trained primary school teachers and volunteers from women's clubs to recognize cases of dengue fever and to implement a programme to reduce the number of *Ae. aegypti* breeding habitats. As a result, *Ae. aegypti* populations were significantly reduced within six months of implementing the campaign.