Section V.
Insects and Excreta

36

Culex pipiens Mosquitoes and the Transmission of Bancroftian Filariasis

CHAPTERS 36 AND 37 are different from the other chapters in Part Two in that they deal not with excreted infections *per se* but with insects that may transmit both excreted and nonexcreted infections and that breed in or visit excreta or sewage. This chapter describes the *Culex pipiens* mosquitoes, which breed in sewage and sullage and are a vector of Bancroftian filariasis. Because of the very different nature of the subject matter, the standard headings adopted for chapters 9–35 have not been used in this chapter and chapter 37.

The Biology of *Culex pipiens* Mosquitoes

The immature stages (eggs, larvae, and pupae) of mosquitoes live in water. Among the many mosquitoes able to transmit human disease, three groups of species are particularly important. One group, the *Culex pipiens* complex, has the most relevance to sanitation methods because it favors polluted water for breeding. Of the other two groups, *Anopheles* species (vectors of malaria) breed in stretches of fairly clean water, such as flood or irrigation water, and *Aedes aegypti* (vector of yellow fever, dengue, and dengue hemorrhagic fever viruses) breeds especially in clean water stored in pots, cisterns, and the like, unless these are carefully screened to prevent their access.

The *Culex pipiens* complex consists of several closely related forms such as *C. p. pipiens*, *C. quinquefasciatus*[1] (previously called *C. p. fatigans*, *C. p. quinquefasciatus*, and *C. fatigans*), *C. p. molestus*, and *C. p. pallens*. These vary in such physiological characters as ability to hibernate or lay their first batch of eggs without taking a blood meal. One or another of the members of the *C. pipiens* complex live anywhere that man accidentally creates suitable conditions for them within the geographical range shown in figure 36-1.

The eggs of *Culex pipiens* mosquitoes are laid in clumps ("rafts") of 50–250. The larvae hatch after 1–2 days and then pass through four stages (instars), lasting a total of 1–2 weeks at tropical temperatures, during which they breathe air through a siphon at the posterior end while hanging diagonally from the surface film of the water (figure 36-2) and feed on detritus. The comma-shaped pupae swim about, like the larvae, and give rise to the adult mosquito after about two days (figure 36-2). The female adults mate once only in the first few days of life and, as with other mosquitoes, only the females feed on blood. One blood meal is taken between the laying of each egg raft. Feeding takes place at night, and the favored blood sources are man and birds.

Bancroftian Filariasis

In some parts of the world, especially in continental Asia, *Culex pipiens* mosquitoes are the vectors of the causative agent of Bancroftian filariasis, the nematode worm *Wuchereria bancrofti* (figure 36-1). *W. bancrofti* is transmitted by quite different mosquito species in different parts of the world. In some places the vector is *Anopheles* (the malaria-carrying mosquito genus), whereas elsewhere the vectors are *Aedes* mosquitoes.

The adult worms live in the lymphatic ducts of man. Embryos (microfilariae) are shed in vast numbers into the blood stream. In the periodic form of the disease, which is the only form transmitted by *C. pipiens*, the microfilariae only occur in the blood at night, and the routine method of diagnosing the infection is by examination of blood samples taken at night for the presence of microfilariae. If a susceptible mosquito

1. This description was proposed by Sirivanakarn and White (1978) and later adopted by the World Health Organization.

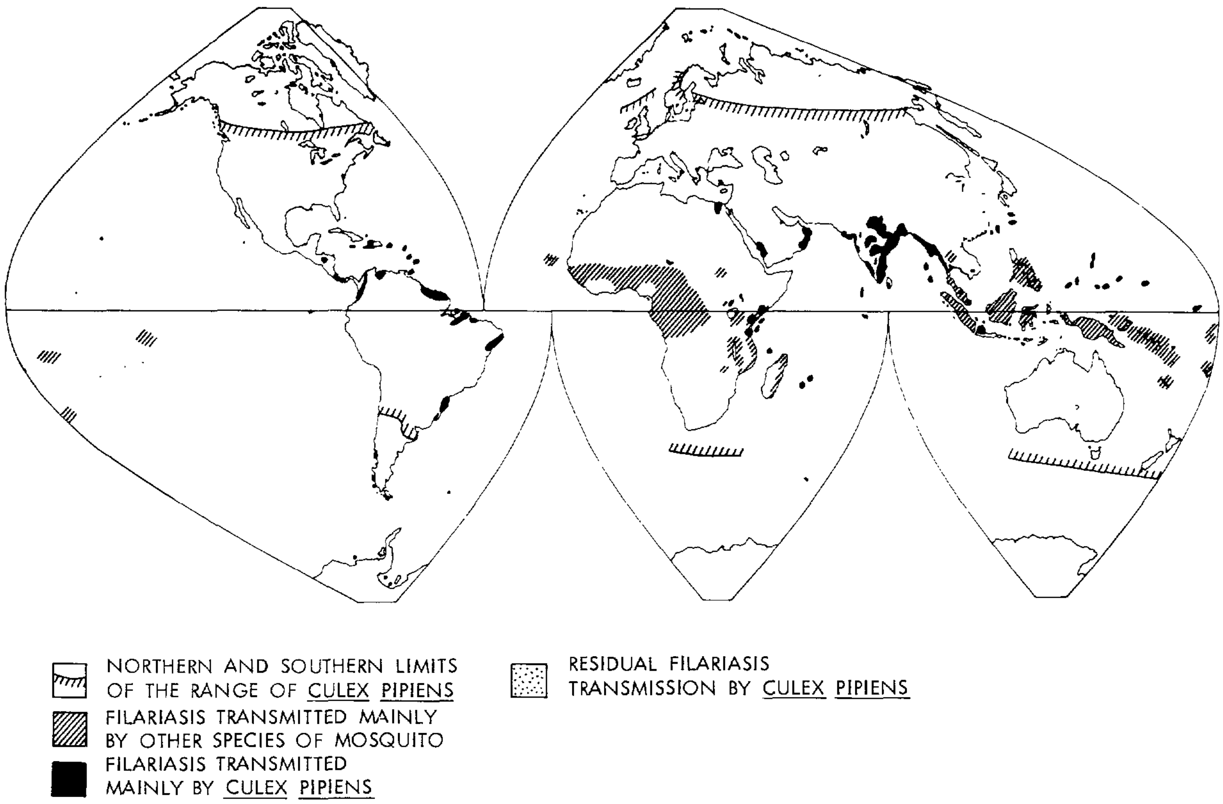

Figure 36-1. *Known geographical distribution of* Culex pipiens *mosquitoes and Bancroftian filariasis*

ingests microfilariae during a blood meal, they develop inside the mosquito over a period of 10–15 days to become infective larvae. When the mosquito feeds again, they may be reintroduced into another person where male and female worms establish themselves in the lymphatic system and recommence the cycle of microfilaria production.

Several years (often 20 or more) after the adult worms have established themselves, a reaction by the tissues of the infected person may block the lymphatic vessels and so prevent the return of the lymph. This may lead to swellings of the genitalia, legs, or arms. The first is known as hydrocele, whereas the stage of gross deformity of the legs or arms is called elephantiasis. Filariasis is not a lethal disease. The economic impact of the disablement that it causes has not been assessed, but the disease is much feared in areas where it is endemic.

There is no vaccine available as yet against filariasis, but the drug diethylcarbamazine is effective against the filarial worms while they are still alive and before severe symptoms of the disease appear. The drug may cause unpleasant side effects if used at the dosages required for effectiveness in a short course of treatment. Nevertheless, drug treatment has been effective in some areas—for example, Japan, Western Samoa, China, and French Polynesia. The other approach to filariasis control, by control of the vector mosquitoes, is dealt with below after further consideration of their ecology.

Figure 36-1 shows the areas in the world in which Bancroftian filariasis is known to occur. More extensive surveys may reveal further infected areas; for example, in India the known infected areas have steadily expanded as surveys have increased in thoroughness. Recent estimates in India are that 8 million people are infected, and that a population of 136 million is at risk from the disease. (ICMR 1971).

Culex pipiens as a Vector and as a Nuisance

The member of the *Culex pipiens* complex most widespread as a vector of Bancroftian filariasis is *Culex quinquefasciatus*. *C. quinquefasciatus* is the principal vector in South America, on the coast of East Africa, and through much of Asia (see figure 36-1). However, in China and Japan the vector is *C. p. pallens*, whereas in Egypt it is *C. p. molestus* (Southgate 1979). *C. p. molestus* is also the vector of Rift Valley fever in Egypt,

Figure 36-2. *Larval and adult* Culex pipiens *mosquitoes.* (a) Two larvae and one pupa of *C. pipiens* mosquitoes suspended from the water surface. (b) An adult *C. pipiens* taking a blood meal. (Photos: R. Page, Department of Medical Entomology, London School of Hygiene and Tropical Medicine, London, UK)

where there were explosive epidemics during 1977 and 1978 (Hoogstraal and others 1979).

As indicated in figure 36-1, there are large areas of the world where *Culex pipiens* exists but there is no Bancroftian filariasis or where other species of mosquito are the main vectors of filariasis. *C. quinquefasciatus* has increased substantially in density in West African towns over the last 30 years, but at present filariasis is mainly a rural disease transmitted by *Anopheles* species in the region. There is evidence that West African strains of *C. quinquefasciatus* have a relatively low susceptibility to *W. bancrofti*, in contrast to Indian strains of *C. quinquefasciatus*. However, there is no cause for complacency about the danger of high *C. quinquefasciatus* populations in West Africa because of the risk that the local *W. bancrofti* will adapt to the new potential vector that has become available in recent years.

Not only in West Africa, but throughout the tropics in recent years there has been rapid urbanization without adequate excreta or sullage disposal systems, and this has led to massive increases in *C. quinquefasciatus* numbers. It is feared that this is leading to corresponding increases in filariasis incidence. Quite apart from their role as disease vectors, *C. quinquefasciatus* are the main nuisance mosquitoes of tropical urbanized areas. They can be extremely unpleasant, especially where most of the population sleep out of doors or in inadequately mosquito-proofed houses. In Calcutta (India), over 700 *C. quinquefasciatus* bites per person per night have been recorded (Gubler and Bhattacharya 1974). In Pondicherry (India) in January, over 9 million *Culex quinquefasciatus* mosquitoes are emerging per day, and 90 percent of these are breeding in drains (Menon and Rajagopalan 1980).

The Association of *Culex pipiens* with Polluted Water

The breeding places of *C. pipiens* are mostly associated with sewage or sullage; stagnant open drains are perhaps the most prolific source. In many cases these drains were installed originally for storm water but, with the increased human population and inadequacies in the sewage disposal system, they have become the repository for sewage and sullage and tend to block and stagnate. Even if excreta are not disposed of in open drains, the use of such drains for sullage water creates equally important *C. pipiens* breeding places if the water is allowed to stagnate.

Pit latrines are another important breeding place, although this problem can be avoided if it is possible to dig the latrines so that they do not reach the water table. The installation of pit latrines in some villages in East Africa has been associated with invasion of these rural areas by *C. quinquefasciatus*. Where septic tanks and soakage pits are not made mosquito-proof, or are cracked, they too can become major breeding places. Examples of the relationship between *Culex* breeding and the availability of polluted water are given below.

It is thought that before 1926 Bancroftian filariasis transmitted by *C. quinquefasciatus* was limited in Sri Lanka to two towns. However, between 1926 and 1946 there was compulsory introduction of a system of bucket latrines in the southwestern part of the island and 30,000 were installed, each with an associated cement-lined pit to receive water used for ablution after defecation. These pits provided breeding sites for *C.*

quinquefasciatus and appeared to be associated with a major spread of filariasis. As part of a control program, 10,874 of the catch pits were converted to the water-seal type with a subsidy of 60 rupees each. Additional control measures included the use of organophosphate insecticides and campaigns to dispose of water-filled receptacles. In areas where the control program was in progress, the proportion of mosquitoes infected with *Wuchereria bancrofti* declined from 12–24 percent in 1949 to 0.7–3.3 percent in 1962 (Abdulcader 1967).

Afridi and Abdul Majid (1938) reported that measures against *C. quinquefasciatus* larvae had been taken throughout the inhabited area of New Delhi and for half a mile around it, but a severe *C. quinquefasciatus* biting nuisance was experienced during the months of April and May. It was thought that the breeding source was a suburban sewage farm in which very large numbers of larvae were found when sewage was pumped onto fields of grass and into stagnant connecting channels. Evidence that the city's problem did originate from this source came from trapping data that showed a gradation in mosquito density as one proceeded for several kilometers away from the sewage farm. Also, in the traps nearer the farm a higher proportion of males was obtained, which is generally an index of nearness to the breeding source. About 138,000 mosquitoes marked with silver dust were released at the sewage farm. Eleven marked mosquitoes were recaptured among the many thousands caught in the traps. Two of the recaptures were at more than 3.5 kilometers from the release point, the farthest being at 5 kilometers. These data indicate that *C. quinquefasciatus* from one massive breeding source could infest the whole city and emphasize the great dispersal power of this species when conditions are favorable.

Subra and Hebrard (1975) studied the ecology of *C. quinquefasciatus* larvae in the Comoro Islands, where this mosquito is the main vector of Bancroftian filariasis. Its main breeding places were pit latrines, soakage pits used for washing water, water-filled receptacles, and streams that became blocked by sand bars and stagnated in the dry season. Of the three main ethnic groups on the islands, the Sakalava (Malagasys) had soakage pits but no latrines in their villages; the Anjouan had pit latrines but no soakage pits; and the Moharais had both latrines and soakage pits. In semiurbanized areas the proportion of houses with pit latrines, soakage pits, or both was greater than in rural areas. Pit latrines did not contain water or become breeding places unless ground water entered them, which only occurred in deep pits and in the wet season when the water table rose. Thus, in villages with deep pit latrines *C. quinquefasciatus* biting densities rose dramatically in the wet season, whereas in villages with soakage pits only there was little seasonal variation. Chlorpyrifos (Dursban) was an effective and persistent larvicide in the pit latrines but has high mammalian toxicity. Drinking water wells were often dug close to pit latrines, and there was serious risk of diffusion of chlorpyrifos from flooded pit latrines to drinking water. Digging pit latrines less deeply so as not to reach the water table was considered the most effective control method. Temephos (Abate), with low mammalian toxicity and lower persistence than chlorpyrifos, was recommended for use as a larvicide in soakage pits.

Goettel, Toohey and Pillai (1980) studied *Aedes* and *Culex* breeding in Suva (Fiji). *C. quinquefasciatus* larvae were found in half of all septic tanks sampled. *C. quinquefasciatus* breeding, unlike that of *Aedes* species, showed no seasonal trend, and this suggests that breeding was associated more with permanent water bodies created by human water use than with ephemeral water bodies created by rainfall.

Bang, Sabuni and Tonn (1973) recorded the changes in mosquito populations between 1954 and 1971 in Dar es Salaam (Tanzania). Whereas urbanization and routine control measures had led to a reduction in malaria vectors, there had been a steady increase, despite control measures, in the population of *C. quinquefasciatus*. Part of the change was attributed to urbanization, which had led to a reduction of the clean pools suitable for *Anopheles* and to an increase in polluted water sources suitable for *C. quinquefasciatus*. Several permanent swamps known for decades as sources of malaria vectors had become *Culex* breeding sites owing to pollution from new human settlements. In an uncontrolled area of Dar es Salaam, for example, the *C. quinquefasciatus* population had increased since 1954 at an annual rate of 0.97 females per room.

The *Culex* breeding problem in Asian towns and cities has been reviewed by Singh (1967). Many towns in Asia are growing rapidly, and the sewerage arrangements are not keeping pace; there is a consequent increase in exposed polluted water that is available for breeding by *C. quinquefasciatus*. The situation is exemplified by Rangoon (Burma), where breeding is intense in drains, swampy ground near bucket latrines, pools polluted by effluent from the overloaded and defective waterborne sewage systems, unprotected septic tanks, and pit latrines in swampy ground. Both Hyderabad and Bangalore (India) were free of *C. quinquefasciatus* in the 1940s, but with increases in population and industrialization with poor sanitation the mosquito is now widespread, and filariasis transmission is occurring. The presence of extensive *C. quinquefasciatus* breeding does not necessarily lead to intense filariasis transmission, since this is only possible where the adult mosquito life span is long enough to allow maturation of the parasite. In the humid parts of south India the mosquito life span is long throughout the year, but in northwest India it is only long enough to allow transmission from July to October.

Useful reviews of *Culex* breeding and filariasis in Asia and Africa have also been prepared by Gratz (1973) and Hamon and others (1967). From this and other literature, several matters of grave concern emerge. First, rapid urbanization unaccompanied by adequate excreta disposal and drainage infrastructure causes substantial increases in the *Culex* population, and these may cause an increase in filariasis transmission, prevalence, and intensity of infection. Second, *C. quinquefasciatus* is becoming increasingly numerous in urban areas of Africa where, at present, the vector of filariasis is the *Anopheles* mosquito. If *W. bancrofti* became adapted to transmission by *C. quinquefasciatus* in these areas of Africa, the consequences would be most serious. Third, there is some evidence that *Anopheles* and *Aedes* mosquitoes, commonly known as clean water breeders, are adapting to take advantage of the breeding opportunities provided by the proliferation of contaminated surface water bodies in fast-growing tropical cities. Chinery (1969) reported that *Anopheles gambiae* and *Aedes aegypti* were found breeding in earth drains, concrete drains, septic tanks, soakaways, and pit latrines in Accra (Ghana). Yao (1975) found *Anopheles stephensi* larvae in puddles of sewage effluent outside Lahore (Pakistan).

It should be pointed out that not all recent increases in *Culex pipiens* populations are associated with sewage and sullage. In villages near Delhi (India) large numbers of seasonally disused irrigation wells, which had been dug as part of the "green revolution" in agriculture, are major sources of *C. quinquefasciatus* breeding (Yasuno 1974). In Egypt a very substantial increase in the *C. p. molestus* population over the past 20 years has been promoted by poorly maintained wells, stagnant pools of spilled water near public taps and handpumps, and by the drastically altered irrigation practices and rising water tables that have followed the opening of the Aswan High Dam in 1971. The increased vector population, together with other factors, is responsible for a marked increase in the prevalence and intensity of infection with Bancroftian filariasis in Egypt and a widening geographical range (Southgate 1979).

Culex pipiens Breeding in Waste Stabilization ponds

Under certain circumstances, waste stabilization ponds can become important breeding places for *Culex* mosquitoes. Beadle and Harmston (1958) studied twenty-six stabilization ponds in the USA. The main mosquito species found was *Culex tarsalis*, which is the vector of western equine encephalitis virus. The presence or absence of mosquito breeding in the ponds was closely correlated with the presence or absence of emergent or overhanging vegetation. Smith and Enns (1967) also studied stabilization ponds in the USA. Two ponds receiving animal waste were overloaded, frequently anaerobic, and had overhanging or emergent vegetation. They produced large numbers of *Culex pipiens* and other *Culex* species (30,000–60,000 larvae in a standard sample). This contrasted with 20–600 larvae in comparable samples from well-planned and well-maintained municipal sewage ponds.

Steelman and Colmer (1970) studied two ponds, also in the USA. One was newly dug, and the other had been used for 6 years for the reception of effluent from a pig farm. For the first 9 months of its life the new pond was filled with rainwater and from wells, but subsequently effluent from the farm began to be introduced. In the old pond large populations of *C. quinquefasciatus* larvae were found at each survey. In the new pond no *C. quinquefasciatus* was found, and the insect larvae before and for a few months after the introduction of effluent differed markedly from those in the old pond. In the old pond 7,000 to 13,000 coliform bacteria were found per milliliter. None was found in the new pond before introduction of effluent, but 7,000 per milliliter were found 5 months after this introduction, and at about this time *C. quinquefasciatus* larvae began to be found in the new pond. After 2 years the bacterial and insect populations of the two ponds had become very similar. Laboratory cage studies showed that suspensions of *Escherichia coli*, *E. freundii*, and *E. intermedia* were more attractive as oviposition sites for *C. quinquefasciatus* than were suspensions of *Aerobacter aerogenes*, and that all these suspensions were much more attractive than sterile water.

Yao (1975) reviewed limited data on mosquito breeding in waste stabilization ponds in India and concluded that pond colonization by vegetation was the main factor predisposing to breeding. In his own experiment outside Lahore (Pakistan), Yao (1975) studied four ponds (each 46 meters by 18 meters in plan and 1.2 meters deep) receiving domestic sewage and an experimental irrigation system. The ponds were lined with bricks, were in good operating order, and had no emerging or encroaching vegetation. Two of the ponds showed no evidence of mosquito breeding, whereas the other two had minimal breeding in one month out of five. Many *C. quinquefasciatus* larvae were found in a roughly vegetated earth pond receiving effluent. Breeding ceased, however, when the vegetation was cleared. Vegetated puddles of effluent in the irrigation canals were also the sites of prolific breeding of *C. quinquefasciatus*, *C. theileri*, and *Anopheles stephensi*.

These studies have shown that the most important measure to prevent mosquito breeding is avoidance of vegetation hanging into or emerging through the surface of the ponds. Other ecological factors associated with the presence or absence of mosquito breeding in stabilization ponds have been studied in the USA, and studies of this subject in tropical countries would be very valuable. Little is known about the relationships between water pollution and female oviposition behaviour or about the ability of mosquito eggs to develop through their larval and pupal stages to become adults. The literature, reviewed by Darwall (1979), suggests that location, salt concentration, organic pollution, dissolved oxygen, surface tension, larval nutrients, and aquatic flora and fauna may be important determining factors. Even after 70 years of research, however, these relationships are poorly understood, and more research is urgently required.

Methods for *Culex pipiens* Control

There are two approaches to *Culex* control, and successful control programs will almost always apply a combination of both of them. The two approaches, which are clear from the discussion above on preferred breeding sites, are modifications of the physical environment and the use of insecticides or other chemicals. Before describing these approaches, it is instructive to report a few case studies of control efforts in various environments.

Case studies in control

White (1971) reviewed the *C. quinquefasciatus* control practices in East Africa and pointed out that malathion is unsuitable as a larvicide in polluted water because it is rapidly destroyed at acid or alkaline pH. Oiling of breeding places is frequently used, but in sullage pits detergents emulsify the oil and reduce its efficiency. Experiments with 110 milliliters of Flit mosquito larvicide oil per pit latrine gave poor control, but dosages of 450 milliliters of used engine oil per pit gave satisfactory results. A granular formulation of the organophosphate chlorfenvinphos (Birlane) was tested at a dosage of 2.5–5 grams per pit latrine. This completely prevented breeding for 9–10 days. One man can apply granules to thirty pits per hour, and it was estimated that the labor costs of a program would be 20 percent of those for oiling. Chlorfenvinphos has fairly high acute mammalian toxicity, and the possibility of seepage from pit latrines into streams must be considered.

In Guyana the breeding place of *C. quinquefasciatus* is principally pit latrines and secondarily clean water in drums and tanks. Spraying of latrines with oil was carried out at a dosage of about 650 grams each, which prevented breeding for 4–6 weeks. The cost of the oil for a monthly program of spraying over 2,000 latrines was US$71. In addition, all unused drums containing water were turned over, but some were used for drinking water and could not be emptied or sprayed. The campaign produced a dramatic reduction in the density of mosquitoes in houses. In addition, the filaricidal drug diethylcarbamazine was issued to all the inhabitants of the area. The result of the program was that the proportion of filaria-infected mosquitoes was reduced from 17.7 to 2.2 percent (Burton 1967).

Graham and others (1972) reported a field trial in Rangoon (Burma) of *C. quinquefasciatus* control in an area of 4 square kilometers. Breeding of the mosquitoes was mainly in open drains, which frequently became blocked by debris and the activities of rats. The drains had originally been built for stormwater, but they were now used for sewage because of the deterioration of the underground waterborne sewage system and the increase in population of the city. Additional breeding sources included soakage pits for sullage, improperly maintained septic tanks, and latrines. Much of the *C. quinquefasciatus* population rests and feeds out of doors, so that a house-spraying program against adult mosquitoes would have been inappropriate, as would the use of organochlorine insecticides because of resistance. Among the organophosphate insecticides, fenthion has been found to be one of the most effective and persistent as a larvicide in polluted water, and this chemical was used for the trial in the form of emulsifiable concentrate applied with a compression sprayer to larval breeding sites, especially drains and septic tanks. No resistance to fenthion appeared over the 3-year period of the trial. The overall effect of the 3-year program was an average reduction by 97 percent in the man-biting rate in the trial area compared with a comparison area, where the municipality's routine program of oiling breeding sources was in progress. Apart from the much greater effectiveness of the fenthion program, it was considered that the higher labor and transport costs of applying the necessary large volumes of oil made oiling more expensive than the use of fenthion. The authors considered this field trial to be a model for what could be done in other tropical cities.

Culex control in Singapore was described by Chan Kai-Lok (1973). Surface flood water drains had originally been built as an *Anopheles* control measure, but these were now used for sullage and had become breeding places for *C. quinquefasciatus*. About 78 percent of the *C. quinquefasciatus* breeding in the city was in these concrete drains. Much of the remainder was in cracked septic tanks. A survey indicated that 6 percent of the septic tanks in the city were cracked and had *C. quinquefasciatus* breeding. Control measures used in the drains consisted of cleansing to improve the flow rate and oiling with Flit MLO refined light oil. Guppy fish (*Poecilia reticulata*) had been established in some concrete drains and canals and had had a significant effect in controlling *C. quinquefasciatus*. Sealing of inspection slabs on septic tanks reduced breeding.

An experiment to eradicate Bancroftian filariasis by vector control in a village in Nagasaki Prefecture (Japan) was recorded by Omori, Wada and Oda (1972). *Culex pipiens pallens* bred in ditches and polluted pools in the village and was the primary vector of Bancroftian filariasis. A program of vector control was carried out for 9 years using diazinon as a house spray against adult mosquitoes and for treatment of breeding sites. The latter treatments were carried out about twenty times per year during the mosquito breeding season, the target dosage being 1 milligram per liter. No filaricidal drugs were given, but all members of the village population (about 500) were examined annually for microfilariae. Entomological observations showed partial suppression of the *C. p. pallens* density in the first two years of treatment relative to the pretreatment year. During the last 7 years of treatment there was almost complete suppression of the vector. The prevalence of human microfilaria carriers declined from 14 percent before the trial to 0.5 percent at the end of it. This experiment is one of the very few demonstrations that filariasis in some areas can be drastically reduced solely by vector control if this is continued long enough for the adult worms in the human population to die out.

Control by modifying the physical environment

Control methods based on environment modification must either eliminate the breeding site or make it impossible for the egg-laying female to reach the site. The particular strategies that might succeed in a particular place can only be designed after a detailed survey of *Culex* breeding in that area. In other words, control methods should be sharply focussed upon eliminating, or restricting access to, the known primary breeding sites. The main methods of environmental control include:

- Avoidance, if at all possible, of using open drains for sewage or sullage
- If the use of open drains for sewage or sullage is absolutely unavoidable for the time being, prevention of stagnation in the drains by frequent cleaning and the provision of adequate garbage disposal services
- Fitting and maintenance of mosquito-proof netting over ventilation pipes on septic tanks, aquaprivies and improved pit latrines
- Sealing and repairing covers on septic tanks, soakage pits, and improved pit latrines
- Fitting of water seals on pit latrines
- Clearance of vegetation from waste stabilization ponds.

Pit latrines are becoming increasingly commonplace in poor urban and rural communities. If they are well constructed and well maintained, they provide an acceptable excreta disposal method for those families that cannot afford more elaborate systems. But if the pits are wet, owing to a high water table or the addition of excess washing water, they provide an ideal breeding ground for *Culex pipiens* mosquitoes. Four approaches to overcoming this problem are recognized. First, to replace the drop-hole slab by a pour-flush slab, thus providing a water seal that prevents the entry or exit of mosquitoes to the pit. Second, to install a ventilation pipe with mosquito-proof gauze at the top (see figure 36-3). Third, to install exit traps over the squat holes. Fourth, to spray the pits with oil or insecticide.

The role of vent pipes (as on ventilated improved pit—VIP—latrines) in controlling *Culex* breeding was investigated in Dar es Salaam (Tanzania) and Gaborone (Botswana) by Curtis and Hawkins (1982). It was found that 67 percent of *Culex* mosquitoes emerging from the pits did so via the vent pipe rather than the squat slab. If the vent pipe was properly screened at the top, these mosquitoes could not escape. The effect of vent pipes on mosquito production was considerably less than their effect on blowfly production, of which about 90 percent went up the vent. Some latrines produced over 1,000 *Culex* per night through the squat slab, despite having a vent pipe.

Insect traps placed over the squat hole can be used on pit latrines with or without vent pipes (figure 36-3). The traps can be cheaply made of a box or tin partly covered in mosquito proof gauze and with a gauze cone in the bottom surface. Mosquitoes and flies enter the trap through this cone, presumably attracted upward from the pit by light and/or fresh air. They do not readily find their way out again, but if some do they go back into the pit. Insects caught in the traps die there in a day or two. No provision is made for removing the corpses, but ants have been seen removing dead mosquitoes. In future a lizard might be placed in each trap to eat captured insects. Provision is made, with appropriately placed flaps, to block other easy exit routes, but a precision fit is not necessary because insects emerging from pits take the obvious route into the well-lit and aerated trap rather than follow the more tortuous alternatives. This is one of the advantages of a trap as compared with a lid—mosquitoes will eventually find small imperfections in the fitting of a lid.

The principle of the trap is readily understood, and catches of mosquitoes or flies obtained from heavily infested pits are impressive and informative in showing the householder where an insect pest problem originates and that it can be stopped at source by the "self-help" measure of always ensuring that the trap is put back in place after using the pit. Initial trials in Dar es Salaam and Gaborone (Curtis 1980; Curtis and Hawkins 1982) on a variety of pit latrines, cess pits, and a soakage pit produced large catches of *C. quinquefasciatus* and blowflies. There were uniformly favorable reactions of householders to the traps, which were always found in place when checks were made. It remains to be seen whether such cooperation can be achieved over the long term by an appropriate initial program of public information followed by periodic checking on the traps for correct usage and for the repair of any damage. It also remains to be demonstrated that the area-wide use of traps is effective in suppressing the density of *C. quinquefasciatus* and blowflies in houses.

Control by insecticides and oils

Control of *C. pipiens* breeding by environmental management methods alone is often not feasible, and insecticidal methods must also be considered. *C. pipiens* mosquitoes are now almost universally resistant to organochlorine insecticides such as DDT and dieldrin (Hamon and Mouchet 1967). Gas oil or used lubricating oil are routinely used on mosquito breeding places in many tropical cities as a control method. The method works by interfering with larval respiration, and studies in Guyana showed that it can be a very effective method in pit latrines if conscientiously applied (Burton 1967). Light oils with high spreading pressures have been developed especially for mosquito control ("Flit MLO") and are routinely used—for example, in Singapore—but relatively large amounts of transport and labor are required for an effective oiling program.

Organophosphate insecticides such as temephos (Abate), chlorfenvinphos (Birlane), chlorpyrifos (Dursban), diazinon (Basudin), and fenthion (Baytex) are lethal to mosquito larvae at extremely low concentrations (much less than 1 milligram per liter) and can be applied as emulsifiable concentrate or absorbed into granules, which greatly reduces the transport and labor required compared with oiling. The chemicals are fairly expensive, but temephos, chlorpyrifos, and fenthion remain effective for several weeks in stagnant polluted water, so that very frequent treatment is not necessary. Large-scale urban trials have shown substantial suppression of adult biting populations as a result of prolonged application of fenthion in Rangoon (Burma; Graham and others 1972), chlorpyrifos and temephos in Bobo-Dioulasso (Upper Volta; Subra, Bouchite and Gayral 1970), chlorpyrifos in Dar es Salaam (Tanzania; Bang, Sabuni and Tonn 1975), chlorpyrifos in Morogoro (Tanzania; Mrope, Bang and Tonn 1974), and chlorfenvinphos in Tanga (Tanzania; White 1971). It has been shown in Japan that applications of diazinon to breeding places several times each year for 9 years suppressed *C. p. pallens* populations and reduced the incidence of filariasis virtually to extinction (Omori, Wada and Oda 1972).

Despite the success achieved with organophosphate insecticides, it would be unwise to rely on them exclusively. It seems possible that they might adversely affect the essential microbial activity in waste stabilization ponds, septic tanks, and aquaprivies, and this question demands investigations of the kind already conducted with regard to the use of kerosene as an insecticide (Razeghi, Lawrence and King 1972). In addition, there are reports from many parts of the world of the evolution of resistance to organophosphates in *C. pipiens* mosquitoes (see, for instance, Curtis and Pasteur 1981; Hamon and Mouchet 1967).

Recent experience in Tanzania provides a good example of the problems caused by the development of organophosphate resistance in *C. quinquefasciatus*. Following the trials in Dar es Salaam and Morogoro described above, chlorpyrifos was adopted in the early 1970s for routine spraying (every 10 weeks) of all pit

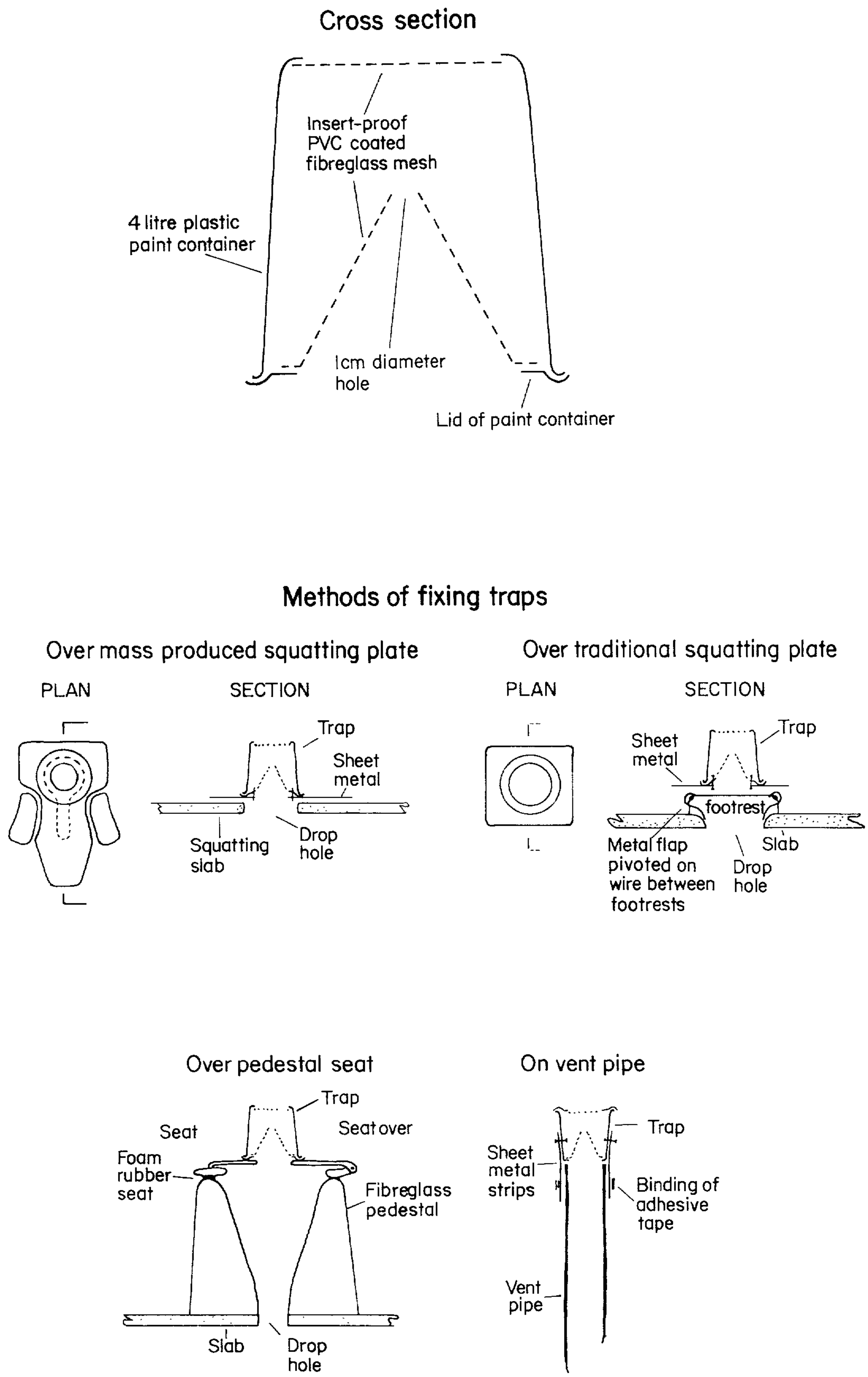

Figure 36-3. *Insect traps for pit latrines.* The traps shown can be fitted over the squat hole or seat of a latrine, or over the vent pipe, to catch flies and mosquitoes emerging from the pit. (from Curtis and Hawkins 1982; reproduced by permission of the Royal Society of Tropical Medicine and Hygiene)

latrines and soakage pits in Dar es Salaam. When the program was initiated, the insecticide residue remaining up to 10 weeks after a spraying was sufficient to give continuous control of larvae. However, unpublished data of Curtis and others indicate that the resistance that has evolved in Tanzania is now seriously interfering with the effectiveness of the program. Freshly sprayed chlorpyrifos is able to kill the resistant larvae, but after the insecticide residue has been degraded, diluted, or both, for 1 to 4 weeks it is no longer able to kill them. Thus, mosquito breeding can proceed in the sprayed pits for a large fraction of the 10-week spraying cycle. The program already costs about US$135,000 per year for the importation of insecticide, and increasing the frequency of spraying would require considerable additional expenditure, as well as the employment of more spray men.

It may be that practical alternatives to conventional insecticides will eventually become widely applicable using insect growth regulators, lipid monolayers (Levy and others 1980), insoluble foams, biological control by pollution-tolerant fish, algae (Ilyaletdinova 1978), microorganisms, or genetic systems based on cytoplasmic incompatibility and genes conferring nonsusceptibility to filaria. All of these methods, however, should be viewed only as ancillary to the installation and maintenance of well-designed excreta and sullage disposal systems that minimize the breeding opportunities available to *C. pipiens*.

Conclusions

It is clear from this review that water supply projects and on-site sanitation systems have the potential for greatly increasing the population of *C. pipiens* mosquitoes in tropical towns and cities. Of special concern are inadequately maintained open drains, flooded pit latrines, soakage pits, and septic tanks. In villages, the construction of pit latrines in areas with high water table, and increased water usage leading to ponded sullage, may bring the traditionally urban problem of *C. quinquefasciatus* to these rural sites.

Minimizing this problem depends on a carefully thought-out combination of correct design features for drainage and on-site sanitation, of appropriate self-help action by the community (for intance, using exit traps on pit latrines and keeping open drains free from garbage), and of larvicide-spraying programs. It is necessary for those designing and implementing water supply and sanitation schemes to discuss their work with entomologists having detailed local knowledge, and sullage disposal systems that will minimize the mosquito-control activities. This is especially important in those parts of the world where *C. pipiens* mosquitoes are the vectors of Bancroftian filariasis, and it will become even more crucial if *Anopheles* and *Aedes* species adapt locally to use polluted water as breeding sites in urban areas.

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